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EVERYTHING FROM WOOD

THE RESOURCE OF THE FUTURE OR THE NEXT CRISIS?

How footprints, benchmarks and targets can support a balanced bioeconomy transition

conducted by

CESR Center for Environmental Systems Research

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Summary

Can wood be used to build our houses, power our heat and electricity grids, clothe us, package our deliveries, and replace our plastics all at the same time?

No, wood cannot be used for everything.

Our consumption levels (in high-consuming countries like Germany) are too high. This report explores nuanced and complex issues, but comes to a simple conclusion: excessive and wasteful consumption must be reduced to reduce our pressure on the world's forests.

Maintaining old-growth, primary and close-to-nature secondary forest areas is at the heart of both biodiversity conservation and climate change mitigation. Both are central challenges to ensuring the long-term well-being of not only the Earth, but also humanity.

The use of wood in the energy, construction and manufacturing sectors is increasing. Wood is going to play a central role in transforming societies from fossil-based economies into bio-based ones. At the same time, forests are being degraded, fragmented and lost at devastating rates. This paper argues that it is not a question of whether to implement a bioeconomy, but how to implement a balanced bioeconomy. That means using wood and forests in a way that is smart, fair – in regard to distribution – and compatible with long-term Sustainable Development Goals (SDGs).

This report begins by reviewing trends related to global forests and the global production and consumption of wood products. We argue that to avoid a collision between conflicting trends and political strategies aimed at both better forest conservation and increased wood consumption, tools are needed to both monitor the total scale of consumption and to compare consumption levels to sustainable supply capacities.

To this end, we present timber footprints for Germany – as indicative of other high-consuming countries – and take the first steps towards developing a benchmark for sustainable wood consumption based on planetary boundaries. Our aim is to start a discourse about what sustainable wood consumption means, in particular in the context of the biodiversity and climate crises.

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Truck on the Trans-Sumatran highway carrying acacia wood for pulp and paper production, Sumatra, Indonesia.

How and why are biodiversity and climate change related to forests?

Forests are home to most of Earth's land-based biodiversity[1]. Losing forests, especially primary and old-growth forests, means losing habitats. Some of the world's most important places for biodiversity are still suffering tree cover loss at disturbing rates. None of the world's high-level commitments to protect biodiversity (e.g. the Aichi Biodiversity Targets) were met by their deadline in 2020. Instead, we have overshot the planetary boundary for biodiversity loss and are at risk of upsetting the very balance of our planet's operating systems. Reversing these trends will require addressing the issue of scale – it is the aggregation of impacts which manifest as threats at the global level.

Forests are both one of the most important carbon sinks for mitigating climate change and their loss is one of the leading causes of carbon dioxide emissions. However, not all forests absorb carbon equally. Old-growth, primary and natural forests are more effective carbon sinks than plantations or industrially managed productive forests. Their loss is also more destructive to the atmosphere and to biodiversity loss. Climate change also impacts forests. Longer growing seasons and elevated carbon dioxide levels could accelerate tree growth in some places, but these effects can be cancelled out by increased disturbances – fire, pests, drought, heat, storms and disease – accelerating forest loss. Altogether, maintaining old-growth, primary and close-to-nature secondary forest areas is at the heart of both biodiversity conservation and climate change mitigation. Both are central challenges to ensuring the long-term well-being of not only the Earth, but also humanity.

What are the major challenges and trends for forests?

Nearly all countries re-confirmed their dedication to halting and reversing forest loss and degradation at the 2021 Climate Change Conference in Glasgow. Such declarations have been made before. Although massive mobilisation efforts are under way, we are still not on track to reaching goals by 2030. More effort is needed to address the underlying drivers of deforestation – growing demands for food, fibre and fuels, on top of already high levels of consumption in not all, but in many countries.

1 All references and sources for further information are given in the main report. The trend assessments in particular are based on a literature review. Specific citations to data generated by other sources are included for the sake of transparency regarding cited versus own results.

Forest health is in decline. Researchers have found that only 40% of global forests have high landscape-level integrity [1] and over 70% are within 1 km of a forest edge [2]. Exploitative logging is one cause of fragmentation, and it can pave the way for forest degradation and deforestation. How forests are managed and harvested matters. Not only goals to halt deforestation, but also dedicated measures to maintain forest integrity and quality are needed.

The world is committed to planting trees. Multiple high-level pledges (e.g. the Bonn Challenge) have been made and the energy for regenerating forests could be a game changer, if it is done right. Currently, nearly half of tree planting efforts have resulted in monoculture plantations on marginal agricultural land [3]. However, timber production is not the primary aim of forest landscape restoration. Done right, it should support goals for socio-economic development, biodiversity conservation and climate change mitigation. The potential is there, but it depends on where, how and what trees are grown.

Plantations comprise around 3% of the global forest area. They have grown by nearly 40% over the last two decades, with growth slowing recently [4]. There is a need to distinguish between (a) plantations (e.g. the New Generation Plantations platform) which aim to incorporate ecological management and social principles and (b) intensively managed monocultures focused on industrialised production. With regard to the latter, land constraints are a major issue. There is evidence of displaced cropland as well as expansion into biodiversity hotspots. Impacts related to increased water scarcity, water pollution and depleted soil fertility have also been documented. However, this does not always have to be the case. Management strategies to achieve timber production and maintain ecosystem services in and around forests are plentiful. Case studies report on positive multi-functionality. The key is where and how plantations are established and managed. Nonetheless, future potentials for sustainable timber supply appear modest compared to future expectations regarding timber demands. This fact clearly reflects the core message of our report – while developing sustainable supply capacities on the production side are important, more attention is needed to transform economies toward sustainable consumption. Policy goals must shift from being centred on increasing supply (e.g. the current discussion on forestry intensification) to a systems perspective that also includes reducing demands. There are low-hanging fruits to this end within the economy.

Global roundwood removals are currently just under 4 billion cubic metres.

Protected areas are the cornerstones of biodiversity conservation. However, evidence shows high levels of deforestation still happening in these areas. Protected areas are not as effective or as comprehensive as they need to be. With only around 18% of global forests in protected areas [4], their coverage is well below the levels needed to meet biodiversity goals. The suggested goal of the post-2020 Global Biodiversity Framework is to ensure that at least 30% of all global land areas are conserved by 2030. Recognition of and support for the role already played by Indigenous Peoples and local communities in conservation could help to achieve overarching aims. The integration of other types of conserved areas (e.g. ICCAs[2] and OECMs[3]) in the protected area landscape could enhance connectivity as well as achievement of multiple-purpose models of sustainable forest use for and by local communities.

The intensity and magnitude of forest fires and pest outbreaks has broken records in many countries in the very recent past. Not only are ecosystem services and forest health harmed, the forest industry is also impacted. In the short term, markets are flooded with salvage timber, distorting wood prices. Over the medium to long term, forests need time to recover. A literature review reveals cases in specific countries and/or regions which have suggested reduced harvest quotas following major disturbances. Climate change increases the frequency and intensity of weather and climate extremes, increasing the severity of disturbances in forests.

What are the trends in wood consumption and production?

Global roundwood removals are currently just under 4 billion cubic metres (Gm^3 under bark (u.b))[4]. Total removals have grown by nearly 60% over the last six decades (from 2.5 Gm^3 u.b. in 1961 to 3.9 Gm^3 u.b. in 2020). Around half of the wood removed from forests globally is used for energy (cooking and heating) while the other half is used for industrial purposes (turned, for example, into pulp, sawnwood, wood composites, chemicals, etc. for manufacturing wood-based products and direct use in construction). What, why and how much people consume around the world differs widely. Europeans, for example, consume on average nearly twice as much as global citizens [5]. The vast majority of removals in Africa, Asia and South America are for woodfuel, whereas nearly 90% of removals in North America and 80% in Europe are for industrial purposes. With regard to woodfuel, the World Health Organization (WHO) estimates that 2.6 billion people

2 Indigenous and Community Conserved Areas; currently over 200 ICCAs have been reported in the online ICCA Registry (www.iccaregistry.org).
3 Other Effective Area-based Conservation Measures; statistics are currently available for five countries and territories on the Protected Planet website (www.protectedplanet.net).
4 This section is based on statistics from FAO (FAOSTAT); www.fao.org

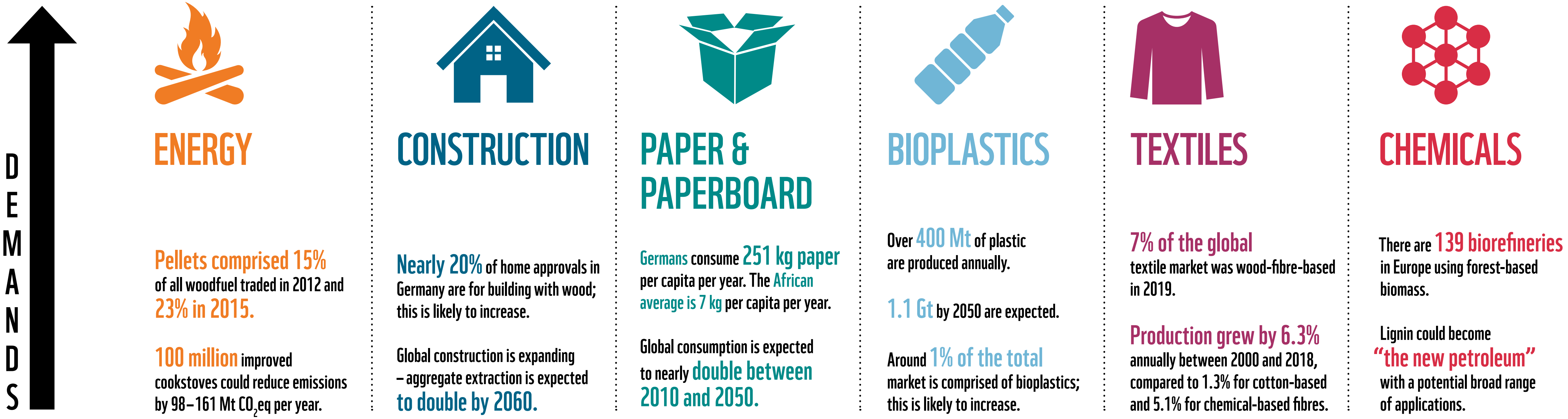

Figure S.1: Sectoral expectations: Increasing consumption with rising shares of wood-based products

Note: Bioplastics comprise multiple bio-based sources, with the majority currently stemming from agricultural biomass.

Sources: Statistics based on FAOSTAT and a literature review as described in the chapters of this report, including [11]–[19]

cook using solid fuels (wood, crop wastes, charcoal, coal and dung) and kerosene in open fires and inefficient stoves, and that in poorly ventilated dwellings indoor smoke can be 100 times higher than acceptable levels for particle emissions. SDG 7.1.2 aims to increase the proportion of the population that relies primarily on clean fuels and technology, and efforts like the Clean Cooking Alliance promote such options. This report aims to call attention to the consumption practices in high-consuming countries, where disproportionately high – and potentially rising – consumption levels place uneven and unwarranted burdens on global land and forest resources.

Wood product markets are expanding (Figure S.1). Global production of wood-based panels (used for construction and furniture), has grown by a factor of almost 15 since the 1960s. Sawnwood production has also started to pick up over the last decade; it is closely linked to construction. In 2021 a 700% price spike [6], coupled with a boom in residential construction particularly in the USA, brought construction wood into the mainstream, potentially foreshadowing future challenges. The paper and paperboard sector already consumes around 40% of industrially harvested wood (e.g. approx. 20% of global roundwood removals), with high levels of projected growth. Here, the multi-faceted effects of digitalisation are evident: while global printing paper and newsprint production are decreasing, packaging is increasing. This is largely a result of e-commerce. Packing already comprises nearly 60% of all paper use. The strongest expectations of future growth are for new and innovative products like engineered wood products in construction and pulp for textiles, as well as new bioplastic and chemical applications. While currently small in terms of volume, these sectors are characterised by high economic value and large levels of investment.

Trade has accelerated rapidly in recent decades. Forest product manufacturing has become more spatially separated across supply chains. This is coupled to higher levels of displaced impacts. For industrial roundwood, trade has outpaced production: world exports of industrial roundwood increased by over 60% between 1990 and 2018, compared to a 15% increase in removals of industrial roundwood over the same time period [7]. Imports to China were the major driving factor behind this trend (China imported around 45 billion USD of forest products in 2020).

“We need a shift from just thinking ‘how to increase supply’ to ‘how do systems of supply and demand interact and how can these systems be made more sustainable?’”

Germany plays a major role in global markets with high levels of both exports (approx. 20 billion USD in 2020) and imports (more than 16 billion USD in 2020). The trade in furniture is an example of increasing globalisation. It has been estimated that 30% of global furniture production is traded internationally (the largest importer is the USA, followed by Germany) and that there has been a migration of furniture production to lower-cost regions [8].

Forestry crimes and trade with those products are massively undermining efforts towards sustainable forest management. Up to nearly one-third of globally traded timber potentially stems from illegal sources. There is a grave mismatch between the resources that governments spend on combating forestry crimes relative to the profits they generate. Environmental crime is the third largest crime sector in the world (after counterfeiting and drugs) and forestry activities make up, by far, the largest share of this type of crime. The crimes range from unauthorised logging to organised crime, with ties to terrorist groups. Illegal logging and trade are valued in economic terms at between 51 and 152 billion USD annually [9]. Increasing demand for wood and wood-based products continues to incentivise illegal activities.

Wood transport in Cambodia. Vietnam is a major supplier of garden furniture to Europe also importing wood from Cambodia.

© Environmental Investigation Agency (EIA)

Demand for wood is increasing. A review of consumption scenarios up to 2050 reveals that wood product markets, in particular, are expected to grow. However, this growth will probably not occur equally across the world. One model showed a 7-fold gap between per capita consumption levels in the tropical countries of sub-Saharan Africa and South Asia and the temperate countries of Europe and North America in 2050 [10]. Consumption scenarios also showed that the way in which wood energy markets develop in high-consuming countries will have major consequences on the magnitude of consumption and the potential for industrial products to be supplied in a more sustainable way. **There is a need for policy makers to prioritise how wood is used in the economy in countries like Germany.** Burning freshly harvested wood, for example, is the worst use option. This raises emissions over the short to medium term while material use stores carbon.

The issue comes down to scale. That is because environmental benefits and impacts at a macro scale are dependent on the total level of demand. If only single products are examined, there may be good evidence of life cycle-wide benefits of substitution. This is especially the case in construction, where, for example, concrete is energy- and resource-intensive to produce. Using wood instead, in particular new engineered wood products with strong structural properties, is generally less carbon-intensive and an attractive alternative. However, it depends on how much wood is used. Under current consumption patterns, not all future homes in Europe can be made of wood from Europe while, at the same time, forests are conserved for biodiversity and climate mitigation.

Ultimately, our review of trends showed that there are many complex issues on the supply side, and it also matters what the wood is used for. We need to shift the focus from how to increase supply to how do systems of supply and demand interact and how can these systems be made more sustainable? Both footprint monitoring (asking how high is consumption) and benchmarks (asking how much is available) are needed to evaluate sustainability.

What is the role of footprints (using Germany as an example)?

Footprints of total consumption are the first step to identifying (a) if there is a problem and, if so (b) how much of a problem. The timber footprint of consumption is defined as the total volume of roundwood equivalents used for final consumption in a country. The German footprint is presented as an example of a high-income country. It was calculated to be just over 100 million cubic metres (Mm^3) u.b. in 2021 (updated results based on [20]). Adjusting for population shows that German per capita consumption (approx. 1.2 m^3 u.b. per person in 2021) is more than double the global average (approx. 0.5 m³ u.b. per person in 2021). Adjusting for bark and harvest losses enables comparisons to be made with growing stock in the forest: it shows that the level of German consumption cannot be supplied from the current German forest area alone. In other words, the German consumption footprint (133 Mm³ over bark (o.b.) in 2021) is higher than the total German forest increment (approx. 122 Mm³ o.b. as estimated by the German national forest inventory in 2012 [21]).

Footprints complement production-based and supply chain-based approaches to provide a more holistic foundation for policy making.

The use of footprints as a monitoring tool complements production-based and supply chain-based approaches to provide a more holistic foundation for policy making. National-level indicators also help to overcome silo thinking. This would help to avoid a distorted expectation of future capacities based on separate sectoral assessments. Footprints combined with benchmarks could also help to navigate and frame a societal discussion on overconsumption. A public discourse on what "we" consider excessive, wasteful and appropriate in the context of overarching sustainability goals is beyond due. People need the tools and knowledge to connect their behaviours "at home" to what happens in the forest.

How much timber can be sustainably harvested within planetary boundaries?

Sustainable forest management is about finding balance between environmental, social and economic aims. Part of this balance means recognising the intrinsic value of forests. In New Zealand for example, a forest has been granted its own legal rights in recognition of the Māori belief that the forest cannot be owned. Germany, like many countries, has legislation that requires the living environment and the natural foundation of life and animals to be protected. At the same time, forests supply wood – and other non-wood forest products – that are an integral part of human existence. For example, 30 kg of paper consumption per year is judged as necessary for education and democratic involvement in society [13]. In comparison, German consumption levels are around 250 kg per person, whereas the African average is 7 kg per person and the Indian average is 9 kg per person.

On the production side, the challenge is balancing needs for conservation with those for forestry operations. To this end, multiple guides for practitioners have been developed. These are geared towards the integrated and sustainable management of distinct forest types in their geographical and socio-economic contexts.

On the consumption side, a benchmark is needed. The impacts of consumption extend beyond borders (e.g. deforestation, degradation, crime) and are increasingly shifted to other countries. Countries must do better to monitor and adjust their levels of consumption towards sustainability. An international agreement to promote sustainable and responsible consumption exists since 1992 (Agenda 21) and it is past time to make the changes needed.

To put consumption levels into the perspective of planetary boundaries, we took the first step towards developing a potential benchmark.
We estimated:

1. **How much forest is available for wood supply** – Combining (a) statistical data from the Global Forest Resources Assessment 2020 (FRA 2020) [4]; (b) spatially explicit land cover maps [22]; and (c) national sources, we determined that nearly half (approx. 47%) of the global forest area is available for wood supply. This comprises production forests (as designated in country reporting or shown as "used" in satellite images) and plantations; it excludes protected forests and primary forests (e.g. those that are inaccessible for timber supply due to a lack of roads and are increasingly recognised as fundamental to biodiversity conservation and climate change mitigation).

2. **How productive that forest is** – Net annual increment (NAI) was estimated for all countries based on best available statistics for each country. Our global average NAI was estimated at 2.5 m³ per hectare per year (m³/ha*y) for production forests and the mean annual increment (MAI) was estimated at 9.3 m³/ha*y for plantations.

3. **What share can be harvested under sustainability considerations** – This study estimates a risk corridor based on removals comprising between 50% (low risk) and 80% (high risk) of NAI on production forests. 100% of MAI is calculated for plantations. The risk corridor refers to the planetary boundary for global wood consumption. The low-risk boundary is 3 Gm³ o.b.; this boundary allows greater incorporation of multiple ecosystem services and aligns with an ecologically safe wood capacity. The high-risk boundary is 4.2 Gm³ o.b.; it is a more quantity-based boundary focused primarily on the maintenance of standing stock and forest area.

Perspectives that go beyond timber supply alone are needed to achieve holistic sustainable forest management. These practices must be implemented on the ground. Our risk corridor aims to provide a benchmark for consumption levels. This is not enough to evaluate how forests are managed and trees are harvested in practice. For that, complementary approaches are needed. Moreover, forests around the world are in poor condition, suggesting that a paradigm shift to redefine how harvest quantities are calculated is needed. This would impact the benchmark for sustainable consumption levels. As such, while our report relies on best available data and existing definitions of "sustainability", the results should be interpreted as preliminary. The aim is to initiate a discourse on how much wood consumption is holistically sustainable in countries like Germany.

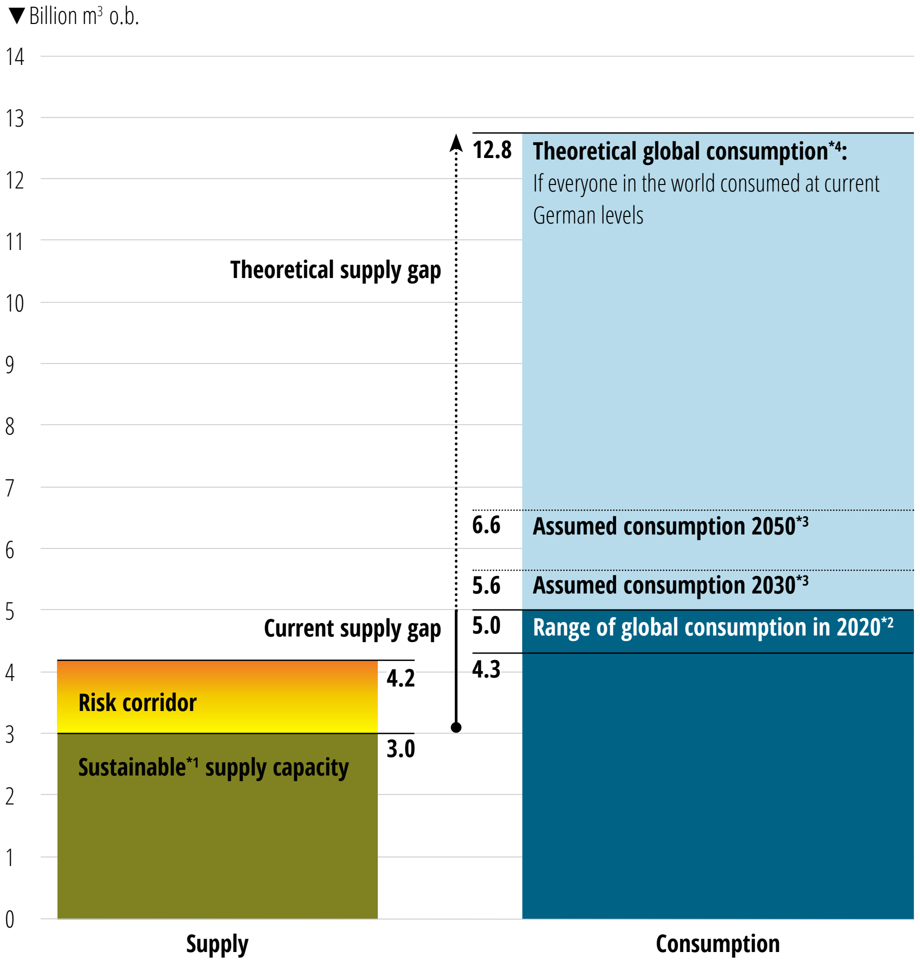

Figure S.2:
The planetary boundary for global wood consumption: comparing the sustainable[*1] supply capacity and the risk corridor to consumption levels

Notes:

[*1] Sustainability here refers to quantity considerations, which is only one consideration when aiming for holistic forest management.

[*2] Global consumption in 2020 is depicted as a range to depict uncertainty in conversion values (e.g. adjustments for bark and harvest losses), share of global consumption that stems from the sources outside the forest (e.g. roadsides), illegally sourced timber and statistical data uncertainty.

[*3] The global consumption values in 2030 and 2050 depict the highest boundaries respectively and are based on an extrapolation of historical trends over the decade 2010–2020.

[*4] The average annual German consumption level between 2015 and 2020 was taken as a reference for calculating "current consumption" because calamities (including massive beetle outbreaks) caused a spike in German harvests in 2020.

How does sustainable supply compare to current and future consumption?

The estimated risk corridor for global timber supply spans a range of 3.0 to 4.2 Gm³ o.b. That implies that a supply capacity below 3 Gm³ o.b. is in the "safe zone". Global consumption in 2020 is estimated to be between 4.3 and 5.0 Gm³ o.b. Consumption is given as a range to depict uncertainty in the data in relation to multiple factors, including conversion values (e.g. adjustments for bark and harvest losses); the share of global consumption that stems from trees outside the forest (e.g. roadsides); illegally sourced timber (e.g. some 190 to 565 Mm³ u.b. are estimated to be cut illegally every year [23]); and inconsistencies in statistics. Comparing consumption to "sustainable" supply showed that the risk corridor was overshot by 3% to 67% (Figure S.2). It is likely that this gap will grow in the future, accelerating climate warming and species extinction.

We asked: How might supply capacities develop in the future as a result of trends and targets? To that end, we performed simple thought experiments as "what-if" considerations. These isolate different parameters in order to illustrate the effect that change alone would have on supply capacities. These scenarios may thus be interpreted as a sensitivity analysis and are not based on integrated modelling.

We found that there is limited potential to expand supply capacities and these are far from sufficient to meet rising demands. Our results (presented in Table S.1) clearly illustrate a growing divergence between potential supply and demand. Global consumption could increase by approximately 28% by 2050 (based on a linear extrapolation of historical trends over the decade 2010 to 2020). None of our what-if supply considerations could increase supply capacities to this level, and especially not if sustainability constraints are included in a more robust way. Furthermore, unchecked deforestation and climate change could instead reduce supply capacities in the future by depleting global forest resources and leaving less space for both nature and wood supply.

Reducing consumption is the best strategy to close the supply gap. However, the transition to a bioeconomy – if it is based on current total consumption patterns – could further raise wood consumption beyond "business as usual" and increase inequality in how and how much wood is used across the world.

Table S.1: What-if considerations of supply and impacts on the risk corridor compared to extrapolated consumption

PARAMETER	RATIONALE	WHAT-IF CONSIDERATIONS	POSSIBLE WOOD SUPPLY EFFECT ON THE RISK CORRIDOR IN 2050		WOOD SUPPLY GAP IN 2050* (GM^3)	
			LOW-RISK BOUNDARY	HIGH-RISK BOUNDARY	MAXIMUM GAP	MINIMUM GAP
Deforestation	Meet international targets and country commitments to halt deforestation	Halt deforestation in 2020	0	0	3.6	1.4
		Halt deforestation by 2030; share of forest available for wood supply (FAWS) is assumed to be the same as it was in 2020	-3.2%	-3.7%	3.7	1.6
		Deforestation is not halted (trend extrapolation); share of FAWS is assumed to be the same as it was in 2020	-10.8%	-12.4%	3.9	1.9
Forest Landscape Restoration	Meet targets for restoration (e.g. the Bonn Challenge and New York Declaration on Forests)	Achieving the Bonn Challenge with half the area (+175) entering supply capacity decades after planting (especially 2040; the other half is assumed to be strictly protected or consist of trees which are not part of FAWS, like fruit trees, tree lines, small copses or tree groups)	+6.6%	+7.5%	3.4	1.1
Afforestation	Continued trends towards afforestation	Trend extrapolation, noting that this only depicts forest area, not forest quality	+1.9%	+2.2%	3.5	1.3
Plantation expansion	Modest illustrative scenarios in light of land constraints (especially due to agriculture)	Halved-trend extrapolation (plantation area increases by approx. 19% to 135 Mha)	+5.5%	+7.7%	3.3	1.2
		Plantation area increases by 35% (to 153 Mha) based on a model projection and literature review	+9.2%	+12.8%	3.2	1.0
Expanding forest available for wood supply (FAWS)	Take wide differences in the share of FAWS in total forest area in different countries into account by considering some expansion of the area of production forests into primary forests	+20% FAWS only in countries with a FAWS share under 50% (i.e. just under 1% expansion per year) so that FAWS would cover 2.04 billion hectares (Gha) in 2050 (increase of approx. 9% compared to 2020)	+4.5%	+5.2%	3.4	1.2
Increased mortality/ Effects of climate change	It is unclear how climate change will impact forest growth. The magnitude of potential challenges related to mortality is illustrated, noting that major differences in regional trends could dramatically shift results	Illustrative – linear trend projection for an estimated light increase based on a literature review and data for 6 EU countries	-28%	-30%	4.4	2.6
		Illustrative – logarithmic function for an estimated moderate increase based on a literature review and data for 6 EU countries	-32%	-35%	4.5	2.9

* Consumption based on a linear extrapolation of the past 10 years until 2050 (+28% in 2050) with a range to depict uncertainty in conversion values (e.g. adjustments for bark and harvest losses), share of global consumption that stems from sources outside the forest (e.g. roadsides), illegally sourced timber and statistical data uncertainty. The minimum gap refers to the smallest distance (between the high-risk boundary and lowest consumption range) and the maximum gap depicts the difference between the low-risk boundary and the highest consumption range.

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Conclusions for policy makers

What are the considerations related to equity and the implications for targets?

Targets provide an orientation to help make new policies more coherent and raise public awareness about certain issues. The challenge for forestry is how and whether to take regional variability into account when considering fair shares. This is because forest distribution is widely different across the planet (two-thirds of the world’s forests are found in just 10 countries [4]). A gradient of orientation levels is presented as an initial idea. These range from a national/regional focus on self-sufficiency to a focus on fair global distribution and, at the highest level, to a focus on sustainable fair shares. To this end, we explored the impact of population growth over time on the per capita global supply capacity and the implications for a gradient of target orientations.

Population growth has a large impact on future supply capacities and the distribution of wood. Considering population growth alone would reduce the per capita risk corridor by 26% between 2020 and 2050. This means less available wood per person and requires increased efficiency in the way wood is consumed. German per capita consumption levels under business-as-usual trends were found to exceed the German, EU and global per capita supply capacities. German per capita consumption could be approximately 230% to 350% higher than the global per capita risk corridor in 2030.

What are some examples of more sustainable wood consumption?

The business model is at the heart of efforts to transform economies toward greater sustainability. Business model innovation could help to shift the focus from selling more (intimately linked to rising consumption levels) to providing value, e.g. for communities. Changed consumption practices are fundamental to reducing pressures on forests. Grassroots innovations toward sharing, exchanging, repairing, reusing and minimalizing, among others, provide examples of alternative ways to “consume” wood. The design of products is also critical to harnessing end-of-life potentials. It is key to realising the potential of cascades (material use first, followed by re-use, recycling and the recovery of energy as the last option). However, around 30% of harvested roundwood is used directly for energy in Germany [24]. Of the waste wood collected in the country (around 10 million tonnes (Mt) in 2020), around 70% is burned for energy and around 15% is used to produce particleboard [25]. While paper recycling in Germany is relatively high and is a step in the right direction, it is not without environmental challenges. More attention must be paid to the social norms that drive consumption, in particular with regard to wasteful, excessive, inefficient and unnecessary consumption. As the Environmental Paper Network concluded: “The answer to the question ‘paper or plastic’ must more often be ‘neither’” [13].

What are the key take-home messages and conclusions for policy makers?

The aim is to prevent problem shifting associated with consumption. This means finding a balance between the level of use (enough to supply humanity with, at least, a decent standard of living) and natural systems (keeping Earth operating systems below their tipping points). We thus applied a downscaling approach to planetary boundaries for monitoring purposes in this report. However, downscaling is not the only approach to operationalising planetary boundaries, nor may it be the best suited for instigating the kinds of deep changes needed in the way business operates and society interacts with nature. Scaling up planetary boundaries could be a more operational approach for stakeholders to link what happens in one place to its impacts at a global level.

We are moving in the wrong direction: wasteful and excessive consumption and behaviours must change.

Right now, our findings show that we are moving in the wrong direction. Targets could provide a framework for change to get development on the right path. Better data is integral to increasing the robustness of footprints, benchmarks and scenarios, in particular with regard to harmonisation, accuracy and reliability. The potential impacts and adaptation strategies for climate change need more attention. That said, there is no time to wait. Wasteful and excessive consumption and behaviours must change. Our report is a warning flag and a call to action for policy makers, industries and society to address wood consumption and forest protection. It is the start of a discourse about how wood should best be used in a balanced bioeconomy.

Perception and acceptance of the problem
According to this report, already today there is not enough wood to meet all demands in a sustainable way. In addition, established and new industries are planning to intensify the use of wood. Without political guidance, this would most likely lead to accelerated deforestation and degradation of forests. We have developed five key messages for policy makers.

Political and social discussion on the most sensible use of wood is necessary.

1. **Prioritise how wood is used**
   A political and social discussion on the most sensible use of wood is necessary. Do not leave it to markets to decide how wood is consumed. Eliminate perverse and potentially conflicting incentives generated by policies to use wood inefficiently (e.g. subsidies). Take an active role in defining priorities on what, where and how timber should be used most efficiently.

   a) Promote wood use that takes long-term sustainable supply capacities into account and prioritise long-term use, durable products and design for reuse.

   b) Invest in building up the infrastructure, knowledge and mindset for reuse, high-quality recycling and the further use of waste wood. A circular economy and cascades are good options for efficient timber use.

   c) The industrial burning of wood for energy is the worst use of our limited wood supply, particularly in light of the climate crisis. The use of wood for energy should be at the end of a utilisation cascade. Remove incentives to burn wood and support finding clean alternatives to inefficient and polluting wood burning for smallholders.

   d) Make excessive and wasteful behaviours more difficult. For example, free newspapers and printed advertising material distributed to households that do not want them or disposable coffee cups are not sustainable. We need to reduce packaging substantially.

   e) Invest in innovative solutions that adapt the way resources are used in the community and in society. Foster a balanced bioeconomy through societal transformation in mobility, housing, food and culture. Lead the way on social norms – be an example of changed behaviours in public procurement.

2. **Stop environmental and forest crime**
   Environmental crime is the third biggest crime sector in the world. Intensify efforts in the fight against environmental/forest crime at national and international levels. Ignoring these crimes will fuel deforestation. It will also impede or destroy political efforts like afforestation or protection of forests. Support reduced consumption in high-consuming countries to make forestry crime less attractive.

3. **Prioritise healthy forests**
   Protect and maintain primary and old-growth forests. Maintain, enhance and increase the resilience of natural forests. Promote robust, multi-functional healthy forests above and below ground (soil, water and species diversity). Develop incentives for forestry operations and forest owners that do not rely on generating economic revenue exclusively through timber sales, but also focus on measurable biodiversity, ecosystem services, climate impacts and conservation goals.

4. **Monitor consumption and set benchmarks**
   Implement footprint monitoring to account for how much wood is consumed in official statistics and set benchmarks to put the scale of consumption into the perspective of planetary boundaries. Together, these indicators should be used to quantitatively identify overconsumption and steer policies towards economies that keep consumption within socio-ecological boundaries.

5. **Invest in research**
   Develop comprehensive data, integrated modelling capacities and the knowledge base for upscaling good practices of sustainable wood consumption.

1 Introduction

Relying on forest management alone – in a global market – is not enough.

The world has committed to sustainable development. World leaders, companies, organisations, communities and citizens have pledged to end deforestation by 2030, reach climate neutrality by 2050 at the latest and conserve biodiversity across all landscapes. But, as a whole, **we are not on track to meet any of these goals**. As a global community, we are moving further away from many Sustainable Development Goals[5]. Hunger has increased – rising from an estimated 8.4% of the world population suffering from undernourishment in 2019 to 9.9% in 2020 [26]. There is a desperate need for a **paradigm shift** in the way global systems of production and consumption currently function.

Forestry, wood and the bioeconomy are at the interface of many complex challenges – biodiversity conservation, climate change mitigation and adaptation, and rights to land and natural resource use. **The issues are nuanced** – no one solution is good or bad. Planting trees can be a "win" for people and nature, but not if those trees are planted as a monoculture on highly biodiverse grasslands or primary forests. Bioenergy has been subject to a heated debate as countries aim to reduce their dependence on fossil fuels by substituting them with wood. At the same time, the vital importance of maintaining primary, intact forest for mitigating climate change is now recognised in global policy. At its heart, the use versus conserve conundrum is one of scale and balance.

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Operation carried out by the environmental crime police IBAMA and the Brazilian army on suspicious illegal logs floating on the river.

THE QUESTION IS: WHAT IS A SUSTAINABLE LEVEL OF TIMBER CONSUMPTION?

This paper argues that a balance must be found between supply and demand that keeps both natural ecosystems and human economies and well-being within planetary boundaries.

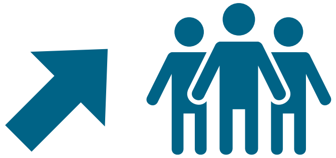
In one sense, those who point to safeguards built into sustainable forest management for determining this balance would be correct. Foresters have managed forests for centuries to ensure that harvest rates do not diminish the capacity of forests to supply timber in the future. However, the health and condition of forests across the Earth are increasingly ranked as poor [27]–[29]. The world's forests have been reduced to only 60% of their original coverage [30], and of the forests left, **only 40% have high ecological integrity** [1]. Soil degradation, pest outbreaks, invasive species, drought and exploitative human activities are just some of the factors increasing pressure on forests. **Forest management must go beyond simple timber provision.** And multi-functionality must be one of the guiding principles behind the sustainable forest management practices employed across the Earth.

Relying on forest management alone – in a global market – is also not enough. Imports may displace impacts (such as fragmentation, degradation and deforestation) between places of consumption and places of production. This is already happening, in particular for beef, palm oil, soybeans and timber commodities [31]–[34]. Researchers have been able to link consumption practices in Germany (in particular for agricultural products) during the early 2000s to substantial land transformation, primarily in other regions of the world [35]. **Wood consumption practices on the demand side drive impacts on the forest by providing incentives** for certain practices. Such incentives could lead to sustainable forest management – for example, when it is valuable to enhance and maintain forests for high-quality species and ecosystem services. It could also lead to a demand for growing specific types of trees (e.g. fast-growing species in monocultures) and/or incentivise illegal activities. **Environmental crime is now the third largest crime sector in the world,** and illegal harvesting and trade of timber massively undermines efforts towards sustainable forest management [23]. Forestry crime continues to evolve and is not adequately understood or addressed at the political level [36].

5 See the UN Sustainable Development Goals (SDGs) report for 2021, showing how the global pandemic in particular has thrown progress towards the SDGs even more off track; https://unstats.un.org/sdgs/report/2021/

Figure 1.1:
Global trends in population, wood consumption and forest area

Based on trends described in the later chapters of this report. Based on UN world population prospects (medium variant), FAOSTAT global roundwood production statistics (under bark) and the FAO Forest Resource Assessment 2020 (FAO, 2020)



GLOBAL POPULATION

World population has increased by more than

2.5-fold since the 1960s.

We may reach nearly 10 billion people by 2050. Pressures on land will increase, especially for agricultural expansion at the expense of forests (and other natural ecosystems).

WOOD CONSUMPTION

Global roundwood consumption has grown by nearly

60% since the 1960s,

accompanied by accelerated trade in recent decades (60% increase in industrial roundwood exports since 1990). Innovation in forest-based product markets is leading to growth, on top of rising global demands for more 'traditional' uses as millions of people, rightly, raise their living standards.

FOREST AREA

The world has lost an estimated area of

420 Mha forests worldwide

through deforestation since 1990. Forest integrity in remaining forests is under threat. Fragmentation, degradation and primary forest loss is coupled to massive declines in biodiversity and the carbon sink.

This report looks closer at trends in Germany.

This report looks at global trends. It provides an overview of where and how the global forest area, forest use and sustainability are shifting, paying close attention to how these trends interact, relate to, and are driven by consumption patterns. Figure 1.1 shows that at a global level, trends point to **more people, rising consumption and less forest area.** On top of that, our forests are becoming less healthy and the gap in distribution between high wood-consuming countries and low wood-consuming countries remains alarmingly high. Under these basic framework conditions, what role can and should wood play in transforming fossil-based economies into biomass-based economies (bioeconomies)? Industrialised, high-income countries across the world are actively promoting such transitions. **This report looks closer at trends in Germany to assess this question in the context of global challenges.** This means that German timber footprints are calculated and examples from Germany are given throughout. However, these **issues are not relevant to Germany alone, but rather are representative of high-consumption behaviours** seen across the globe. **It is not a question of whether to implement the bioeconomy, but how.**

The German National Bioeconomy Strategy [37] emphasises the need for **holistic solutions** to global challenges, in particular taking the "availability of natural resources within ecological limits" into account. The aim is not to be prescriptive, but rather to foster innovation towards using resources like wood in an **efficient and smart way.** Cascading use and the use of long-lived products result in a better life cycle performance than when disposable goods are used. However, caution is also needed. The benefits of substitution on a case-by-case basis may seem clear. For example, using wood instead of concrete in construction generally shows climate benefits, when individual buildings are compared [38]. However, **at what point does the level of consumption override the benefits?** Just as all energy cannot be supplied by wood, all homes cannot be made of timber without destroying the world's forests. Yet, multiple sectors are betting on wood as their "green" resource of the future – to house, heat and clothe us while packaging our deliveries and furnishing our homes. **Tools are needed that monitor the total scale of consumption to put rising sectoral expectations into the context of total demand and sustainable supply.**

Policy makers must prioritise where, when, how and what wood can best be utilised in the balanced bioeconomy transition.

The basket of forward-looking policies, research and innovation addressing facets of these challenges is vast. This report aims to provide an introduction to the sectoral challenges and progress in the context of the overarching question – do we have enough wood? To this end, **sustainable supply capacities are defined and compared to wood consumption scenarios.** Our goal is a **balanced bioeconomy** – one that uses wood, land and biomass in a way that is smart, fair and compatible with long-term sustainable development. We must provide for people in a humane way while also leaving space for the flora and fauna of our world to thrive.

Overall, this report argues that **policy makers must prioritise where, when, how and what wood can best be utilised in the balanced bioeconomy transition.**

To that end:

a) **footprint monitoring** could assist policy makers to better **evaluate trade-offs** and the pressures associated with the **scale of use (Chapter 3)** and

b) **benchmarks /targets** can put those footprints into the perspective of **planetary boundaries (Chapter 4).**

Such monitoring must be **accompanied by ongoing efforts** to improve the sustainability of supply chains, support local governance, foster sustainable forest management and reduce the scale of consumption **(Chapter 5 and Chapter 6)**.

KEY QUESTIONS INCLUDE:

Chapter 2	How and why are biodiversity and climate change so strongly related to global forests? What are the major challenges and trends related to forest area, forest health/resilience and forest structure/intactness?
Chapter 3	What are the trends in consumption and production, what impact could the bioeconomy transition have on stimulating wood demand in different sectors, and what is the role of footprints (using Germany as an example)?
Chapter 4	How much timber can be sustainably harvested within planetary boundaries, what are the considerations related to equity, and what are the implications for targets?
Chapter 5	What are some examples of the types of innovations that reduce burdens and promote more sustainable consumption practices?
Chapter 6	What are the key take-home messages and conclusions, in particular for policy makers?

2 Forests: Trends, challenges and opportunities

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For your Orientation

CHAPTER OVERVIEW

The world is in a biodiversity and climate change crisis. Chapter 2 describes why biodiversity and climate change are so intricately connected to what happens in the forest.

We explore some of the activities to preserve, restore and maintain forests, including the missteps, achievements and challenges related to such efforts. Specifically, this chapter looks at trends in:

» Deforestation, degradation and fragmentation
» Forest landscape restoration
» Plantation expansion and impacts
» Protected, conserved and Indigenous and community conserved areas and their effectiveness
» Forest fires, pests and disease

This chapter 2 provides the overarching context for the trends in wood production and consumption presented in Chapter 3. For that reason, we focus here on the forest resource as a whole, paying special attention to both the role and implications of logging and forest management practices.

Chapter 2 also builds the basis for exploring some key elements of sustainable forest management in Chapter 4. This forms the rationale for calculating sustainable timber supply capacities grounded in ecological principles. The key trends explored are also used as the basis for what-if considerations for future supply capacities in Section 4.3.4.

Overall, this chapter shows why using and conserving global forests in a sustainable way is so important. Although ambitious global goals to this end have been signed by nearly every country in the world, actual progress has so far been slow.

KEY MESSAGES

1 Maintaining primary, old-growth and close-to-nature secondary forest areas is at the heart of both biodiversity conservation and climate change mitigation.

2 Halting deforestation requires addressing the root causes linked to incentives for clearing forests. Consumption practices in high-income countries – especially related to food and one-use wood products – must be addressed as part of the response mix aimed at zero deforestation.

3 Fragmentation caused by exploitative logging, agriculture and expanding infrastructure, for example, could lead to further degradation and eventually deforestation. Dedicated measures to maintain forest integrity/intactness in addition to halting deforestation are needed.

4 The world is dedicated to planting trees and restoring forests. Harnessing this potential – when implemented appropriately – could promote multi-purpose forestry.

5 Where and how plantations are established and managed affects trade-offs or synergies for biodiversity, climate change mitigation and socio-economic conditions. Low-risk pathways are characterised by planting mixed, locally native species in degraded land previously used for pastures and/or cropland under close-to-nature management and integrated into the local social context. This translates to a more modest potential for meeting rising demands for wood.

6 Protected and conserved areas are the cornerstone of biodiversity conservation. While these areas are expanding on paper, their effectiveness in practice is subject to scrutiny. There is great potential to recognise and support the role already played by Indigenous Peoples and local communities in conservation, including sustainable, multi-functional use.

7 The intensity and magnitude of forest fires and pest outbreaks has broken records in many countries in the very recent past. These disturbances are flooding the market with salvage timber in the short term and impacting the medium- to long-term productive capacity of those forests to provide timber. Ecosystem services and forest health are also harmed.

Global forest area and coverage

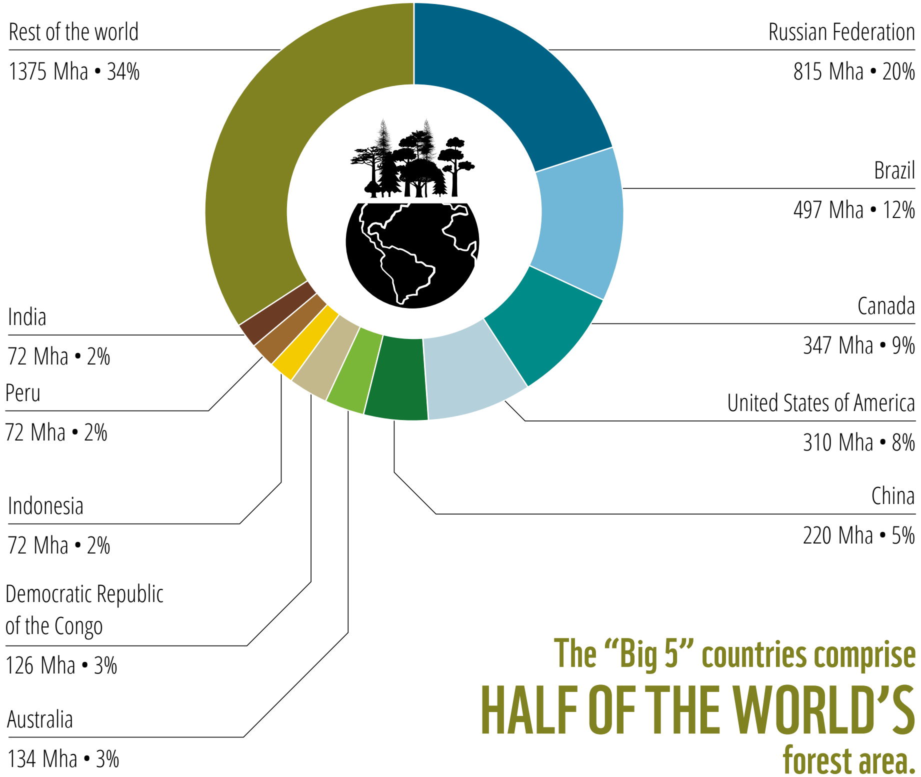
Forests cover 30.8% of the global land area, or 4.06 billion hectares [4]. They are unequally distributed across the world, with forest area highly concentrated in a limited number of countries. The "Big 5" contain half of the world's forests (Russia, Brazil, Canada, the USA and China) and two-thirds of forests are found in 10 countries (Figure 2.1). The majority of world forests are found in the tropical domain, followed by boreal, temperate and subtropical domains (Figure 2.2) [4].

More than one-third of the world's forests are primary forests [4]. More than 60% of primary forests are found in Brazil, Canada and Russia. In the EU, primary and old-growth forests are estimated to cover around 3% of land cover, and are generally small and fragmented [39].

Box 1: What are primary and secondary forests?

Primary forests are defined as naturally regenerated forests of native tree species where there are no clearly visible long-term indications of human activity and the ecological processes are not significantly disturbed (based on FAO [4] and modified by WWF).

Secondary forests are a broad range of forests that have been regrown and may be maintained or managed (see Chapter 4.1 on types of management) for multiple purposes. They have been defined by Chokkalingam and de Jong (2001) as: "forests regenerating largely through natural processes after significant human disturbance of the original forest vegetation at a single point in time or over an extended period" [40]. Close-to-nature secondary forests display, although used, just smaller differences in forest structure and/or canopy species composition with respect to nearby primary forests on similar sites (based on [40]).



The "Big 5" countries comprise **HALF OF THE WORLD'S** forest area.

Figure 2.1:
World forest distribution by country
Source: FAO 2020

Güeppi-Sekime National Park, Loreto, Peru.

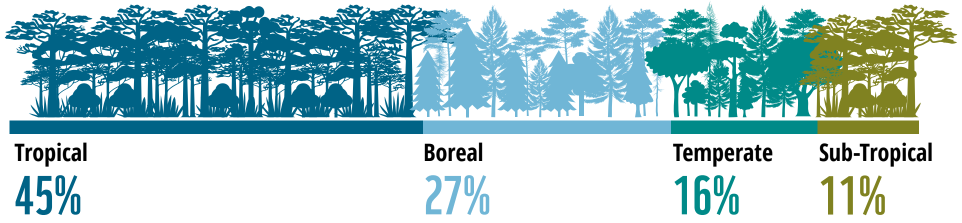


Figure 2.2: World forest distribution by vegetation zones
Source: FAO 2020 [4]

FORESTS AND BIODIVERSITY

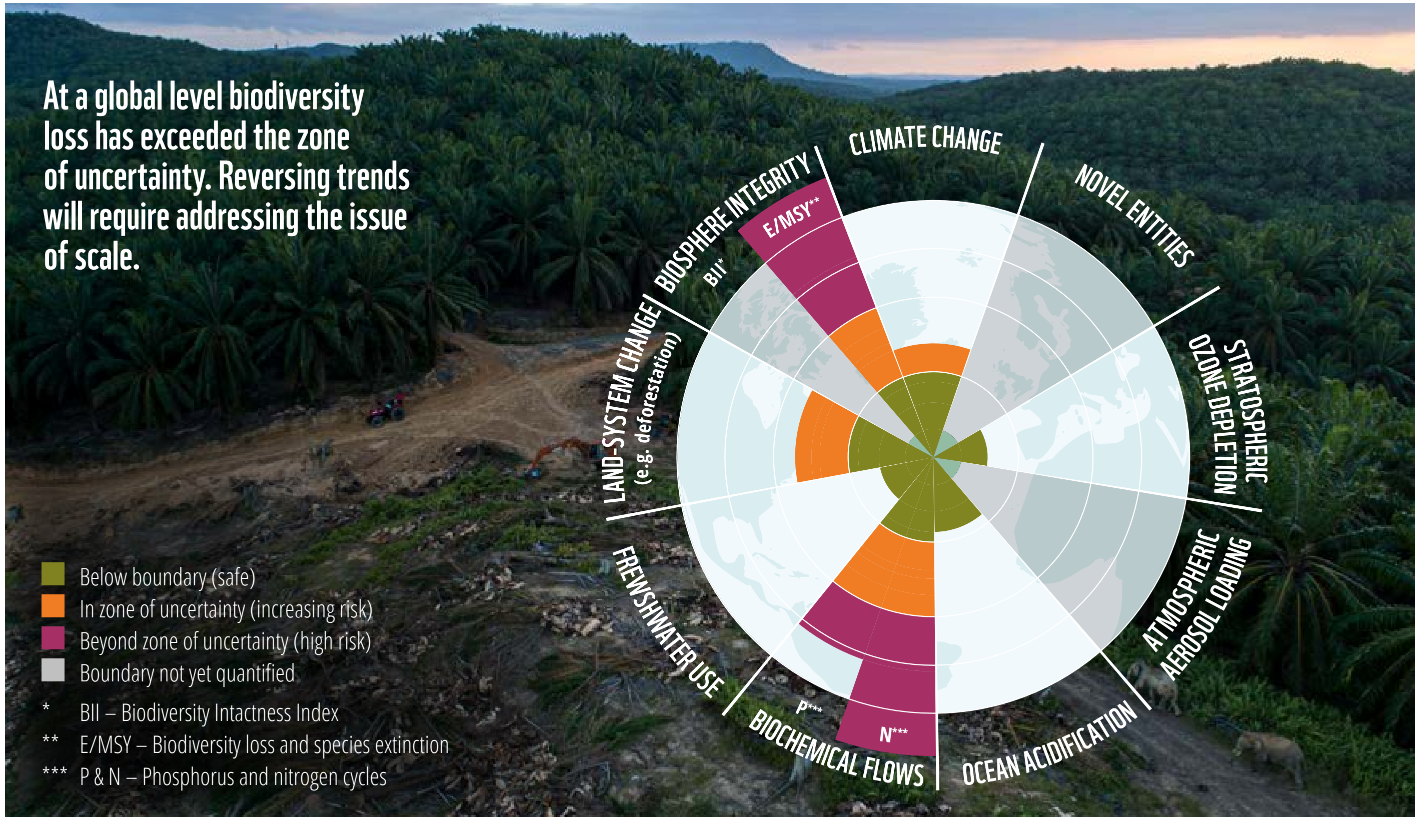
What is biodiversity?

Biodiversity is, simply put, the variety of life on Earth. It spans multiple levels, from genetics to species to ecosystems. Ecosystem diversity is the variety of ecosystems within and between different forest, wetland and grassland communities which enable populations of species to interact, adapt and evolve. This means not only that species and genetic diversity must be maintained to preserve biodiversity, but also that efforts must be made to **enable dynamic interaction within and between different ecosystems.** In its 2019 assessment, the IPBES[6] made it clear that there was an urgent need to protect biodiversity: **currently around 25% of species assessed in animal and plant groups are threatened with extinction [41]. Of the ecosystem services associated with the regulation of environmental processes, 9 of 10 are in decline [41].**

The planetary boundary framework aggregates individual changes to assess impacts at a global level. Scientists have defined **tipping points for major Earth operating systems,** beyond which the risk of irreversible change will push the Earth from the relatively stable Holocene (characterised by a mild climate enabling 10,000 years of development) into an uncertain future [30], [42]. The biodiversity planetary boundary is accounted for as the sum of species and ecosystem dynamism. It plays an important role in biogeochemical cycles (e.g. carbon, water) and in regulating climate (e.g. as stocks). **The planetary boundary for biodiversity is one of four which has been exceeded** (Figure 2.3). It is already in the red zone. Land system change and climate change – vital interacting boundaries – are both in the zone of uncertainty.

Figure 2.3: Planetary boundaries

Source: J. Lokrantz/Azote based on Steffen et al. 2015 [30]; Online Stockholm Resilience Centre



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The role of forests – habitats under threat

Forests are home to most of Earth's terrestrial biodiversity [43]. **Habitat loss and fragmentation are the biggest drivers of species loss [43].** The World Resources Institute[7] estimates that 782 million hectares (Mha) of forest had "highly intact biodiversity" in 2018 [44]. This means that these forests were minimally impacted by humans. Of these forests, two-thirds were located in only five countries (Brazil, Canada, the Democratic Republic of the Congo, Peru and Russia) and 32% were legally protected. The World Resources Institute also classified 455 Mha of forest as "highly significant" for biodiversity, meaning that those forests were disproportionately important to the species they supported. This was particularly the case for islands (41%) due to their unique composition of species. One-quarter of these forests were found in Australia, Brazil and Indonesia. Around 24% were in protected areas [44]. Both trends point to the under-representation of key forest ecosystems for biodiveristy in protected areas (see Section 2.4 on protected areas and their effectivness).

6 The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) global assessment included about 150 experts, assisted by 350 contributing authors. It analysed more than 15,000 scientific publications and a substantive body of Indigenous and local knowledge; www.ipbes.net/global-assessment

7 The Global Forest Review; available at: https://research.wri.org/gfr/indicators-monitoring-global-forest-trends/indicators-biodiversity-and-ecological-services/biodiversity-conservation

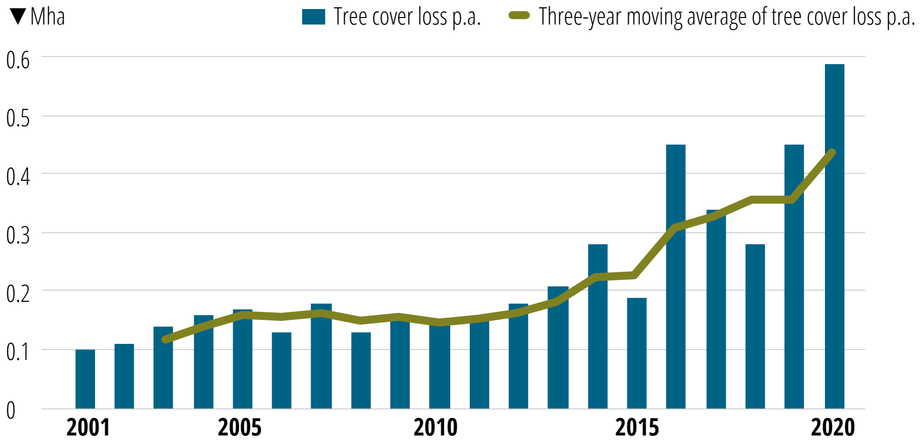


Figure 2.4: Area of tree cover loss in Alliance for Zero Extinction (AZE) areas (2001–2020)

Source: World Resources Institute [44]

Note: AZE areas contain species that are endangered or critically endangered following the IUCN classification. Tree cover loss in these regions has been estimated to increase by an average of 15% per year.

Nowhere is this more evident than in Key Biodiversity Areas (KBAs). These are "the most important places in the world for species and their habitats"[8]. In 2010 there were an estimated 435 Mha of tree cover within KBAs [44]. Despite their importance, **tree cover loss in these KBAs increased by an average of 9% per year since 2001 [44].** Alliance for Zero Extinction (AZE) sites contain species classified as either "endangered" or "critically endangered" on the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species[9]. Tree cover loss in these regions has been estimated to be even more pronounced (see Figure 2.4) with estimates of an average increase of 15% per year [44].

There is a clear and compelling consensus among scientists: the further loss of biodiversity must be prevented.

Altogether, deforestation, degradation and fragmentation of the planet's forests are devastating biodiversity at unprecedented levels. The impacts of these externally induced changes in ecosystems – and the connectivity between them – are discussed throughout the following chapters of this report. **There is a clear and compelling consensus among scientists: the further loss of biodiversity must be prevented.** The challenge is understanding what activities lead to incentives (intentional or not) to alter forest landscapes, and harm the biodiversity supported by those landscapes. This is the rationale behind this report.

In 2020 the world missed all of its commitments to protect biodiversity.

Missed targets and future potential

In 2020 the world missed all of its commitments to protect biodiversity. Some of the 20 targets set out by the Convention on Biological Diversity (CBD) in its global Strategic Plan for Biodiversity 2011–2020 in Aichi[10] were partially met; at a country level, more than half of the measurable indicators (for targets 1, 4, 5, 7, 11, 12, 19 and 20) showed "little or no progress" and in nearly one-quarter of the countries, development was "moving away from target" [45]. There has been an outpouring of efforts to turn these trends around, not least through better monitoring, management, integration and cross-cutting policies. Scientific modelling supports the idea that **a transformational shift with positive outcomes on biodiversity is possible** [46], [47]. For example, in 2018 around 60 experts in biodiversity and land use modelling joined forces to illustrate the potential for innovative modelling techniques for informing robust science-based targets [48]. Using four global land use models and eight global biodiversity models they illustrated that the biodiversity trend could be bent upwards (Figure 2.5).

Key to successfully bending the curve are changes across all areas: consumption (excess, diets, waste), production (land management practices integrating biodiversity) and conservation (protected areas).

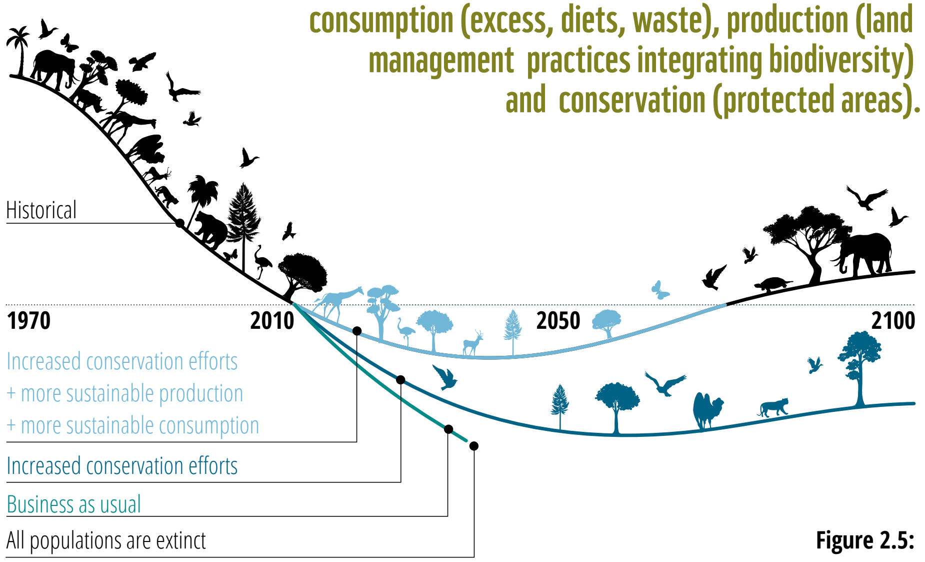


Figure 2.5: Bending the biodiversity curve

Source: Leclère et al. 2018 [48]], modified by WWF

Note: The historical biodiversity curve shows the monitoring results as the average abundance of 20,811 populations representing 4,392 vertebrate species. The average reduction from 1970 to 2016 was 68%.

8 https://www.keybiodiversityareas.org
9 https://www.iucnredlist.org
10 The plan contains multiple goals to halt loss, safeguard ecosystems and implement changes, see https://www.cbd.int/sp/targets/. The UN developed a new set of goals for the post-2020 period, which will be adopted in 2021 and will be centred around a vision for 2050 of "Living in harmony with nature".

Deforestation is one of the largest contributors to carbon emissions.

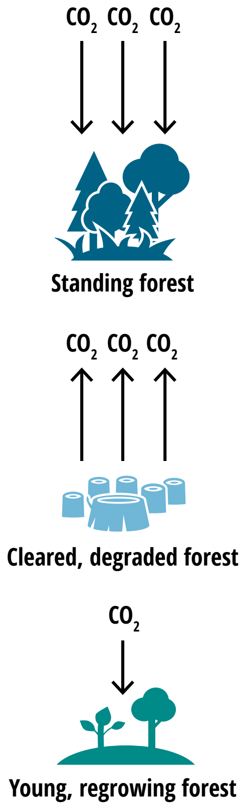


Figure 2.6:
Forests act as both a source and sink for carbon

Source: Global Forest Watch[12]

FORESTS AND CLIMATE CHANGE

The Earth is rapidly warming up [49]. **Around 23% of total net anthropogenic greenhouse gas emissions are related to land use** (agriculture, forestry and other land use); **deforestation is one of the largest contributors to carbon emissions** [50]. The 2021 Intergovernmental Panel on Climate Change (IPCC) report states: “Human-induced climate change is already affecting many weather and climate extremes in every region across the globe” [49]. These extremes – such as heatwaves, heavy precipitation, drought and cyclones – are expected to be greater in frequency and intensity with every additional increment of global warming. However, the Climate Action Tracker[11] reports that **the world is not doing nearly enough to mitigate these impacts.** The national targets that countries have made – let alone their policy responses to meet those targets – are not enough to reach the Paris Agreement target (of limiting global warming to well below 2 (preferably 1.5) degrees Celsius compared to pre-industrial levels). Countries like Germany, Switzerland and the USA are ranked as insufficient in their Climate Action Rankings[11].

The role of forests – a sink or source of carbon

The knowledge base for understanding the role forests play in mitigating climate change has expanded in recent years. Harris et al. (2021) estimate **that global forests provide a net carbon sink of around 7.6 billion tonnes of carbon dioxide equivalents (Gt CO2eq) annually** [51] (Figure 2.7). This is nearly three times higher than the EU’s annual emissions. However, deforestation and other forest disturbances emit CO_2 into the atmosphere. It is estimated that deforestation emits around 8 Gt CO_2eq. These are offset by forest absorption levels of (currently) 15.6 Gt CO_2eq to create a net “sink” [51]. These results can be explored online on the Global Forest Watch platform[12]. It should be noted that, while the science is improving, there are still disputes as to exactly how much of a role different types of forests play in the global carbon cycle.

Illegal slash-and-burn to clear the forest area for soy fields, Gran Chaco, Argentina.

11 Climate Action Tracker, 2021, https://climateactiontracker.org/publications/global-update-september-2021/; accessed September 2021
12 https://www.globalforestwatch.org/blog/climate/forests-carbon-emissions-sink-flux/; accessed September 2021

Different types of forests have different absorption and storage capacities. Plantations and intensively managed forests aimed at maximising timber production may be less effective carbon sinks than unmanaged natural forests [52] (Figure 2.6). One study found that this may be due to large differences in the soil [53]. Another study found that large-diameter trees store disproportionally high amounts of carbon[13] compared to smaller trees [54]. Luyssaert et al. (2008) argue for the role old-growth forests play as carbon sinks [55], whereas Gundersen et al. (2021) argue that Luyssaert et al. overestimate this effect [56]. Harris et al. (2021) observe that new forest areas (less than 19 years old) represented less than 5% of global gross carbon removals [51]. **Altogether, this emphasises the need to protect and maintain old-growth, primary forests from deforestation and degradation.** Moomaw et al. (2019) coined the term **proforestation,** arguing that keeping existing, mature and old forests as intact forests is a low-cost approach to immediately increase atmospheric carbon sequestration and reduce climate risk [57]. This is seen as doubly important because harvesting those forests releases carbon into the atmosphere. Deforestation and climate stress may currently be turning the Amazon forest into a carbon source instead of a sink [58]. The carbon mitigation potential associated with planting trees and/or promoting tree growth (especially with regard to restoration and afforestation) depends on how and where those trees are grown [52] (see also Section 2.2).

Maintaining primary forest area is at the heart of both biodiversity conservation and climate change mitigation. The question for determining sustainable consumption levels is, how much of the forest resource is available for wood supply, taking these considerations into account?

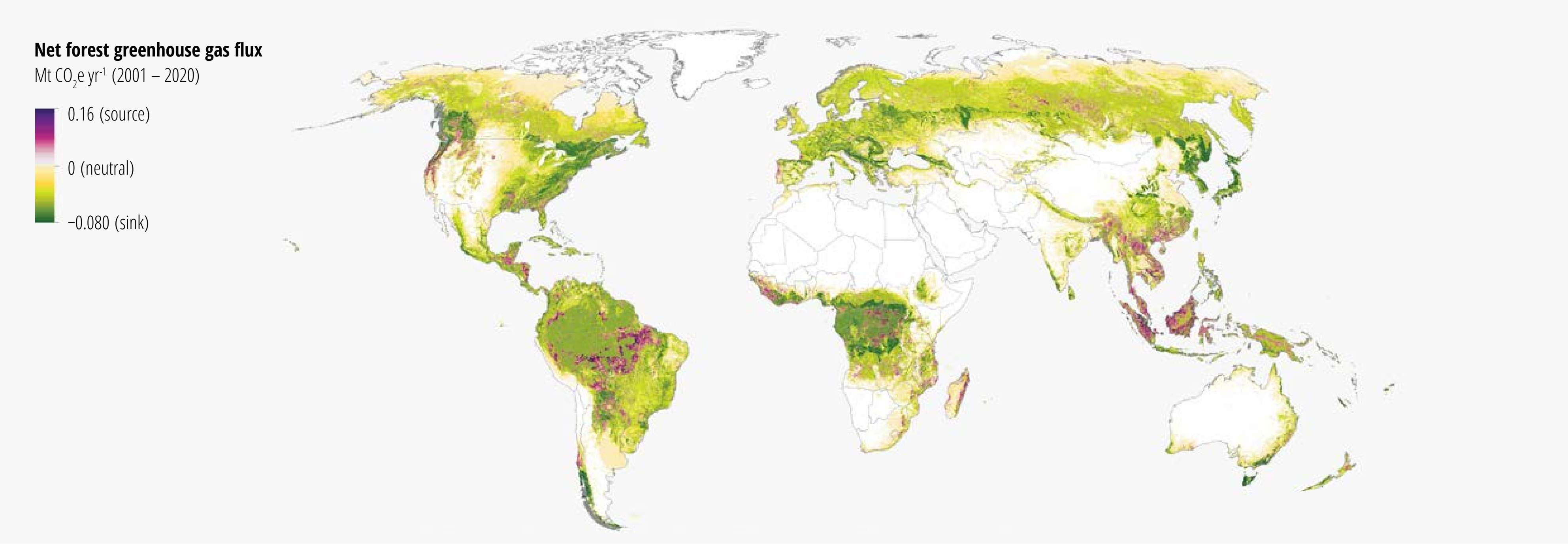


Figure 2.7: Net greenhouse gas fluxes from forests

Source: Harris et al. 2021

13 An analysis of forest inventory data from 3,335 plots in Oregon and Washington states showed that large trees accounted for 3% of the trees on the inventory plots, but stored 42% of the total above-ground carbon [54].

Governments have recognised the importance of forests to climate change mitigation. Finance for maintaining forests, and the ecosystem services they provide, is available through REDD+[14], adopted in 2003 in Warsaw and reiterated in the Paris Agreement. New EU rules to account for forests in Nationally Determined Contributions (NDCs) were established by the 2018 Land Use, Land Use Change and Forestry (LULUCF) Regulation. This has sparked an intense debate in scientific circles on the extent to which forest should be used or preserved, not only with regard to bioenergy (see Section 3.2.1) but also to the degree to which trees are best used as a sink: as growing stock in the forest or as wooden products integrated into the built environment (e.g. by using wood in construction) (see, for example, the Joint Research Centre's brief on this subject in the European context [59]). The key question here, and for this report, is **where to find the balance between conservation and use.** How the wood is likely to be used (market incentives) plays a major role in defining this balance.

Governments have recognised the importance of forests, G20 Summit, Rome, Italy, 2021.

© IMAGO/ZUMA Wire

The impact of climate change on forests – increased uncertainty in future projections

Climate change impacts forests in multiple ways, including changes observed in growth, drought-induced mortality, fire and species distribution (see Figure 2.8). Research that focuses on either productivity gains or the increased occurrence of disturbances arrives at widely different projections for forest growth potential in the 21st century. This increases the inherent uncertainty involved in estimating future supply potential.

➔ **Tree growth and climate change** – Some climate models in particular focus on the "CO_2 fertilisation effect". This has been shown to occur in greenhouses and trials where more CO_2 in the air acts as a "fertiliser" for plant growth [60]. However, this effect may also be short-lived in some cases, as some experiments have shown [61], [62]. With a narrow focus on just silver fir and European beech in the German Black Forest, Sperlich et al. (2020) found a tipping point when initial gains in growth were turned into losses [63]. The forest type and climate conditions appear to play a role here.

➔ **Increased disturbances and climate change** – The impacts on forests have become more severe (e.g. fires, pests, drought and disease; see Section 2.5). Moreover, there is a significant knowledge gap on adaptive forest management responses specific to different forests and climate conditions [64]. This could lead to mistakes and large-scale mismanagement, further decreasing the resilience of future forests.

In a study focused on Europe, Reyer et al. (2017) found that **including disturbances in model simulations cancelled out possible productivity gains** [65]. Ultimately, the way in which climate is considered has major consequences for the key question posed in Chapter 4 – how much wood is available for consumption under sustainable forest management conditions? The answer is critical for policy, with some unusually large supply projections leading to unrealistic sectoral expectations (see Section 3.2). Policy makers must be better informed about the base assumptions relating to how climate change impacts are modelled in relation to forest extent, availability, productivity and the underlying health of forests.

14 Reducing Emissions from Deforestation and Forest Degradation in developing countries. Since January 2020, 50 developing countries have submitted a REDD+ forest reference level or forest reference emission level for technical assessment to the UN Framework Convention on Climate Change (UNFCCC). These areas cover more than 70% of the total forest area in developing countries. For more information, see https://redd.unfccc.int

Figure 2.8: Summary of major ecological and eco-physiological factors associated with climate change and their impacts on various biological processes in trees

Source: Based on Sperlich et al. 2020 [63], modified by WWF

2.1 Deforestation, degradation and fragmentation

"[We] commit to working collectively to halt and reverse forest loss and land degradation by 2030 while delivering sustainable development and promoting an inclusive rural transformation."

Signed by 141 countries (including the "Big Five" forest-rich countries) in Glasgow in 2021[15]

15 The declaration is available at: https://ukcop26.org/glasgow-leaders-declaration-on-forests-and-land-use/; accessed 23 January 2022.

Primary rainforest destruction increased by 12% between 2009 and 2020.

The world has lost a net area of 178 Mha of forest since 1990 [4]. While the global rate of forest loss is decreasing, regional trends differ vastly (Figure 2.9). WWF found that **two-thirds of total global forest cover loss occurred in the tropics and subtropics between 2000 and 2018.** Primary rainforest destruction increased by 12% between 2009 and 2020[16]. Deforestation fronts[17] are "places that have a significant concentration of deforestation hotspots and where large areas of remaining forests are under threat" [66]. WWF has identified 24 deforestation fronts covering an area of 710 Mha [66].

Drivers of deforestation

Researchers studying the causes of deforestation distinguish between direct and indirect causes. **Agriculture is the largest direct cause of deforestation.** For example, agricultural area increased by over 100 Mha between 1980 and 2000 across the tropics; half of this increase was at the expense of intact tropical forests [67]. Driving this need for crops and pastures is a demand for food, fibre and biofuels in – in some cases – distant markets. Already in 2010 scientists pointed to a growing global displacement of land use for national forest transitions [34]. A 2012 study found that **30% of global species threats are linked to international trade** [68]. Pendrill et al. (2019) estimated that 62% (5.5 Mha per year) of forest loss between 2005 and 2013 was due to the expansion of commercial cropland, pastures and tree plantations [31]. Around 26% of the commodities produced (meat from cattle, forestry products, oil palm, cereals and soybeans) were attributed to international demand. The vast majority of the countries importing these products (87%) experienced either decreasing deforestation rates or increasing forest cover over the same time period. As a result, the authors suggest that achieving a global forest transition, with nowhere left to displace consumption pressures to, will be substantially more challenging than countrywide experiences indicate. A key indirect driver of land expansion for agriculture is the shift towards animal-based diets [69], [70], possibly overriding population growth as the largest driver [71]. FAO writes: "We need to transform our food systems to halt deforestation and the loss of biodiversity. The biggest transformational change is needed in the way in which we produce and consume food." FAO 2020 [72]

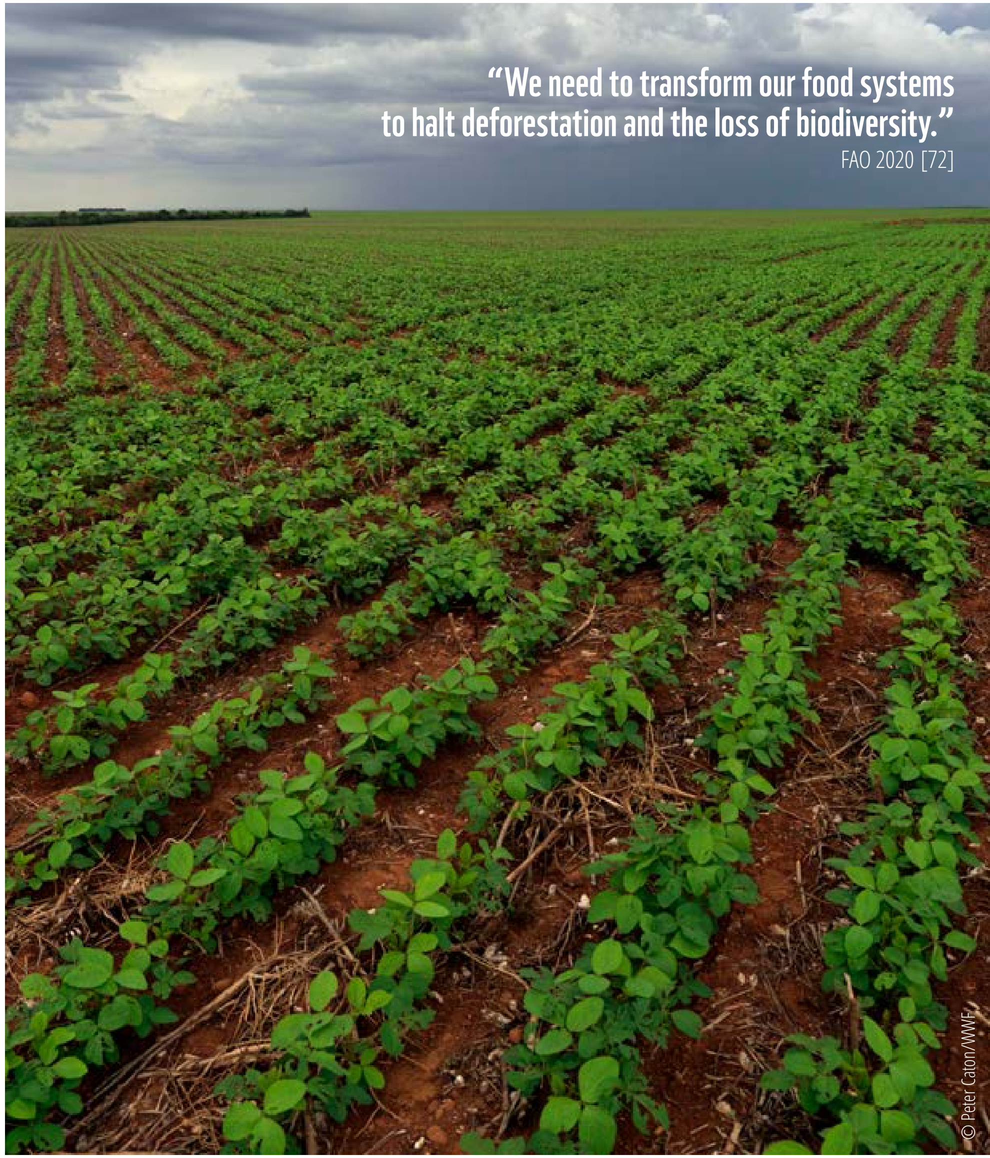
Box 2: What is forest loss/deforestation, degradation and fragmentation?

Forest loss/deforestation: Conversion of forest to another land use or significant long-term reduction in tree canopy cover. This includes the conversion of natural forest to tree plantations, agriculture, pasture, water reservoirs and urban areas but excludes logging areas where the forest is managed to regenerate naturally or with the aid of silvicultural measures.

Forest degradation: Changes within forests that negatively affect the structure or function of the stand or site over many decades, and thereby lower the capacity to supply products and/or ecosystem services.

Fragmentation: A form of degradation that changes the spatial pattern and structure of forests into smaller patches or "islands". This damages forest functions (e.g. carbon storage, water provision, maintenance of species habitat).

Source: Pacheco et al. 2021 [66]



Large soy fields destroy the Cerrado forests, bush and grassland mosaic for feeding our livestock.

16 The Global Forest Review, published by the World Resources Institute, available at: https://research.wri.org/gfr/global-forest-review?utm_medium=homepage&utm_source=wriwebsite&utm_campaign=globalforestreview

17 www.panda.maps.arcgis.com/

Forestry was found to represent around 26% of all global forest disturbances in the period between 2001 and 2015 [73]. In other words, using satellite imagery, researchers were able to distinguish between temporary forest loss and permanent deforestation. The map in Figure 2.9 depicts key results. In the case of forestry, re-growth was found to follow harvests. Shifting agriculture, which was defined as small to medium-scale forest and shrubland conversions, was also followed by subsequent forest regrowth, and comprised around 24% of the forest disturbances observed. However, the largest share (around 27%) of forest disturbance was associated with permanent commodity-driven deforestation for agriculture, mining or energy infrastructure. **The study warned that despite corporate commitments by companies to implement zero deforestation supply chains, the rate of commodity-driven deforestation has not declined.**

Commodity-driven deforestation accounts for 27% of forest loss and represents permanent forest loss. The Forestry category depicts areas most often followed by recovery.

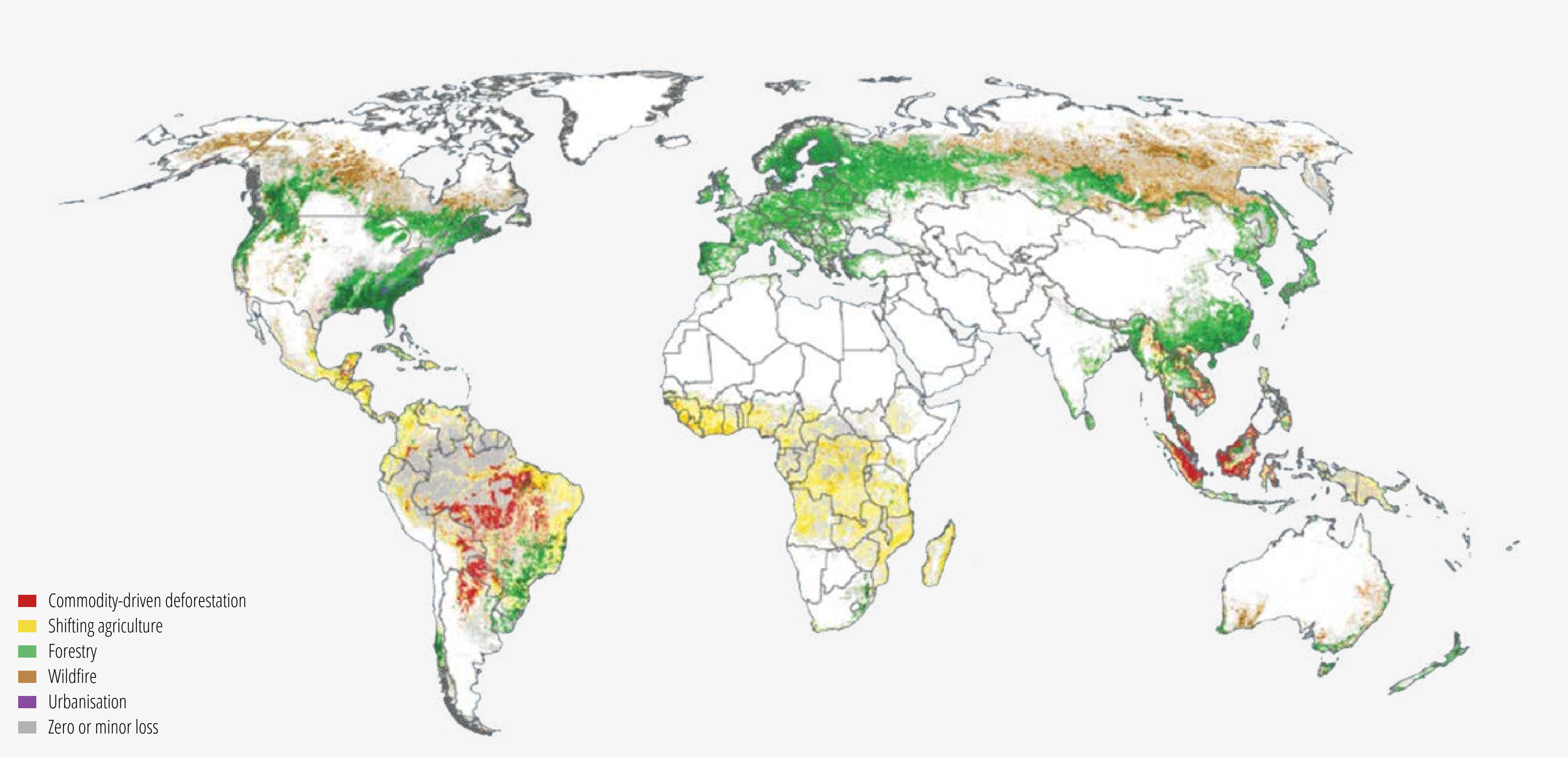


Figure 2.9:
Main drivers of forest cover loss for the period 2001 to 2015

Source: Curtis et al. 2018 [73]

Note: Darker colour intensity indicates greater total quantity of forest cover loss.

The response framework – a bundle of options is most effective

In 2019 the Accountability Framework[18] reported that commodity-specific disclosures (most were for timber, followed by palm oil, soy and cattle) on forest-related policies were made by 411 companies [74]. In practice, however, these **commitments were found to lack consistency in scope, ambition and terminology** and did not align with the consensus-based definitions and guides developed by the Accountability Framework. This is consistent with the findings published by Pacheco et al. (2021): "Commodity or sector specific responses like voluntary certification, payments for environmental services (PES) and deforestation-free supply chains are important but thus far have had limited impact at scale." [66]

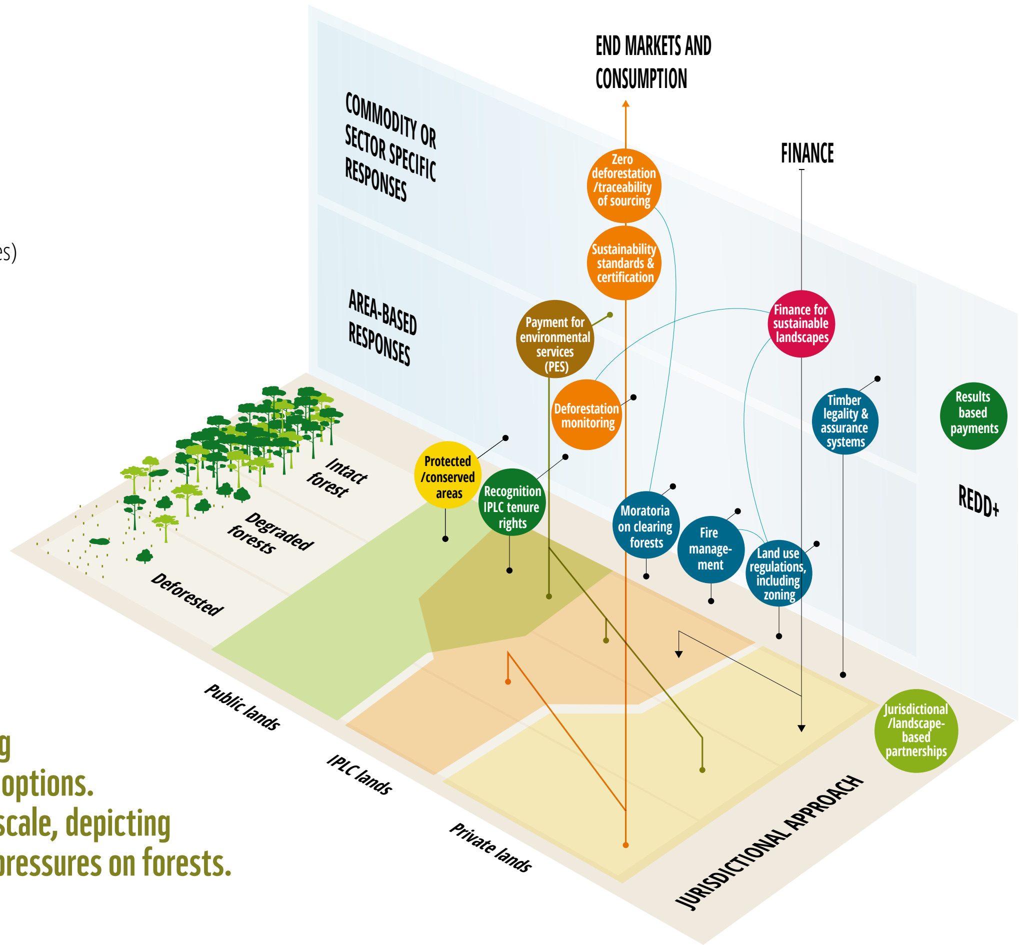
Robust and credible voluntary certification systems can support and push transformation towards deforestation-free supply chains.

© iStock/Getty Images

"Commodity or sector specific responses like voluntary certification, payments for environmental services (PES) and deforestation-free supply chains are important but thus far have had limited impact at scale." [66]

18 https://accountability-framework.org

- Public lands
- IPLC lands (Indigenous Peoples' and Local Communities' lands and territories)
- Private lands
- Landscape/jurisdication
- Finance and investement (flows of money)
- Supply chains (flows of products and services)
- Scope of influence
- Interactions



Footprint monitoring in consuming countries could join the response options. Footprints address the issues of scale, depicting how overconsumption increases pressures on forests.

Figure 2.10: Multiple response options to combat deforestation

Source: Pacheco et al. 2021 [66]

Such efforts make up one pillar of societies' efforts to halt deforestation. At the same time, industry-led campaigns, scientific literature and social media are teeming with examples and case studies of good practice. Tools like Global Forest Watch[19], SPOTT[20], GRAS[21], Trase[22] and Forest 500[23] are continually evolving and increasing their outreach. Third-party, near real-time deforestation monitoring[24] is now applied in some regions. While progress in such tools is encouraging, the knowledge generated must lead to specific actions by governments and their agencies, investors, businesses or customers to be effective in combating deforestation. **Ultimately, multiple responses used in combination are most effective** (Figure 2.10) [66]. In the future, footprint monitoring and benchmarks could join the toolbox for addressing the consumption pressures associated with the scale of demand.

On the ground, **a landscape approach**[25] [75] may be used to frame actions towards area-based responses. This means encouraging land use choices that retain forests for multiple purposes and optimise the productive capacity of the surrounding landscape (e.g. agriculture and biodiversity). FAO emphasises the importance of a landscape approach for **increasing resilience,** not only for the purposes of climate mitigation and disaster risk reduction, but also as a **safety net for vulnerable segments of society in times of crisis** to provide food (e.g. nuts, honey, wild meat, fruit), fodder and woodfuel [76].

19 Global Forest Watch is an online platform that provides data and tools allowing anyone to access near real-time information about where and how forests are changing around the world. More information is available at: https://www.globalforestwatch.org/about/
20 The Sustainability Policy Transparency Toolkit (SPOTT) assesses commodity producers, processors and traders on their public disclosure, and scores tropical forestry, palm oil and natural rubber companies annually against over 100 sector-specific indicators to benchmark their progress over time.
21 The Global Risk Assessment Services (GRAS) project supports companies by calculating a risk index based on land use change heat maps, which allow the identification of high-risk areas and indicate which regions are highly affected by unsustainable forest clearings.
22 Trase uses publicly available data to map the links between consumer countries via trading companies to the places of production. See https://trase.earth
23 Forest 500 ranks the most influential companies driving tropical deforestation. Its latest assessment of the 500 biggest companies in these supply chains – and the financial institutions that fund them – found that almost half did not have any commitments to prevent deforestation. See www.forest500.org
24 For example, the GLAD alert system devised by the University of Maryland uses satellite imagery to collect weekly data on deforestation across the tropics. It indicates when a 30 by 30 metre area has experienced disturbance in the forest canopy to automatically flag areas which have changed in comparison to historical data. More information is available at: https://glad.geog.umd.edu
25 The "landscape approach" is a term used to describe collaborative initiatives that span multiple sectors and go beyond the scale of individual farms, forest management units and protected areas.

Degradation and fragmentation – critical challenges with strong ties to forest management practices

A landscape approach is becoming particularly important as scientific evidence on **degradation**, and the harm it causes, is increasing. Grantham et al. (2020) found that **only 40% of global forests have high landscape-level integrity,** and only 27% of these forests are found in protected areas [1]. For example, Matricardi et al. (2020) found that, in the Brazilian Amazon, **forest degradation is a "separate and increasing form of forest disturbance, and the area affected is now greater than that due to deforestation"** [77]. Another study by Gandour et al. (2021), conducted as part of the Climate Policy Initiative, also called attention to the issue of forest degradation in Brazil, finding that it is concentrated along the "Arc of Deforestation"[26] [78]. There is an urgent need to stop forest degradation globally and to protect the old-growth forests in remaining patches.

The overall increase in fragmented forest area between 2000 and 2018 is larger than deforestation during the same period, except in subtropical forests.
(Pacheco et al., 2021 [66])

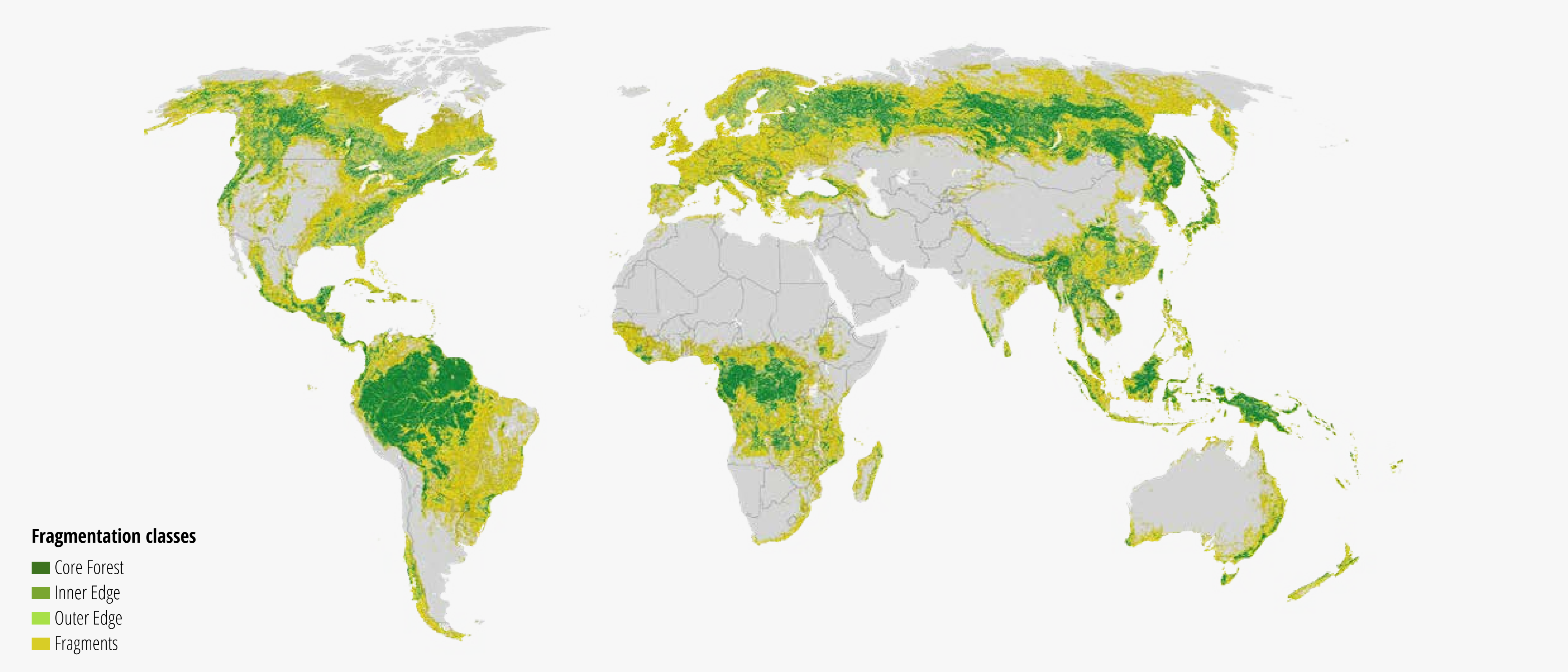


Figure 2.11: Forest fragmentation in 2018
Source: Pacheco et al. 2021 [66]

26 The Arc of Deforestation refers to a wide region of the Amazon Biome that extends from western Maranhão and southern Pará towards the west, passing through Mato Grosso, Rondônia and Acre [78].

The New York Declaration on Forests is a common, multi-stakeholder framework for forest action, consolidating various initiatives and objectives that drive forest protection, restoration and sustainable use. There are currently over 200 endorsers, including national governments, sub-national governments and multinational companies.
Source: www.forestdeclaration.org

Forest fragmentation is one form of degradation. Nearly **half of the forests in the deforestation fronts identified by WWF have been fragmented to some degree.** Haddad et al. (2015) found that **fragmentation reduces biodiversity by 13 to 75%** [2]. Their study looked at high-resolution maps of global tree cover over 35 years to find that **more than 70% of global forests are within 1 kilometre of a forest edge.** This makes these forests more accessible to human activities (like logging) as well as to influences that may degrade forest ecosystems (e.g. altered climate, invasive species) by decreasing biomass, pollination and erosion control and altering nutrient cycles. Moreover, **forest fragmentation is often the first phase of land conversion from forest to other land uses** [72]. According to WWF (2020), around 20% of total forest loss occurs in core forests, whereas 80% is in edge and patch forests [66]. Factors which may induce fragmentation include natural changes (like fire), forest exploitation (unmanaged logging or woodfuel harvesting) or land use conversion to human uses (initiated by the introduction of roads). In this case, the role of exploitative versus managed harvesting should be distinguished. In the EU, a pilot study [79] aimed at developing a forest fragmentation indicator noted that forest felling does not result in fragmentation where the forest is regrown. The study found that, for the majority of species in temperate forests, small patch forest clearings do not represent significant biodiversity barriers. This points to **the importance of the management regime and harvesting practices on the ground.** Altogether, "indices only using forest extent may inadequately capture the true impact of human activities on forests, and are insensitive to many drivers of forest modification and the resulting losses of forest benefits" [1].

Major commitments to change, but little progress so far

Countries across the world have committed to halting deforestation and degradation in various ways, for example, in Global Forest Goals [80], in the New York Declaration on Forests, as part of biodiversity strategies [81] and in various climate commitments (Paris Agreement and most recently at the 2021 Climate Change Conference in Glasgow). On the one hand, **progress has been slow.** In addition to monitoring the extent of forests, "the retention and restoration of forest integrity should also be addressed in nationally-defined goals" [1]. On the other hand, **massive mobilisation efforts are under way.** New legislation aims to address also the indirect causes of deforestation and degradation in supply chains (for example, on 17 November 2021, the EU published a proposal for a regulation on deforestation-free products[27]). The effectiveness of such policies, in light of increases in demand potentially incentivising unsustainable practices and illegal activities, remains to be seen. Ultimately "real impact will come from transforming our economies", including the food and financial system, "to place nature and people at the centre" [66].

27 Available at: https://ec.europa.eu/environment/publications/proposal-regulation-deforestation-free-products_en

2.2 Restoration

THE BONN CHALLENGE

Bring 150 Mha of degraded & deforested landscapes into restoration by 2020 and 350 Mha by 2030.

THE NEW YORK DECLARATION OF FORESTS

Increase global restoration of degraded landscapes and forestlands to restore and maintain 350 Mha of landscapes and forestlands by 2030.

THE UN STRATEGIC PLAN FOR FORESTS

Increase forest area by 3% worldwide by 2030.

THE EU'S GREEN DEAL

Plant at least 3 billion additional trees in the EU by 2030.

Box 3: What is forest landscape restoration (FLR)?

The Bonn Challenge defines it as the ongoing process of regaining ecological functionality and enhancing human well-being across deforested or degraded forest landscapes.

FLR is meant to be more than just planting trees – it is "restoring a whole landscape to meet present and future needs and to offer multiple benefits and land uses over time". The majority of restoration opportunities are found on agricultural or pastoral land adjacent to forests, while sometimes there is an opportunity to restore large contiguous tracts of degraded or fragmented forest land.

Source: https://infoflr.org/what-flr; accessed 19 October 2021

The United Nations declared 2021–2030 the **Decade of Ecosystem Restoration.** This reflects the multitude of widespread commitments, pledges and resources dedicated to forest landscape restoration.

However, progress towards these targets at a global level is slow. In 2020 FAO concluded **"The world is not on track to meet the target** of the United Nations Strategic Plan for Forests to increase forest area by 3 percent worldwide by 2030" [72]. The New York Declaration on Forests (2020) reported that "there are indications that we are not on track to meet the goal" [82]. While the commitments demonstrate **significant levels of political will, only a small amount of restoration has actually been reported to be in progress. In fact, the study found indications that the rate of forest restoration has actually declined since the start of the Bonn Challenge in 2011.** It reports that around 27 Mha have experienced "tree forest gain" since the year 2000, noting the inadequacies of this indicator for providing a complete picture on forest restoration. The Bonn Barometer (2019) reported somewhat different results, but still not on a scale nearing targets. They found that – at the time of publishing – **43.7 Mha were attributed to the implementation of a restoration target.** As of August 2020, Bonn Challenge pledges made by countries, sub-national governments and companies totalled 172.82 Mha [83].

Box 4: Further examples of international, big restoration initiatives

- The United Nations Convention to Combat Desertification, aimed at **achieving land degradation neutrality,** supports countries in setting baselines, targets and measures. **www.unccd.int/actions/achieving-land-degradation-neutrality**
- The FAO **Forest and Landscape Restoration Mechanism** (FLRM) provides direct and normative support at all levels, through knowledge management, innovative financing and resource mobilisation, forest landscape restoration (FLR) monitoring and communications. It has developed multiple guides for practitioners. **www.fao.org/in-action/forest-landscape-restoration-mechanism/en**
- **Trillion Trees** is a joint venture of BirdLife International, Wildlife Conservation Society and WWF to make practical progress and inspire the world to protect and restore a trillion trees by 2050. It acts as a connector between investment and initiatives sourced through our extensive networks. **trilliontrees.org**
- **1t.org** was launched by the World Economic Forum to support existing initiatives to plant 1 trillion trees by 2030 by mobilising the private sector, facilitating multi-stakeholder partnerships and inspiring innovation and ecopreneurship. **www.1t.org**

WHERE AND HOW NEW TREES GROW

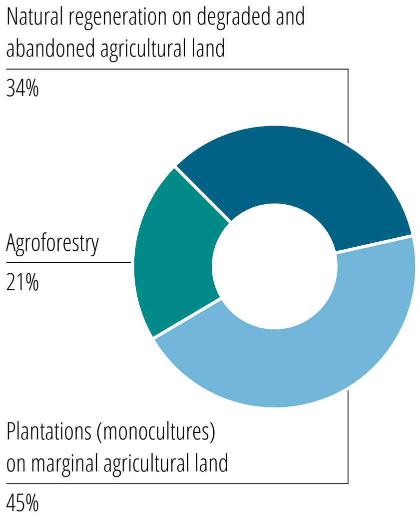


Figure 2.12: Breakdown of forest restoration in tree planting efforts assessed by Lewis et al. 2019

Source: Lewis et al. 2019 [3]

Note: Covering two-thirds of the Bonn Challenge pledged areas in 24 countries at the time of analysis.

Forest landscape restoration aims to be more than just increasing tree cover. It is intended to be linked to goals for socio-economic development, biodiversity conservation and climate change mitigation, among others. This makes **how and where trees are planted critical to success – socially and ecologically** (see also the discussion of plantations in the next chapter). For example, Lewis et al. (2019) found that the amount of carbon storage potentially attainable through achieving restoration targets depends critically on the type of forest restoration implemented [3]. So far, Lewis et al. (2019) found that, of the countries in the Bonn Challenge which have published detailed restoration plans (covering two-thirds of the pledged area and 24 countries), monoculture plantations make up nearly half of tree planting efforts, with planted trees consisting of species like eucalyptus, acacia and Pinus radiata (see Figure 2.12). Natural regeneration, in contrast, means protecting land from disturbances and allowing trees to return, potentially assisted by the planting of native species as pioneered in Costa Rica. If, for example, targets for restoring 350 Mha used natural regeneration, some estimates show that the area could store 42 petagrams of carbon (Pg C)[28] by 2100. In contrast, monoculture plantations on the same area are estimated to sequester just 1 Pg C and agroforestry 7 Pg C [3].

Strassburg et al. (2020) also found that **area alone is an ineffective metric for ensuring that restoration leads to biodiversity conservation and climate mitigation.** They prioritised areas for restoration using a multi-criteria approach at a biome-specific level, finding that "restoring 15% of converted lands[29] in priority areas could avoid 60% of expected extinctions while sequestering 299 gigatonnes of CO_2 – 30% of the total CO_2 increase in the atmosphere since the Industrial Revolution" [84]. Their findings **emphasise the potential of restoration – when done "right".** However, they also discuss the large geopolitical differences in the location of their "priority areas", underscoring both the necessity of international cooperation as well as a synergistic pursuit of goals.

Under the European Green Deal, the EU pledged to plant 3 billion additional trees by 2030. The EU Commission's roadmap to reach this commitment sets a framework to **"plant and grow the right tree in the right place, for the right purpose".**

A landscape under restoration in Tigray, Ethiopia.

This includes doubling the forest expansion rate in the EU (i.e. twice as much expansion compared to the period 2005–2020)[30] and establishing trees outside the forest (e.g. in urban areas). The planted trees must, in general, be native species and they cannot be harvested for several decades after planting (to avoid short-rotation coppice). The roadmap sets forth what they describe as an ambitious but feasible plan for getting on track to climate neutrality and reverting biodiversity loss.

Ultimately, the energy and excitement around tree planting worldwide has the potential to be a game changer [85]. Done wrong, it could also have unintended impacts or missed potential for mitigating climate change and biodiversity conservation. Multiple resources demonstrate how to get it right[31].

28 1 Pg C equals 1 billion tonnes. Around 10 Pg C are released annually from burning fossil fuels; https://gml.noaa.gov/ccgg/carbontracker/; accessed September 2021.
29 The study considered only lands previously converted from natural ecosystems to croplands or pastures.
30 To restore 77 Mha of natural ecosystems and 4.8 Mha from abandoned agricultural land; it should be noted, however, that the EU (like Germany) is already a net importer of agricultural land [35] and trade-offs with food supply capacities must be carefully evaluated.
31 See, for example, https://www.wri.org/insights/want-grow-trees-consider-these-5-lessons

2.3 Plantations

Is the aim of a new plantation centred exclusively around timber production or does the new plantation have multiple aims further connected to local socio-economic development and ecosystem services?

Box 5: What is the difference between planted and plantation forests?

The term "planted forest" is an overarching category that encompasses plantations. Changing nomenclature and classifications may lead to confusion when interpreting studies. This is because FAO's Forest Resources Assessment reports have sometimes included both planted and plantation forest areas, and sometimes only reported on one category.

Planted forests:

"Forest predominantly composed of trees established through planting and/or deliberate seeding" [90].

Plantations:

"Planted forest that is intensively managed and meets ALL the following criteria at planting and stand maturity: one or two species, even age class, and regular spacing" [90].

Note: Plantations are now typically expressed as a sub-category of planted forests.

Divergent views persist about the benefits and impacts of tree plantations for nature and people. The answer to the question above has major implications for how and where plantations are established and managed, and is particularly relevant for investors.

On the one hand, plantations do have negative impacts on biodiversity when replacing natural forests – they are a main driver of the deforestation connected to EU consumption [86] – and can have further negative impacts on the landscape as well as socio-economic and health impacts on local communities. On the other hand, they are simultaneously recognised for their potential to deliver environmental services and social benefits [87]. Systematic reviews [88] have criticised those working with large-scale timber and pulp and paper plantations, especially for promoting the benefits of these plantations without necessarily acknowledging the negative impacts on nature and people. Done poorly, plantations can cause negative impacts such as habitat conversion, soil damage, aquifer damage, forest fires and the creation of poorly planned infrastructure. They can also encourage the spread of invasive species outside of plantation boundaries, lead to violations of the rights of Indigenous Peoples and local communities, and cause the flourishing of corrupt and/or unlawful practices.

This section argues that there is a big difference between intensively managed monocultures focused on industrialised production and plantations that are managed according to the "New Generation Plantations" concept (see Box 6), which aim to incorporate ecological management and social principles. We argue that the latter, if established in the right places, can help conserve biodiversity, especially by lowering the use pressure of protected areas and primary forests, and meet local human needs. At the same time, they can contribute to sustainable economic growth and local livelihoods [89] and have the potential to balance timber production needs with biodiversity conservation and climate change mitigation. However, this is again a question of increased or decreased consumption levels.

FAO reports that plantations (see the definition in Box 5) expanded by 38% from 2000 to 2020. They comprised around 2.3% (94 Mha) of total forest area in 2000 and approximately 3.2% (130 Mha) in 2020 [4]. However, **the speed of expansion has decreased.** While the total plantation area grew by 25.7% between 2000 and 2005, the increase declined to 5.1% between 2015 and 2020.

Box 6: The New Generation Plantation platform aims to ...

Multi-stakeholder participation in a landscape restoration project, Chile.

© NewGenerationPlantations

WWF together with government forest departments and private companies created New Generation Plantations in 2007. It has evolved into a platform for sharing knowledge, best practices and collaborative learning.

Since 2020 it has been implemented by WWF's Forests Forward programme (forestsforward.panda.org), generating projects for WWF's Bankable Nature Solutions. Over the last decade, the New Generation Plantations project has shown that forest plantations can produce timber efficiently and profitably while maintaining ecosystems and contributing to socio-economic development. It aims to have a positive impact for people and the planet.

More information is available at newgenerationplantations.org

What are the risks of negative impacts associated with intensively managed monocultures?

In some regions, plantations have expanded at the cost of intact forests and grassland habitats. Fagan et al. (2021) found that tree plantations dominated tree cover gains across the tropics, with **92% of plantation expansion occurring in biodiversity hotspots.** They observed that "tree plantations expanded into 9.2% of accessible protected areas across the humid tropics, most frequently in southeast Asia, west Africa, and Brazil" [91]. The Southern United States [92] and Spain [93], [94] have documented cases of highly productive pine and eucalyptus plantations replacing natural forests. WWF (2021) identified tree plantations as the fourth direct driver of tropical deforestation [86].

Afforestation which occurs on historically non-forested land may be associated with particularly detrimental effects on biodiversity and ecosystems, depending on how and where it is implemented.

Forest plantation in Yueyang, China

© Theodore Kaye/WWF China

For example, a review of scientific papers done by Camia et al. (2021) showed that all afforestation on grassy biomes is particularly risky for biodiversity and ecosystem conditions [95]. Another major concern linked to afforestation of prior cropland is indirect land use change [95]. For example, China's tree cover grew by 32% between 2000 and 2015 due to massive afforestation efforts. However, Hua et al. (2018) found that afforestation based on converting cropland also led to displacement of cropland at the cost of native forests (which suffered a net loss of 6.6% over the study period) [96].

Water and the impact of forest plantations on watershed management on multiple scales is also an area of concern, especially in water-scarce regions [97]. Run-off of fertiliser and pesticide residues can impact water quality. Fast-growing species managed for maximum extraction may also **deplete soil fertility.** The review of scientific papers assessing **biodiversity impacts** conducted by Camia et al. (2021) found "consensus across the literature that substituting native, naturally regenerating forests with intensively managed plantations has negative consequences for local biodiversity across regions and taxa assessed" [95].

What is the positive potential for models like New Generation Plantations?

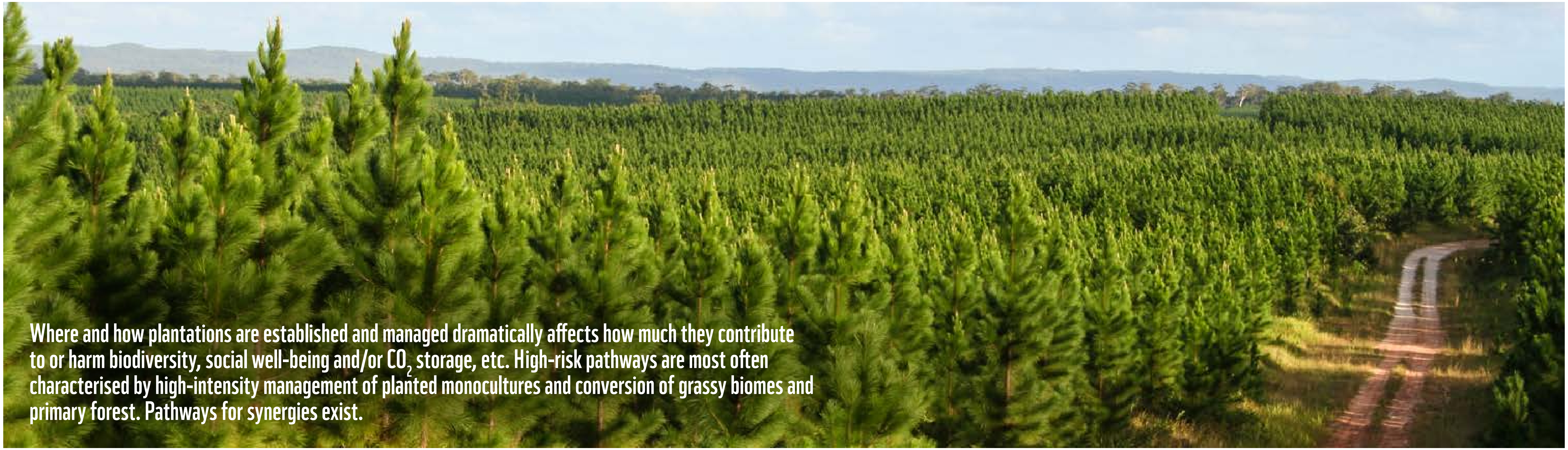
Management strategies to achieve timber production and maintain ecosystem services in and around forests are plentiful. The Pan-European Guidelines for Afforestation and Reforestation recommend several approaches[32]. Brown et al. (2020) argue that long-rotation forest plantations that include selective harvesting have a critical role to play in forest rehabilitation and climate change mitigation in the tropics [98]. Silva et al. (2019) present data from WWF's New Generation Plantations project, in which the participants manage over 11 Mha of land worldwide, with approximately 43% in plantation forestry. They present multiple examples of how mixed species plantations fit in landscape mosaics with multiple co-benefits [89]. The EU's Joint Research Centre has published a report identifying high-risk and low-risk pathways for plantation expansion based on a literature review [95]. Ultimately, well-managed plantations that take ecological and social principles seriously could play a role in timber supply in the future and could reduce the pressure to source raw materials from primary forests, depending on the total level of demand, effective mitigation of the rebound effect (Jevons paradox[33]) and accompanying conservation (see Section 2.4).

32 Such as favouring native species, promoting structural and species diversity, promoting landscape connectivity and protecting soil and water quality and quantity.
33 This describes cases where increased efficiency leads to increased consumption. For example, if prices go down as a result of efficient production, it could further stimulate demand, increasing the pressure to expand production. Strong institutions and accompanying policies are crucial to mitigate this effect.

How much land is available for plantations?

The key question is: **how much land is available for plantations, managed in a way that joins both humankind's and nature's objectives?** Elias and Boucher (2014), for example, differentiated between two possible futures: "one in which demand for wood products is met in a sustainable way through the careful use of forest plantations; and another in which business as usual for wood and paper production continues to degrade and destroy tropical forests" [99]. They recommended establishing plantations following strict best management practices and estimated that 125 Mha would be needed globally to meet their projected demand for wood products. However, their study may have significantly overestimated productivity[34] and thus underestimated land requirements. The last decade has also seen increased scientific consensus on critical land limits. While land demands for agriculture are expected to continue to grow – increasing the risk of conflicts – the latest assessments show that agricultural expansion is already close to limits or already in the zone of uncertainty (e.g. for land system change in the planetary boundary framework) [30], [42], [100], [101]. Afforestation and deforestation to establish plantations are serious concerns. More modest and recent projections for planted forests indicate a +9 to +14% increase by 2055 [102]. These are lower than projections from previous studies, which estimate ranges of +46 to +66% by 2070 for planted forests [103]. We rely on more modest projections and a continuation of recent trends for our scenarios of potential supply in Section 4.3.4. **This reflects our core message – while developing sustainable supply capacities on the production side is certainly important, more attention is needed on transforming economies toward sustainable consumption levels. The focus must shift from per se increasing supply to decreasing demand.**

Pine plantation, Queensland, Australia



34 They refer to an increment of 30 m³/ha*y, which is more than three times the mean annual increment for plantations we use in Section 4.3.2.

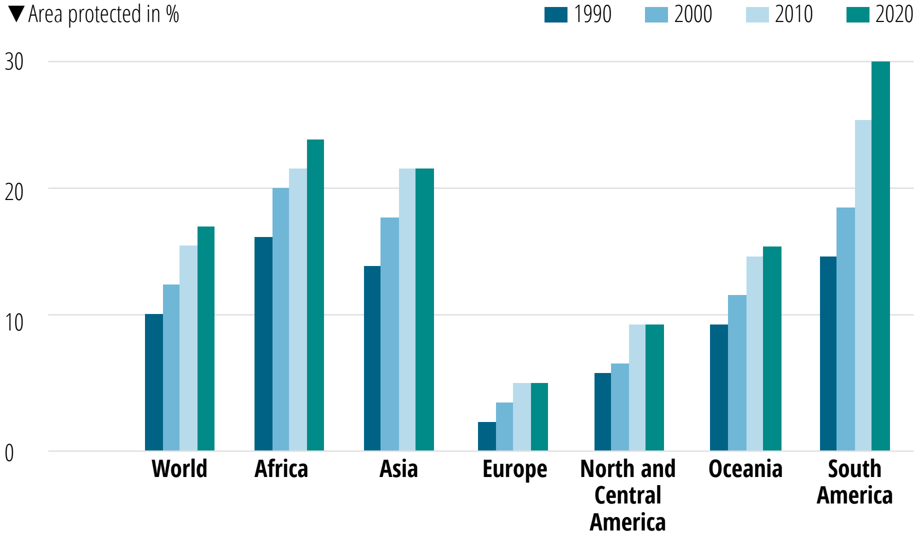
2.4 Protected, conserved and Indigenous Peoples’ land

Protected and conserved areas, including Indigenous and Community Conserved Areas (ICCAs), are one of the main tools to achieve conservation and sustainable development (see Box 7 for key definitions). Such areas have been characterised as the cornerstone of biodiversity conservation. However, protected areas are **“woefully below what the results of most scientific studies show are necessary to meet widespread conservation goals”** [104]–[106]. IPBES (2019) states that protected areas only partly cover important sites for biodiversity and they “are not yet fully ecologically representative, well-connected and effectively or equitably managed” [41].

Figure 2.13:
Share of protected forest area in the total regional area from 1990 to 2020

Source: Database, FAO Global Forest Resources Assessment 2020

Note: This figure depicts the data downloaded from the 2020 Forest Resource Assessment Database (available online: https://www.fao.org/forest-resources-assessment/en/). There is a discrepancy between the total world protected areas reported in the assessment report (726 Mha) and the data presented in the database (701 Mha) potentially due to an actualisation, for example. The shares of forest area in protected areas as given in this figure were used in the calculation in Chapter 4 to help define the forest area theoretically available for wood supply (see Section 4.3.1).



▼Area protected in Mha

	World	Africa	Asia	Europe	North and Central America	Oceania	South America
1990	437	124	85	18	42	18	150
2000	530	143	106	32	51	22	175
2010	662	148	137	48	73	27	229
2020	701	158	136	50	71	29	257

FAO (2020) estimated that 726 Mha of forest, or nearly 18% of the global forest area, are in protected areas [4]. This estimate is based on country reporting and includes IUCN protected area categories I–IV (see Box 7 for definitions). FAO estimates that the area of forest in protected areas has increased by 191 Mha since 1990, but the rate of annual increase slowed down between 2010 and 2020 [4]. South America, Africa and Asia have the highest share of forests in protected areas (Figure 2.13).

Box 7: Definitions related to protected, conserved and Indigenous and community conserved areas

Protected area:

A protected area is a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values (IUCN definition 2008)[35].

Protected forest area:

FAO defines this as a “forest area within formally established protected areas independently of the purpose for which the protected areas were established” [4]. It includes IUCN categories I–IV (Ia: Strict Nature Reserve, Ib: Wilderness Area; II: National Park; III: Natural Monument or Feature; IV: Habitat/Species Management Area). Categories V and VI are excluded (V: Protected Landscape/Seascape and VI: Protected Area with Sustainable Use of Natural Resources[36]. For more information on the IUCN classifications see www.iucn.org/theme/protected-areas

Conserved area:

Other Effective Area-based Conservation Measures (OECMs) are defined by the Convention on Biological Diversity (2018) as “a geographically defined area other than a Protected Area, which is governed and managed in ways that achieve positive and sustained long-term outcomes for the in situ conservation of biodiversity, with associated ecosystem functions and services and where applicable, cultural, spiritual, socio-economic, and other locally relevant values” [81].

Indigenous and community conserved area:

Iso termed “territories of life”, these are territories and areas governed, managed and conserved by custodian Indigenous Peoples and local communities. They are characterised by (a) a close and deep connection between a territory and its custodian Indigenous People or local community, (b) enforcement of decisions and rules about the territory by those people, and (c) governance decisions and rules that positively contribute to the conservation of nature [112].

35 www.iucn.org
36 The latter (category VI) describes areas where a low level of non-industrial use of natural resources, compatible with nature conservation, is seen as one of the main aims of the area. Such combined uses are at the heart of multifunctional use, and these areas may appear in our calculation of forest available for wood supply in Chapter 4. Categories I–IV are excluded from our calculation in Chapter 4.

Conservation policies that aim to protect wilderness on Indigenous lands need to ensure that these policies not only deliver biodiversity returns but receive strong local support and align with Indigenous Peoples' motivations, governance and capacities.

Wolf et al. (2021) found that, **after adjusting for effectiveness[37], 6.5% of the world's forests are protected** [107]. They found that protected areas did not eliminate deforestation, but reduced it by 41%, and argued that while policy is currently focused on expanding the coverage of protected areas, it must do better to also **increase the quality and effectiveness** of those areas towards achieving aims.

One strategy involves ensuring greater recognition of and support for the role that Indigenous Peoples and local communities already play in conservation. Garnett et al. (2018) estimated that Indigenous Peoples manage and/or have tenure rights to over a quarter of the world's total land surface across 87 countries [108]. Their combined lands intersect with around 40% of terrestrial protected areas [108]. Fa et al. (2020) estimated that at **least 36% of intact forest landscapes[38] are within Indigenous Peoples' lands** [109]. They provide evidence that the rate of forest loss is lower on Indigenous Peoples' lands than on other lands [109]. Similar findings by Ricketts et al. (2010) and Ceddia et al. (2015) point to slowing deforestation when Indigenous Peoples' land rights are formally recognised [110], [111]. Such experiences form the basis for rights-based conservation [72].

This is the idea behind the classification category **"Indigenous and community conserved areas" (ICCAs).** Over 200 ICCAs are currently reported in the online ICCA Registry[39]. The registry also provides estimates showing that ICCAs **may cover an area greater or equal to government-designated protected areas, demonstrating how crucial these areas are to the global conservation network.** Dedicated efforts are made to further identify, recognise and support these communities[40]. At the same time, there must not be an assumption of willingness or implied expectation of conservation. Garnett et al. (2018) wrote:

"Conservation policies that aim to protect wilderness on Indigenous lands need to ensure that these policies not only deliver biodiversity returns but receive strong local support and align with Indigenous Peoples' motivations, governance and capacities. This reinforces the importance of 'bottom-up' approaches to conservation investment and policy design" [108].

Integration of **Other Effective Area-based Conservation Measures (OECMs) in the protected area landscape is another strategy for enhancing connectivity41 and integrating multiple-purpose models for forest use.** This category was first recorded in 2018 and statistics are currently available for five countries and territories[42]. The Protected Planet Report 2020 finds that "[the] further identification and recognition of OECMs is likely to contribute significantly to improved performance on all criteria, including connectivity, ecological representation, governance diversity and coverage (including of areas important for biodiversity and ecosystem services)"[43].

Natura 2000 is a coordinated network of protected areas in the EU that includes both strictly protected nature reserves as well as sites that aim to combine conservation with sustainable use. The network stretches across 18% of the EU's land area[44] and aims to protect the EU's most valuable and threatened species and habitats (as listed in the Birds Directive[45] and Habitats Directive[46]). WWF (2017) found scientific evidence of some successes with Natura 2000 (e.g. the recovery of some populations) when properly implemented. The study [113] emphasised that EU nature laws are not yet living up to their full potential, and provided examples of implementation towards effective conservation. It concluded that Natura 2000 sites must be more than just "paper parks".

37 The study defined this as "deforestation rates within protected areas compared with rates in matched control areas with similar characteristics" [107].
38 Based on Potapov et al. (2017), intact forest landscapes (IFLs) were estimated to cover 23% of the global forest area. They are defined as "seamless mosaics of forests and associated natural treeless ecosystems that exhibit no remotely detected signs of human activity or habitat fragmentation, and that are large enough to maintain all native biological diversity, including viable populations of wide-ranging species. Although all IFLs are a part of the global forest zone, some may contain extensive naturally treeless areas, such as grasslands, wetlands, lakes, alpine areas, and ice" [109] based on [312].
39 www.iccaregistry.org
40 See, for example, www.protectedplanet.net
41 According to the Protected Planet Report 2020, 7.84% of the world's terrestrial surface is both protected and connected, facilitating the movement of species and maintenance of ecological processes (see Chapter 8 in the Protected Planet Report, https://livereport.protectedplanet.net).
42 These can be explored on the Protected Planet website (www.protectedplanet.net). This website combines data to map, monitor and report data on protected areas and OECMs: it includes the World Database on Protected Areas (WDPA), World Database on OECMs, Global Database on Protected Area Management Effectiveness (GD-PAME), among others.
43 Written by UNEP, UNEP-WCMC and IUCN, the live report is available at: https://livereport.protectedplanet.net
44 Natura 2000 sites can be viewed online at: https://natura2000.eea.europa.eu/#
45 Directive 2009/147/EC, http://data.europa.eu/eli/dir/2009/147/oj
46 Directive 92/43/EEC, http://data.europa.eu/eli/dir/1992/43/oj

Verkerk et al. (2014) assessed the **trade-offs between protection in forests and wood supply capacities in the EU, Norway and Switzerland** [114]. They found that about 33 Mha of forests (equivalent to 20% of the total forest area in those countries combined) were protected in 2005[47], and identified varying degrees of felling restrictions in forests under protection. For example, in forests where they identified that the main aim was to protect biodiversity, 52% of the wood volume could be potentially felled. According to the study, Germany has some of the highest levels of protection in terms of share of forest area, but its felling restrictions are among the lowest in the EU. **In Germany, felling was reported to be allowed in more than approximately 65% of protected forest areas for biodiversity** [114][48]. Verkerk et al. (2014) concluded that: “Careful planning is required to accommodate both the protection of biological and landscape diversity and demand for wood, while not forgetting all other services that forests provide” [114]. They call for planning that identifies and prioritises areas for strict conservation, and for integrated forest management [114].

Ensure that 30% of global land areas are in effective and well-connected systems of protected areas and OECMs [115]. Some scientists promote the idea that “Nature Needs Half”, calling for 50% protection.

A proposal within the post-2020 Global Biodiversity Framework conference was made to ensure that **30% of global land areas were in effective and well-connected systems of protected areas and OECMs** [115]. Some scientists promote the idea that “Nature Needs Half”, calling for 50% protection [106], [116], [117]. Büscher et al. (2017) argue instead for 100% integration of biodiversity conservation across the whole Earth [118]. How these issues are defined (by policy and society in light of robust scientific evidence) has major implications for the consumption benchmark calculated in Chapter 4. Effective implementation, management and recognition of protected, conserved and Indigenous Peoples’ land is fundamental to curbing biodiversity loss and mitigating climate change.

Black stork (Ciconia nigra) feed juveniles in the tree crown, Germany.

47 Defined according to the Ministerial Conference on the Protection of Forests in Europe (MCPFE) guidelines on protected forest and other wooded land (see also Parviainen et al. 2010).
48 Trochet and Schmeller (2013) also found that Germany is in the middle range in terms of coverage of endangered species in Natura 2000 sites [314].

2.5 Mortality and disturbances

Forests have made headlines in countries across the world, as fires and pests have caused unprecedented levels of harm. Fires, in particular in boreal regions, have always been a component of forest ecosystems. Pests and disease (caused by bacteria, fungi, phytoplasma or viruses) are also integral parts of the forest ecosystem. However, the intensity and extent of "catastrophic disturbances" have increased significantly:

» **Wildfires in Siberia broke records** for annual fire-related emissions of carbon dioxide in 2021.[49]

» The d**amage to forestry** caused by extreme weather events from 2018 to 2020 is estimated at more than **€12.7 billion in Germany** [119].

» Since 2015, Czechia has experienced the **worst bark beetle outbreak ever** recorded [95].

» In Australia, the 2019–2020 fire season was the **worst in living memory** [120] .

» **Droughts and heatwaves on the west coast of the USA have contributed to a longer fire season characterised by hotter and larger fires.**[50]

This is in line with expectations about the impacts of climate change, which is expected to increase severe weather events (storms, drought and heat) and shift the conditions in which forests grow, affecting wood production, carbon storage and ecosystem services [64], [121], [122]. The vulnerability of forests may also be increased due to mismanagement (especially when ecosystem services, natural structures and dynamics are neglected; see Section 4.1), increasing the susceptibility to drought, pests and fire.

"Without active, climate-smart forest management, the potential of bioeconomy cannot be achieved."
Leskinen et al. (2020) on Russia's forest resources [127].

Evidence of such impacts on a countrywide basis is accumulating. However, at a global level, data on the overall amount of forest area impacted by disturbances is poor. The Global Forest Resources Assessment (2020) struggled with inconsistent or large gaps in country-level reporting. At the same time, major progress has been made in the global monitoring of fire through the use of remote sensing and data processing advancements. For example, the Global Wildfire Information System[51] provides not only near real-time information on fire risk around the world, but also country-level statistics on the area burned over multiple years. Based on this data [123], FAO estimates that around **400 Mha of total land (not just forests) were burned annually between 2001 and 2018,** with somewhat lower global averages between 2013 and 2018. More than two-thirds of all fires were in Africa. It is estimated that around 29% of them affected forests. This is consistent with data collected by the Global Forest Resources Assessment (and reported by countries) that 98 Mha of forests, or 3% of the global forest area, were affected by fire in 2015. While an estimated 90% of fires are readily contained, the other 5 to 10% of fires exceed the limits of suppression and burn larger areas. According to Seidl et al. (2014): "Many scientists, fire mangers and fire management agencies consider that wildlands face increasingly difficult fire weather conditions, extended fire seasons and larger fires influenced by climate change" [124]. In the Brazilian Amazon, the level of fires within forest areas increased in 2020. This is unusual in humid tropic forests [44]. The trend in 2020 was a result of dry conditions and human-lit fires getting out of control [44].

With regard to other disturbances, 75 countries reported in the FAO forest survey that a total of 142 Mha were affected by insect pests, diseases and severe weather events between 2003 and 2012 [125]. This represents 5% of the total forest area in those countries [125]. In Europe, for example, disturbances have dramatically increased over the last 40 years, including **insect outbreaks (+602%), wildfires (+231%) and windstorms (+140%)** relative to 1971–1980 [124]. In Germany, the National Forest Report 2021 [126] concluded that the forest is not doing well: **Four out of five trees in Germany suffer from crown defoliation[52]. All tree species have suffered from a lack of water and almost all show loss of vitality [126].**

The National Forest Report concluded that "The calamities of recent years have led to the worst damage to the forest and the worst crisis in forestry since the Federal Republic of Germany began."

49 https://www.space.com/2021-record-wildfire-season-from-space; Accessed October 2021
50 https://www.theguardian.com/world/2021/oct/10/wildfire-climate-emergency-us-west; Accessed October 2021
51 https://gwis.jrc.ec.europa.eu/apps/country.profile/; Accessed October 2021
52 Forest vitality is assessed using an indicator of crown condition. According to the Thünen Institute, 42% of Germany's forests are classified at warning level (crown damage/defoliation of 11–25%) and 37% of Germany's forests are classified in the red zone due to significant crown defoliation (25–100%) (reported in the National Forest Report 2021 [126]). More information on the survey to monitor crown condition is available at: https://www.thuenen.de/en/wo/fields-of-activity/soil-protection-and-forest-health/crown-condition-survey/

HOW HAVE DISTURBANCES AFFECTED HARVEST LEVELS?

Harvests are affected by disturbances in two ways. Over the short term, disturbances like insect outbreaks may increase **salvage logging.** This is a common practice in the EU, for example, to prevent the spread of disease. In some years, salvage logging can flood the market with wood, distorting markets by reducing wood prices and/or switching woody biomass flows for energy (due to the quality of salvaged wood). For example, due in part to bark beetle outbreaks in Czechia, total removals doubled in 2019 compared to 2014 [95], [128].

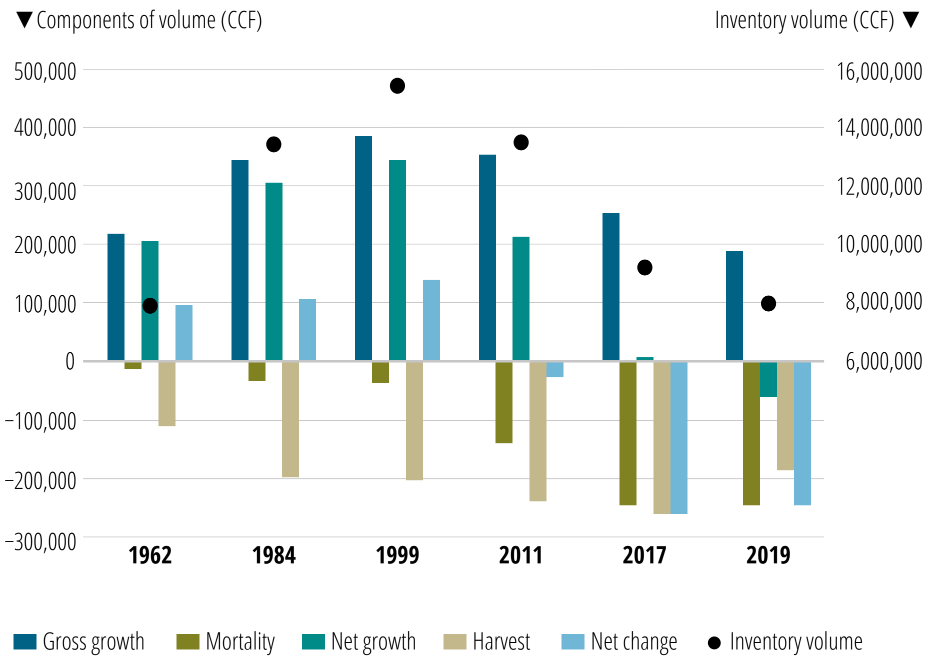
Over the long term, increased mortality is associated with **reductions in potential harvest volumes. In the USA as a whole, for example, mortality increased by 90% as removals fell by 20% between 1996 and 2016.** The Rocky Mountains saw the highest increase in mortality (900%) and the highest decrease in removals (30%)[53].

Mortality in the Black Hills National Forest was equivalent to 0.16% of standing stock volume in 1962. This increased to approximately 1% in 2011 and more than 3% in 2019. Combined with harvests, the net change in forest stock was negative in 2011, 2017 and 2019.

Figure 2.14:
Growth, mortality and harvest dynamics in the Black Hills National Forest, USA

Source: Graham et al. 2021 [129]

Note: CCF stands for hundreds of cubic feet, which is a measure of standing stock volume in the US. The inventory of trees in the study refers to over 5 inches (12.7 centimetres) diameter at breast height.



53 See "The State of America's Forests" at: https://usaforests.org.

Forest damaged by bark beetles develops into a more natural National Park, Bavarian Forest, Germany.

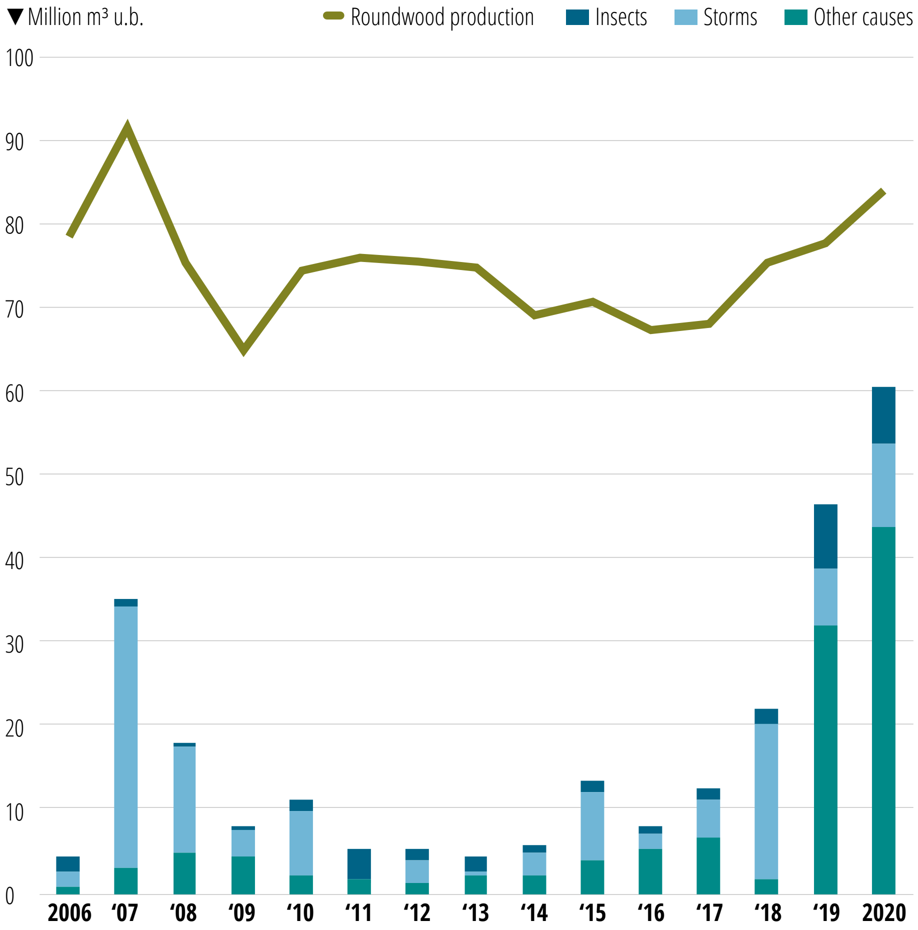
Such trends have caused the United States Department of Agriculture to evaluate sustainable timber harvesting rates. For example, Graham et al. (2021) developed more than 60 scenarios to assess the sustainable productive potential of the Black Hills National Forest in light of increased recent disturbances (especially bark beetle epidemics and fire) over the short, medium and long term [129]. They found that the current allowable harvest level under the Forest Plan is not sustainable. This is because mortality and harvests (combined) exceeded growth in 2011, 2017 and 2019, resulting in a net loss with regard to forest standing stock (see Figure 2.14). In 2019, for example, 3% of growing stock was lost to mortality and 2.31% to harvests, while gross growth amounted to the equivalent of 2.33% of growing stock. Their future scenarios considered different rates of growth, mortality and harvests, finding the best outcomes for maintaining forests over the long term in scenarios which **reduce the maximum sawtimber harvest level by 50 to 60% compared to the current Forest Plan.** They argue that short-term monitoring and adjustment can be used to reflect a dynamic forest ecosystem and conclude that: "History shows that allowing the forest to recover after large disturbances provides opportunities to adjust future harvest levels" [129].

Figure 2.15:
Comparison of German roundwood production volume with forest calamities between 2006 and 2020

Source: Calamity data from Destatis (see the press release N050 for more information*1) and production data from the Thünen Institute (ex-post removals*2); see also Figure 3.23 for a comparison of removal statistics, with the Thünen Institute estimating higher removals than official sources

*1 See the press release on "Concern about German Forests" from the German Aerospace Center (DLR) from 21 February 2021: https://www.dlr.de/content/en/articles/news/2022/01/20220221_concern-about-german-forests.html

*2 See the press release N050 for more information; https://www.destatis.de/DE/Presse/Pressemitteilungen/2021/08/PD21_N050_41.html; accessed March 2022.



This is similar to evaluations made after record-breaking fires in Australia in the 2019–2020 fire season. The Forestry Corporation of New South Wales[54], which is a state-owned corporation that produces around 14% of Australian timber, applied **the precautionary principle** to review its operations. This requires "careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment" [120]. In some places, like Tumbarumba, short-term wood supply is focused exclusively on regeneration and the removal of fire-killed trees. In other regions, assessments are under way to map the effect on trees as well as the impacts on threatened species across landscapes in order to revise their sustainable yield model (for example of how much timber is available under strict environmental rules that exclude areas such as old-growth forests, rainforest and wildlife corridors from harvesting) [120].

Figure 2.15 shows the severe and recent effects of insects and storms in Germany. Two strong storms (Friederike and Sabine) in 2018 were followed by three years of drought. As a result, **a total of 177 Mm³ of calamity wood (i.e. wood affected by environmental influences or the bark beetle) were removed from the forest from 2018 to 2020,** of which 60 Mt were removed in 2020 alone, representing up to 72% of total production in 2020. Close to 90% of the calamity wood came from coniferous tree species. The German Federal Ministry of Food and Agriculture (BMEL) calculated that about 285 thousand ha need to be reforested [130] which corresponds to about 400,000 football fields. However, Möhring et al. (2021) find that the BMEL calculations systematically underestimate the actual calamity area because they do not include pre-regenerated areas, areas without regeneration needs, and areas with natural regeneration potential. Taking these areas into account, the total calamity area would be over 395 thousand ha [130]. A recent satellite-based assessment revealed that as much as 500 thousand ha of forest area in German are heavily impacted by tree loss[55]. Forziere et al. (2021) estimate that altogether in Europe around 33.4 Gt of forest biomass could be impacted due to increasing vulnerability of European forests to climate-related disturbances [131].

54 https://www.forestrycorporation.com.au/sustainability/timber-volumes-and-modelling; accessed November 2021.

3. Trends in the production and consumption of wood

For your Orientation

CHAPTER OVERVIEW

Chapter 3 narrows the focus from forests to wood production and consumption. It is split into three subsections.

Global trends are explored in Section 3.1. This includes historical wood production and trade data as well as future consumption scenarios. The main countries trading in global markets are identified. The impact of wood from illegal sources is presented in this context. These **forestry crimes** not only make it difficult to understand how much wood is harvested and consumed, but they also massively undermine sustainable forest management (and trade) across all scales.

Sectoral expectations are assessed for six areas in Section 3.2: energy, construction, paper and packaging, plastics, textiles and chemicals. Boxes in this section also provide examples of some of the **innovation** happening in forest product markets. The sections in this sub-chapter are conceptualised as short case studies that reflect future expectations across multiple scales (in Germany, at an EU level and globally).

Why timber footprints are useful monitoring tools, what they are and key results for Germany are presented in Section 3.3. This section also looks at how footprint monitoring can contribute to assessing sustainability and self-sufficiency using German data. Germany is used as an example of a high-consuming country.

Overall, this chapter forms the basis for evaluating **whether we are on the right path when it comes to wood consumption trends.** This in turn establishes the basis for comparing current and future supply and demand trends in Chapter 4.

KEY MESSAGES

1 Markets for wood-based products are expanding. Traditional uses of timber in construction, for energy and for packaging in particular are increasing, while newsprint and printing paper are decreasing. New products in textiles, plastics and chemicals are growing rapidly. While currently small in terms of volume, these sectors are characterised by high economic value, large levels of investment and strong expectations of future growth. They are also interdependent; supply capacities are linked to cross-sectoral trends.

2 While substituting individual wood-based products for fossil-based products typically leads to environmental benefits on a case-by-case basis, caution is needed when deriving wider policy implications from the micro scale. At a sector, country or global level, demand for wood accumulates, resulting in pressures on forests with risks of unintended consequences.

3 Modelling reveals widely different potential outcomes regarding equity and environmental sustainability in global wood consumption scenarios, depending on what products are consumed (e.g. long-lived versus disposable products or woodfuel) and how they are sourced (e.g. recycled flows versus wood from monoculture plantations).

4 There is a high share of wood in the current renewable energy mix in the EU. New policies rely on countries to manage their forests in a sustainable way to achieve their climate commitments, but the incentives for burning wood conflict across scales. The industrial burning of stemwood is not an option under sustainable development, and finding clean alternatives to inefficient and pollutive woodfuel use for heating and cooking is a high priority.

5 Timber consumption footprints enable comparisons to be made to both other countries and to benchmarks for evaluating sustainability. They cover one piece of the monitoring patchwork; namely that of scale.

6 In Germany, per capita consumption levels (similar to those in other high-income countries) are more than double the global average, and its consumption level exceeds capacities for national production. Despite having a relatively large forest resource per capita, increased demand will increase Germany's import dependency.

3.1 Global trends

Global roundwood removals are currently just under 4 billion cubic metres (Gm³; e.g. 3.91 Gm³ were removed in 2020). **This in an increase of 56% compared to 1961**[56] (Figure 3.1). At a global level, annual roundwood removals are considered equivalent to annual roundwood consumption levels[57]. In per capita terms, roundwood consumption decreased from around 0.8 to 0.5 m³/person between 1961 and 2020. This decrease is a result of population growth. **Over the last six decades, the population has increased by around 150% whereas wood production has grown by nearly 60%**[58] (Figure 3.1).

These trends, however, mask large differences in both what and how much people consume around the world. **Europeans, for example, consume nearly twice as much as the global citizen on average** [5], [10]. A basic linear extrapolation of the 10-year global trend (2010–2020) over the next 30 years would lead to a global consumption level of around 5.1 Gm³ in 2050 and a rather stable per capita consumption of around 0.53 m³/person. Extrapolating the 20-year trend – with somewhat lower levels of growth – would lead to more modest increases by 2050 (4.7 Gm³ and 0.48 m³ per capita).

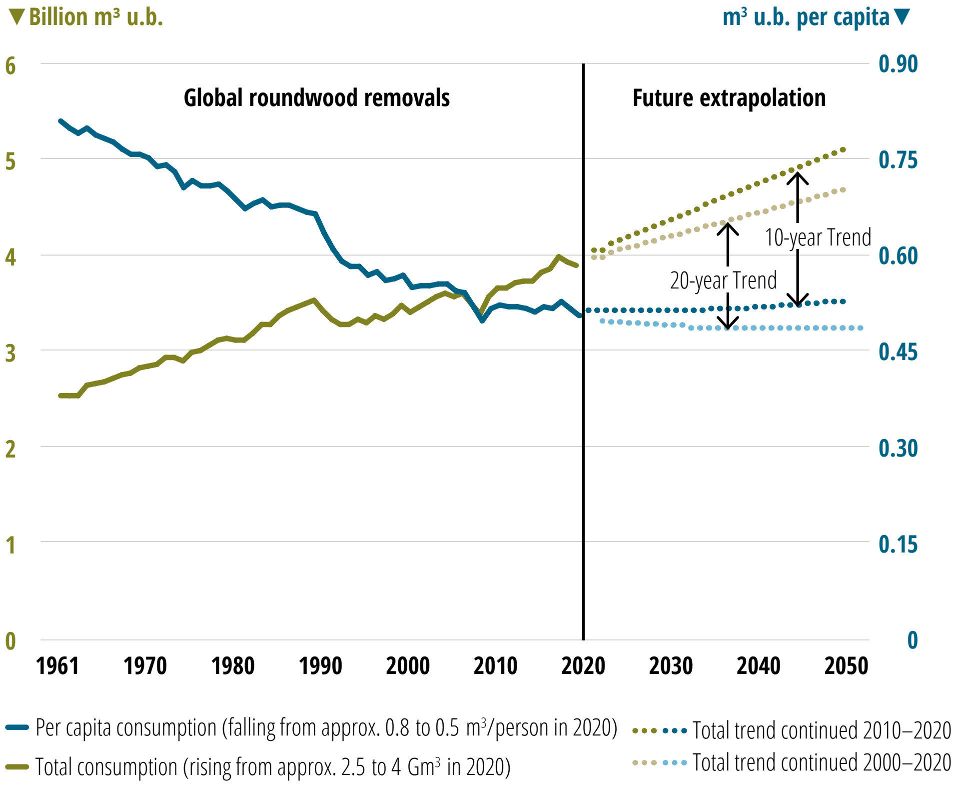


Figure 3.1:
Global roundwood removals and per capita consumption trends, 1961–2050

Source: Based on FAOSTAT global roundwood removal statistics (under bark) and UN World Population Prospects (medium variant)

Note: At a global level, annual roundwood removals are considered equivalent to annual roundwood consumption.

56 1961 is used as it is the first year statistical data is available from FAOSTAT; see also https://www.fao.org/faostat/en/#data/FO to explore further data.
57 This is only possible at a global level. At a country level, imports and exports skew the balance, making a national-level footprint approach necessary to calculate countrywide consumption levels in terms of roundwood equivalents (see Section 3.3).
58 Based on data from FAOSTAT and UN world population data. Wood consumption grew by 60% between 1961 and 2018. It declined in 2020, probably due to the pandemic, making total growth over the period between 1961 and 2020 56%.

Around half of global roundwood removals are for industrial uses and around half are for woodfuel. In 1961 the share was around 60% woodfuel and 40% industrial wood, and 2018 was the first year that the share of industrial wood overtook woodfuel. Industrial roundwood removals, in particular, are expected to continue to grow in the future (see the consumption scenarios below). The distribution regarding what is produced differs widely across the world. Around 80% of global woodfuel removals are in Africa, Asia and South America [7]. In Africa, nearly 90% of roundwood removals are for woodfuel, whereas nearly 90% of roundwood removals in North America and 80% in Europe are for industrial roundwood (Figure 3.2).

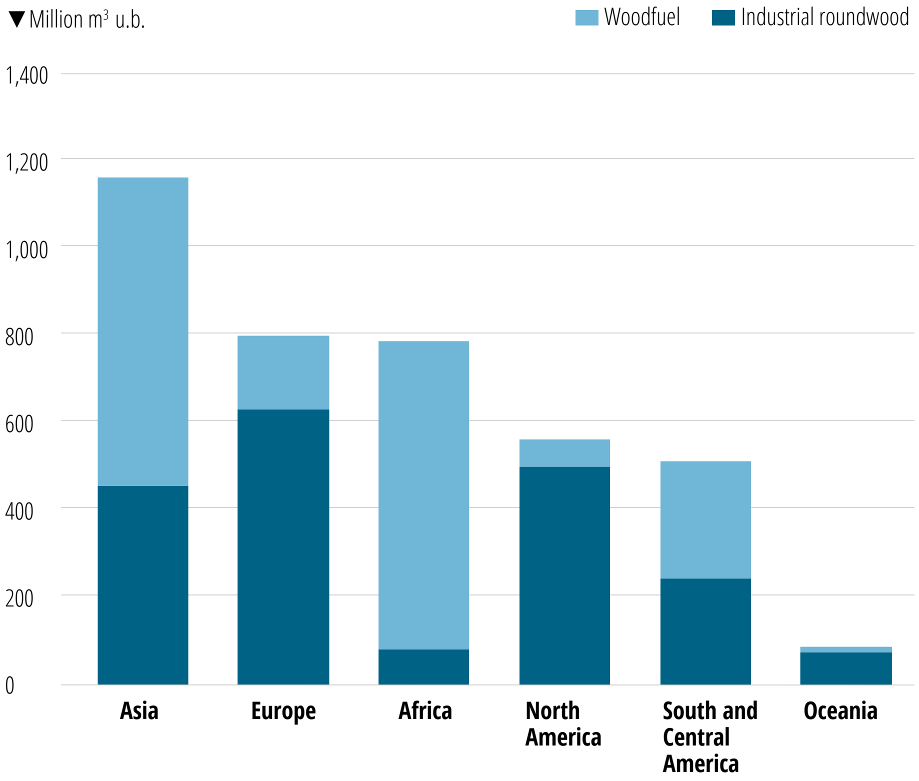


Figure 3.2:
Breakdown of total roundwood removals ($3.91 Gm^3$) by region and use – woodfuel versus industrial roundwood, 2020

Source: Based on FAOSTAT global roundwood production statistics (under bark)

The majority of woodfuel is used for cooking and heating, sometimes with high costs for human health. The World Health Organization (WHO) estimates that 2.6 billion people cook using solid fuels (wood, crop wastes, charcoal, coal and dung) and kerosene in open fires and inefficient stoves, and that in poorly ventilated dwellings indoor smoke can be 100 times higher than acceptable levels for particle emissions. It is estimated that close to 4 million people die prematurely from illness attributable to household air pollution caused by inefficient cooking practices[59]. SDG 7.1.2 aims to increase the proportion of the population with primary reliance on clean fuels and technology[60]. Section 3.2.1 presents an overview of the energy sector (focusing on the EU and Germany), whereas the bulk of this report focuses on industrial roundwood consumption trends, in particular in high-consuming countries.

Box 8: What is roundwood?

Terms in this chapter are based on the FAOSTAT classification of forest product production statistics. A further breakdown of definitions and data structure can be found online at https://www.fao.org/forestry/statistics/80572/en/. All three of these categories are reported in cubic metres solid volume under bark (i.e. excluding bark) as defined by FAO.

Roundwood:
All roundwood felled or otherwise harvested and removed. It comprises all wood obtained from removals (see FAO definition), i.e. the quantities removed from forests and from trees outside the forest, including wood recovered from natural, felling and logging losses during the period, calendar year or forest year. It is an aggregate comprising woodfuel that includes wood for charcoal and industrial roundwood (wood in the rough).

- **Industrial roundwood:**
  Roundwood removals intended for industrial uses. In that sense, it comprises all roundwood except woodfuel. It consists of sawlogs and veneer logs; pulpwood, round and split; and other industrial roundwood.

- **Woodfuel:**
  Roundwood that will be used as fuel for purposes such as cooking, heating or power production. It includes wood harvested from main stems, branches and other tree parts (where the tree is harvested for fuel) and wood that will be used for the production of charcoal, wood pellets and other agglomerates.

59 WHO (2021): Household air pollution and health; available at: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health, accessed 20 March 2022.
60 See https://sdg-indikatoren.de/en/7-1-2/, accessed 18 March 2022.

Changing dynamics in wood product markets

Changing dynamics in production and consumption are leading to structural shifts in timber product markets [7], [132]. Figure 3.3 depicts trends in major aggregated wood product categories. Global production of **wood-based panels,** for example, grew by a factor of almost 15 between 1961 and 2020. These panels are used for construction and furniture (see Figure 3.4 for a breakdown of product categories, uses and interlinkages). **Paper and paperboard** have seen strong growth overall, but this masks trends for specific products and regions. For example, newsprint and printing paper show declining trends at a global level, whereas consumption of wrapping and packing materials is increasing rapidly. Both trends are due to digitalisation – with digital media increasingly replacing printing paper and e-commerce leading to growing demands for packaging (see Section 3.2.3). After a period of stagnation, **sawnwood production** grew steadily at the beginning of the 21st century, but fell during the world financial crisis and recession. It rose again between 2010 and 2019, falling in 2020 with the onset of the COVID-19 pandemic. Sawnwood is particularly linked to the construction sector, and thus to housing starts [133]. Although not yet reflected in global production statistics, this was clearly evident in the recent price spikes for wood as the US housing market picked up in early 2021 (Box 9).

Long-life application: wood frame construction.

© iStock/Getty Images

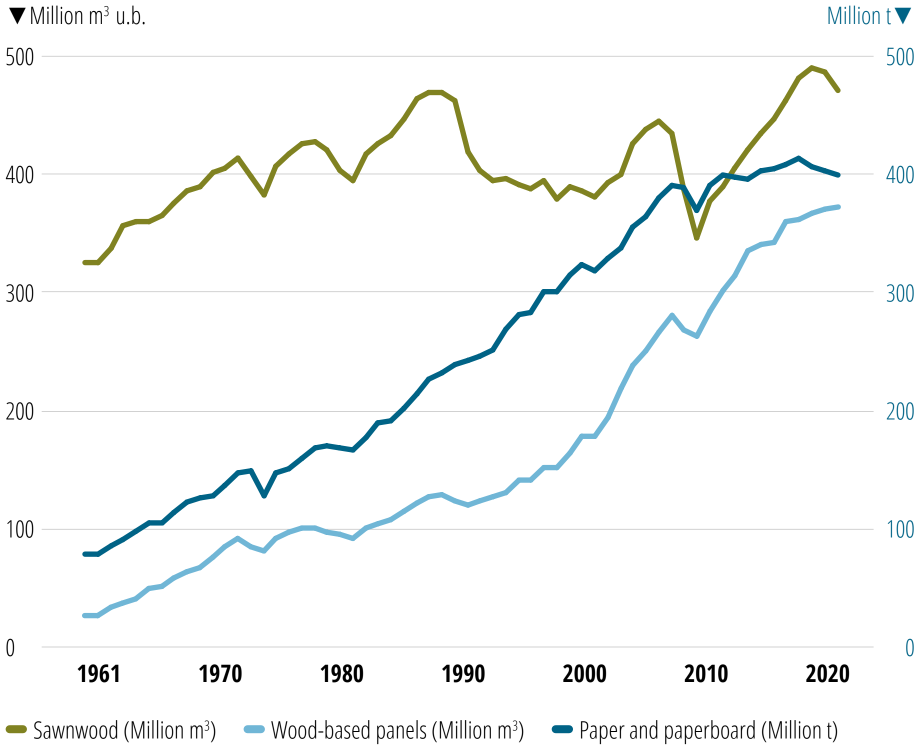


Figure 3.3: Global trends in the production of sawnwood, wood-based panels and paper and paperboard, 1961–2020

Source: Based on FAOSTAT global industrial roundwood production statistics (under bark)

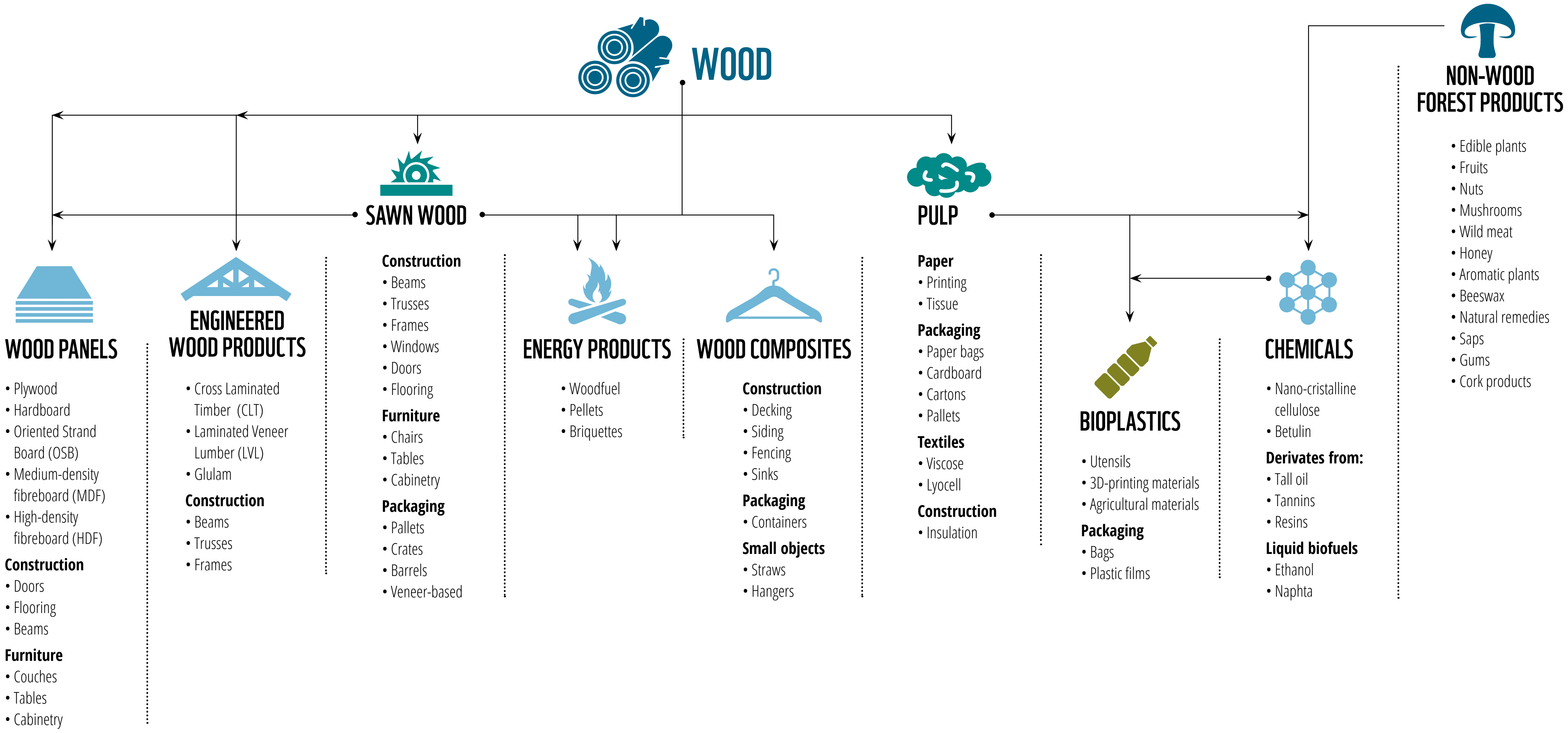


Figure 3.4: Breakdown of wood use categories and product examples

Source: Based on Verkerk et al. 2021 [38]

The most significant increase in forest-based product markets are **“expected to include innovative, engineered wood products in the construction sector, pulp used for textiles, chemicals, bioplastics and energy,** and for a number of small niche markets, including cosmetics, food additives, pharmaceuticals, etc.” [7]. This will have impacts on the demand for roundwood. On the one hand, the increased level of engineering in wood products may increase demand for low-quality timber, **potentially incentivising investment in the expansion of fast-growing species in monocultures** or making harvest residues, like branches, more attractive for industrial use. Both are risky, with general consensus on the important role harvest residues play in well-managed forest and soil ecosystems [95]. On the other hand, some engineered wood products may also be **manufactured using recycled materials (e.g. demolition wood) and by-products** (e.g. sawdust, wood chips, black liquor from pulping) [38]. When done “right”, this could stimulate a circular bioeconomy and encourage a cascading use of wood (see Chapter 5).

Box 9: 2021 price spikes for construction wood in Germany and the world

The price of wood spiked in 2021, with a 700% price increase in one year [6]. This was a result of multiple factors, including an initial “recovery” after the price dropped as one of the effects of the COVID-19 pandemic. In the USA, a boom in residential construction increased demand for timber. This demand could not be met in the USA or by Canadian imports, following large beetle outbreaks in Canada, as well as import tariffs following years of lumber disputes between Canada and the USA. As a result of high levels of salvage logging due to massive beetle outbreaks (see Section 2.5), Germany exported 10 Mm^3 of coniferous lumber (or 40% of Germany’s coniferous harvests) to meet global demand. **Exports to the USA doubled compared to the year 2018.** At the same time, demand from China, and inter alia Chinese imports, also increased. **Germany became China’s second largest source of imported whole logs,** and coniferous lumber imports increased by 20% compared to the prior year. In Germany, the price spikes and shortages for home builders made national news and brought the forestry sector to the attention of a mainstream audience. According to the documentation from the “scientific services” advising the German parliament on national and international trade with construction timber from Germany (published on 17 September 2021), the key recommendations were to lift or suspend the logging limit for spruce as soon as possible and to provide tax relief for forest owners [6]. **This raises questions about the priorities for forest recovery and sustainable use, in light of the economic and political pressures to secure supply at stable prices over the short term. It also foreshadows challenges for the future,** as competing uses for forest biomass and forest function intensify (conservation, climate mitigation and raw material provision).

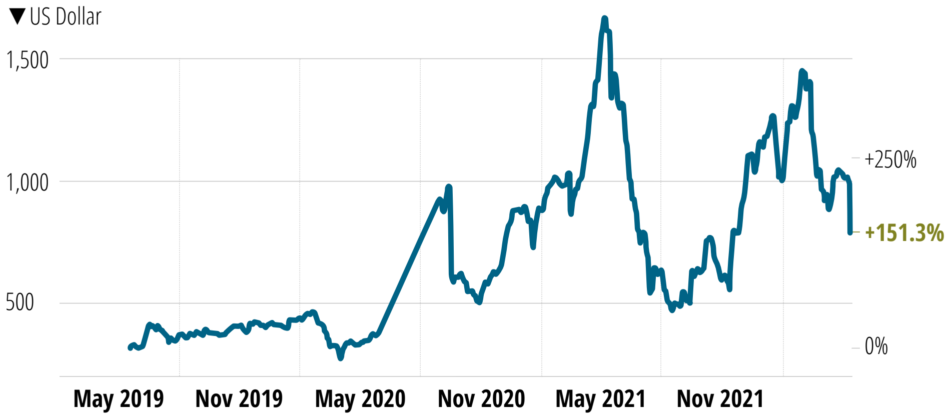


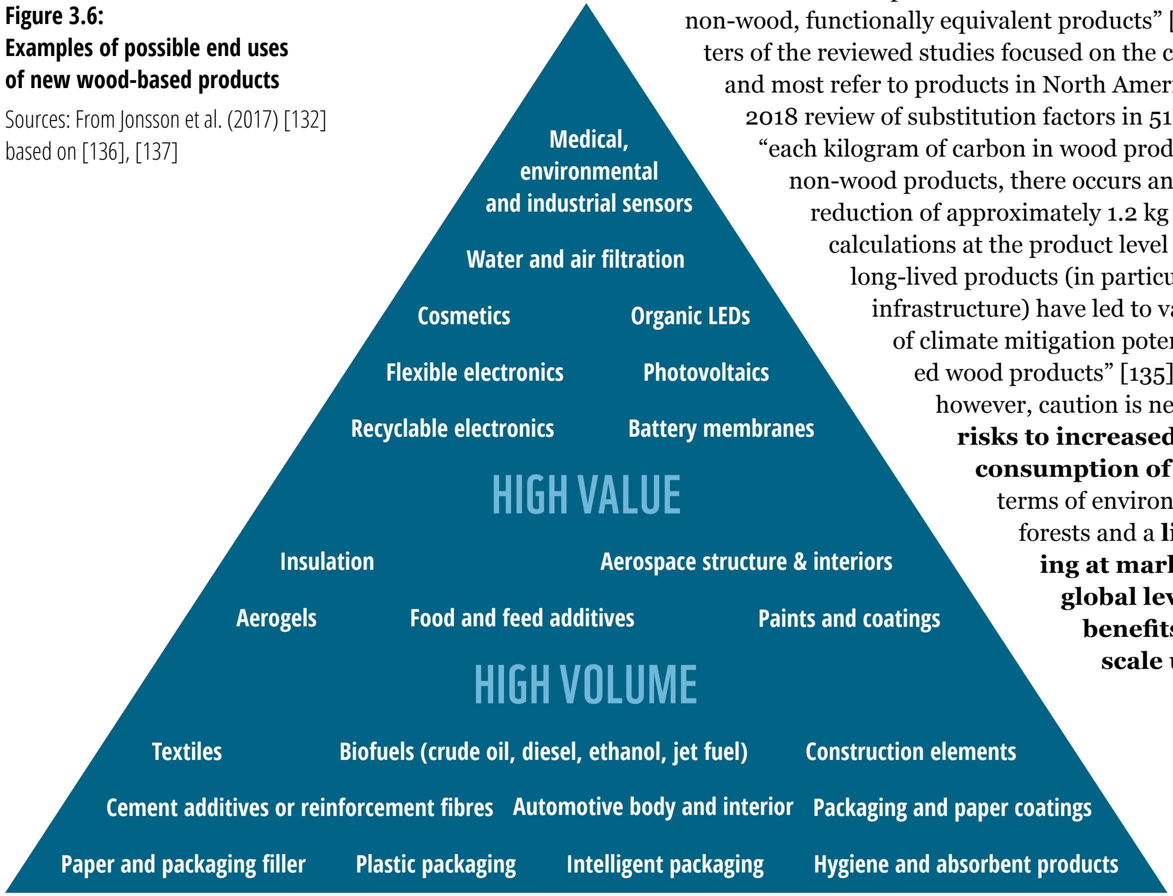
Figure 3.5: Three-year trend in the price of timber

Source: https://www.finanzen.net/rohstoffe/holzpreis

Note: The price of timber is measured in US dollars per 1,000 board feet. One board foot is equivalent to 2,359.74 cm^3. Timber is traded on the Chicago Mercantile Exchange in Chicago. The timber price future is listed in the Rogers International Commodities Index.

Figure 3.6:
Examples of possible end uses of new wood-based products

Sources: From Jonsson et al. (2017) [132] based on [136], [137]



The environmental performance of wood products – scale matters

The overall, system-wide benefits of substituting wood for non-renewable materials are unclear. At a macro level, effects depend on the total level of demand. **If only individual products are considered, there is strong evidence of life cycle-wide benefits of substitution.** For example, Verkerk et al. (2021) reviewed 64 published studies and 488 substitution factors, finding that the "use of wood and wood-based products is generally associated with lower fossil and process-based emissions when compared to non-wood, functionally equivalent products" [38]. Three-quarters of the reviewed studies focused on the construction sector and most refer to products in North America and Europe. A 2018 review of substitution factors in 51 studies found that for "each kilogram of carbon in wood products that substitute non-wood products, there occurs an average emission reduction of approximately 1.2 kg carbon" [134]. Such calculations at the product level and especially for long-lived products (in particular in buildings and infrastructure) have led to various calculations of climate mitigation potentials in "harvested wood products" [135]. At the same time, however, caution is needed. **There are risks to increased production and consumption of forest products** in terms of environmental pressures on forests and a **limited understanding at market, country and global levels of how climate benefits at a product level scale up** [38].

The risk of rebounds and land use pressures on degradation, fragmentation and illegal forest exploitation may be stimulated by rising demands intended to develop sustainable solutions. This is not to advocate for a complete halt to efforts, but rather to emphasise the point that **scale matters** and monitoring total consumption levels is critical to ensuring that micro-scale benefits may be realised without unintentional macro-scale impacts.

Box 10: New forest-based products

The concept of "new forest products" is increasingly on the policy and industry agenda. So far, these are small in terms of volume, but are often expected to provide high value. For example, the secondary wood products sector (e.g. joinery and carpentry, prefabricated wooden buildings) in the EU already exceeds the sawmilling sector in terms of production value, despite the production volume being an estimated 10 times lower [132]. Jonsson et al. (2017) distinguish between three categories: 1) old products with newly increasing demand due to changes in the operating environment (e.g. pulp for textiles); 2) old products with incremental improvements, such as lighter weight or lower production costs (e.g. paper and packaging coatings); and 3) novel products or products with radical improvements (e.g. the use of nanoscale organic matter in electronics) [132]. There are strong interdependencies between more traditional forest products (in particularly sawnwood and pulp) and these "new forest products". That is particularly the case when using by-products of sawmills to manufacture such products, with the risk that demand for the new products will outpace the demand for sawnwood. Jonsson et al. (2017) find that "the overall scale of independent, transparent academic market research is alarmingly low" and that "there is also **a need to better connect market developments to wider sustainability"** [132].

There is a lack of comprehensive and complete data on what, where and how forests are used for roundwood removals.

Production hotspots

There is a lack of comprehensive and complete data on what, where and how forests are used for roundwood removals. This makes it difficult to assess sustainable management and supply capacities. The online FAO database[61] provides some key statistics generated through their countrywide surveys on countries with high levels of removals. The following are some examples of these statistics.

» **More than 18% of global industrial roundwood removals in 2020** were in the USA (followed by Russia (10%), China (9%), Brazil (7%) and Canada (6.5%).

» **Two-thirds of industrial roundwood removals** occurred in 10 countries (the "Big 5" forest-rich countries, followed by Indonesia, Sweden, Germany, Finland and India in that order) in 2020.

» **More than 15% of global woodfuel removals in 2020 occurred in India.** This is almost twice as much as the next largest producer (China).

» **More than 50% of global woodfuel removals in 2020 occurred in 10 countries** (in most cases, the woodfuel was used within the individual country) (India, China, Brazil, Ethiopia, Democratic Republic of the Congo, Nigeria, USA, Ghana, Uganda and Indonesia in that order).

Global satellite mapping of large-scale forestry operations is another method used to estimate where "production forests" are located. The Global Forest Review[62] presents data to this end, noting that, due to the resolution of satellite images, such an approach misses forests in which selective logging is the main form of harvesting (see also [73]). We also incorporate spatially explicit forestry maps in our accounting in Chapter 4.

Congo Basin, Africa.

61 FAOSTAT roundwood production statistics: https://www.fao.org/forestry/statistics/84922/en/; accessed 20 November 2021.
62 Online resource of the World Resources Institute; available at: https://research.wri.org/gfr/forest-designation-indicators/production-forests

Trade – accelerated growth and displaced impacts

Globalisation has led to the development of a global market for wood-based products. The rate of increased trade in industrial roundwood has significantly outpaced the rate of market growth: world exports of industrial roundwood increased by 61% between 1990 and 2018, compared to only a 15% increase in removals [7]. Imports to China were the major driving factor behind this trend. China imported around 45 billion USD in forest products in 2020 (Figure 3.7b). Looking at just extra-regional importers, the UN Economic Commission for Europe (UNECE) calculated that China imported four times more industrial roundwood in 2019 than the other top nine extra-regional importing countries combined.

In terms of value, global imports in 2020 reached 241 billion USD (down from 254 billion USD in 2019) compared to 154 billion USD in 2000 and 113 billion USD in 1990 (FAOSTAT[63]). In general, forest product manufacturing has become more spatially separated over time, with **processing steps occurring at different geographic locations along the value chain** [132]. According to Jonsson et al. (2017): "Intensively managed forest plantations in the southern hemisphere are gradually replacing temperate and boreal forests as the predominant raw material resource for the manufacture of wood products, not least wood pulp, where production has increasingly been moved to e.g. Latin America" [132]. The largest net exporters in terms of value in 2020 were Canada, Sweden and Brazil. Germany was the 8th largest net exporter in terms of value, with high absolute levels of both exports and imports (Figure 3.7a). However, in terms of self-sufficiency, the picture looks different. Germany's consumption levels are already higher than what can be supplied, sustainably, within the country (see Section 3.3).

International trade is of growing importance, especially for industrial roundwood. If guardrails are not implemented, this will increase the risk of burden shifting between consuming and producing countries.

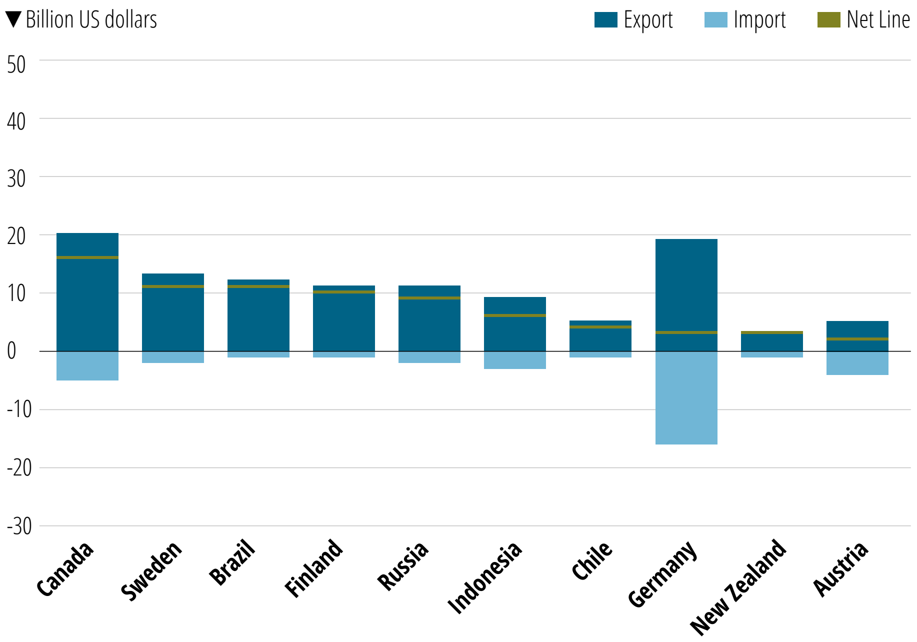


Figure 3.7a: Top 10 net exporters of forest products in 2020, in terms of value

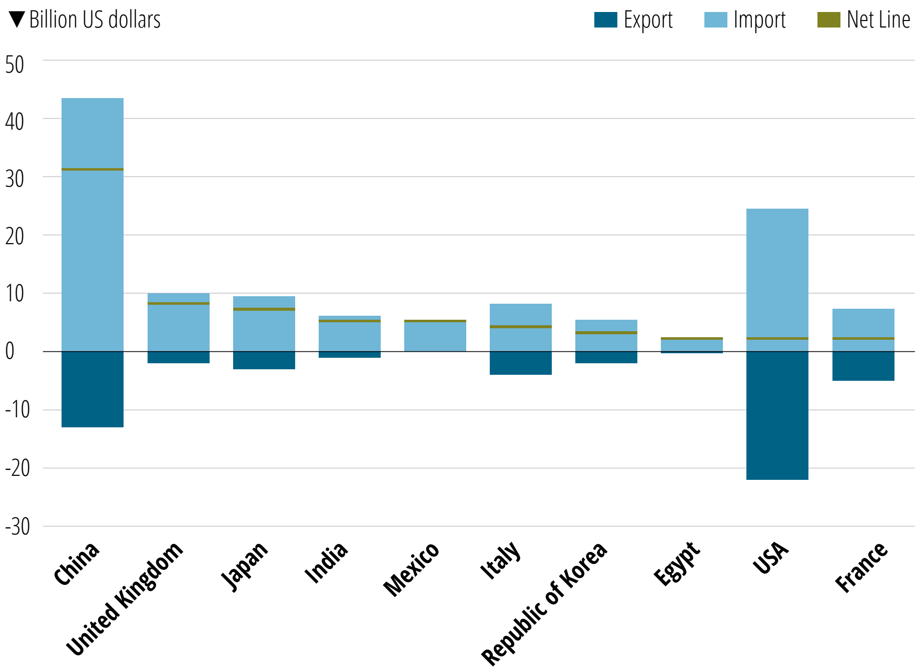


Figure 3.7b: Top 10 net importers of forest products in 2020, in terms of value

Source: FAOSTAT; accessed 20 November 2021

Note: Net line is shown as a line.

63 FAOSTAT forest product trade statistics; available at: https://www.fao.org/forestry/statistics/84922/en/, accessed 20 November 2021.

Box 11: Furniture – an increasingly globalised wood product market

The furniture sector is an example of a wood product market with increasing relevance at the international scale. In 2019 UNECE's Annual Market Review[64] reported that furniture trade had grown more quickly than furniture production over the previous 10 years. In 2009 the value of world furniture trade was valued at 96 billion USD; in 2018 it was valued at 150 billion USD [8]. The 2019 UNECE report pointed specifically to a migration of furniture production to lower-cost regions and estimated that 30% of global furniture production is traded internationally [8]. The largest importers are the USA, Germany, France, the UK and Japan (by value; see Figure 3.8). China is the largest exporter, followed by Germany, Poland, Italy and Vietnam (by value and in that order in 2018). The pandemic impacted global production and consumption – total consumption of furniture contracted by around 10% in 2020 to reach around 400 billion USD [138]. A rebound is expected for 2021, in particular with significant growth in online furniture sales. In the future, manufacturers in Asia may face roundwood supply issues that impact furniture production capacities. UNECE's 2021 Annual Market Review reported that more than 50% of global furniture manufacturing takes places in Asia (mostly China and Vietnam) and that both regions import large volumes of hardwood logs from Europe, North America and Russia [138]. China is also a key importer of tropical hardwood [139].

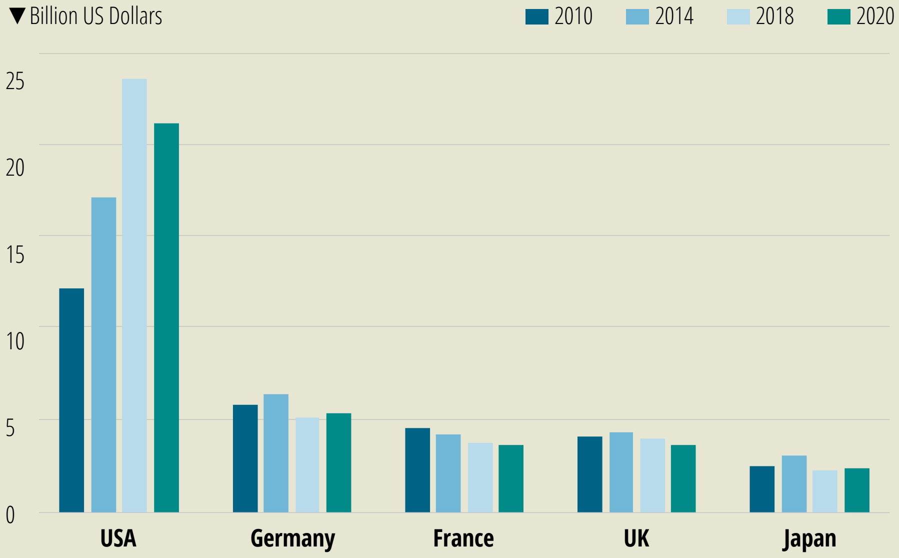


Figure 3.8: Wooden furniture imports, top five importing countries, 2010–2020

Sources: UN 2012[65] [140], UN 2015[66] [141], UN 2020[67] [142], UN 2021[68] [138]

Notes: Base data sometimes differs between the years, which may have been due to updates over time, and could slightly alter the results. This illustrates one aspect of the challenge regarding statistical reporting. At the same time, this figure is also a small reflection of the massive amount of data that UNECE has amassed and reports on annually; see the Forest Products Annual Market Review for more information, https://unece.org/forests/annual-market-reviews

64 The review is published annually and covers a wide range of products: from roundwood and primary processed products to value-added and innovative wood products. It also includes chapters analysing policies, economics and housing. Underlying the analysis is a comprehensive collection of data. The reports (and data) are available at: https://unece.org/forests/fpamr2021

65 Based on data from Eurostat, 2012; Trade Statistics of Japan issued by the Ministry of Trade and Customs; United States International Trade Commission, 2012.

66 Based on data from Eurostat, 2015; Trade Statistics of Japan, 2015; US International Trade Commission, 2015.

67 Based on data from UN Comtrade, 2020.

68 Based on data from UN Comtrade, 2021.

3.1.1 Future consumption scenario

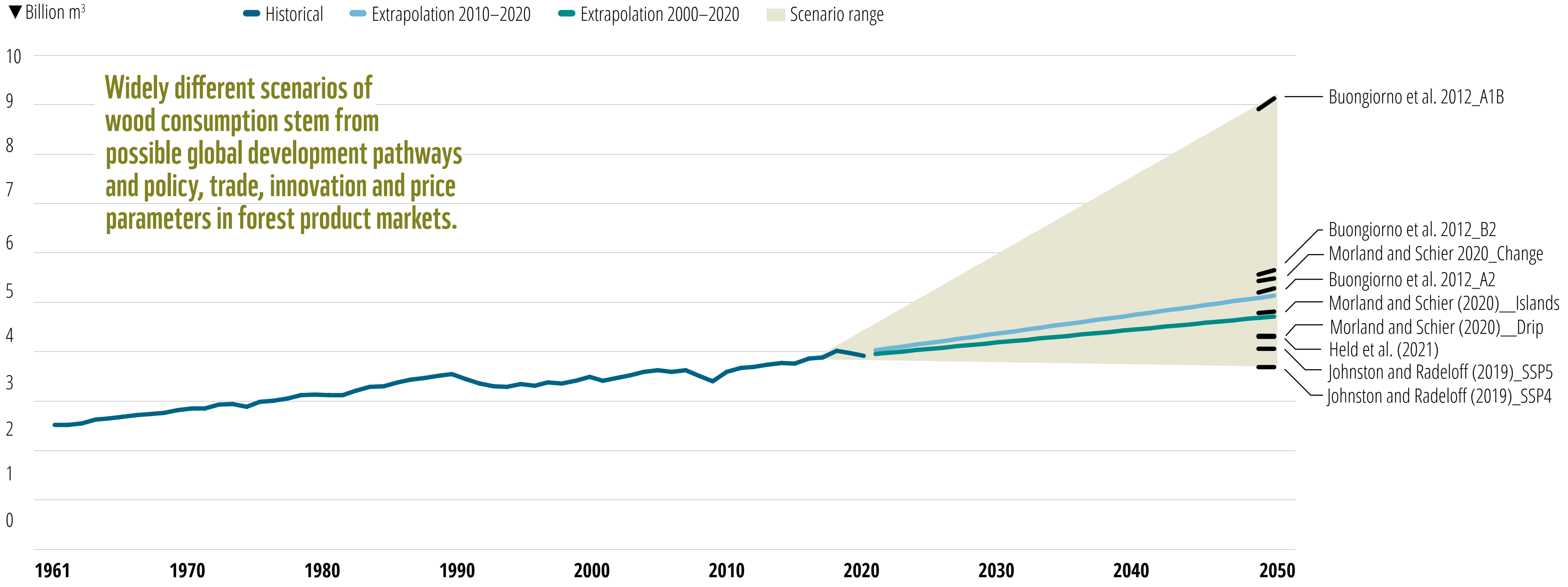
Future consumption scenarios show widely different results depending on policy, innovation, trade and price considerations in forest product markets. They also show different global development pathways (population, economic growth and prosperity) and modelling goals (e.g. what-if questions). Multiple scenarios from different sources are depicted in Figure 3.9. **The largest differences are due to assumptions about woodfuel growth or decline,** underscoring the importance of energy markets to the scale of future wood consumption. Industrial roundwood consumption is, in most scenarios, expected to continue to grow. However, **large differences in per capita consumption may persist.** For example, Figure 3.10 depicts the breakdown of global consumption for one scenario in 2050, showing a per capita consumption level that is seven times lower in the tropical countries of sub-Saharan Africa and South Asia compared to the temperate countries of Europe and North America.

Buongiorno et al. (2012): The **Global Forest Products Model (GFPM)** was used to make projections about the future consumption of forest products as well as the impact on the forest area and forest stock until 2060. The GFPM is a dynamic economic model of 14 forestry commodity groups in the world economy linked to forest stock (volume) on a changing forest area according to the Kuznets curve (linking forest area growth with income prosperity) and stimulating changes in production, consumption and trade. It calculates the final demand and raw materials supply in world equilibrium according to econometric equations. To set the context for timber demand, IPCC scenario storylines are used: A1B shows continuing globalisation, high income growth, low population growth and a 5.5-fold increase in biofuel demand; A2 is based on a slowdown of globalisation, lower income and higher population growth with a 2.7-fold increase in biofuel demand; and B2 shows medium projections. These scenarios show a decrease in industrial roundwood consumption between 2030 and 2060 in all scenarios [143].

Figure 3.9:
Comparison of global consumption scenarios and trends, 1961–2050

Sources: Historical and linear trend extrapolations based on FAOSTAT and depicting extrapolations of the 10-year trend and 20-year trend (see Figure 3.1); sources depicted in the legend of the graph and described in the text include Buongiorno et al. (2012) [143], with IPCC scenarios A1B, A2 and B2; Morland and Schier (2020) [144]; Johnston and Radeloff (2019) [135] with scenarios SSP4 and SSP5; Held et al. (2021) [10]

Note: This figure is illustrative and shows the end-points of multiple scenarios in 2050. However, they may start from different base years, e.g. 2015 for [10], [135]. The studies [143] and [135] also end at different points (in 2060 and 2065, respectively) and linear interpolation of annual average growth rates is assumed between start and end points to estimate results in 2050. All are based on the Global Forest Products Model.



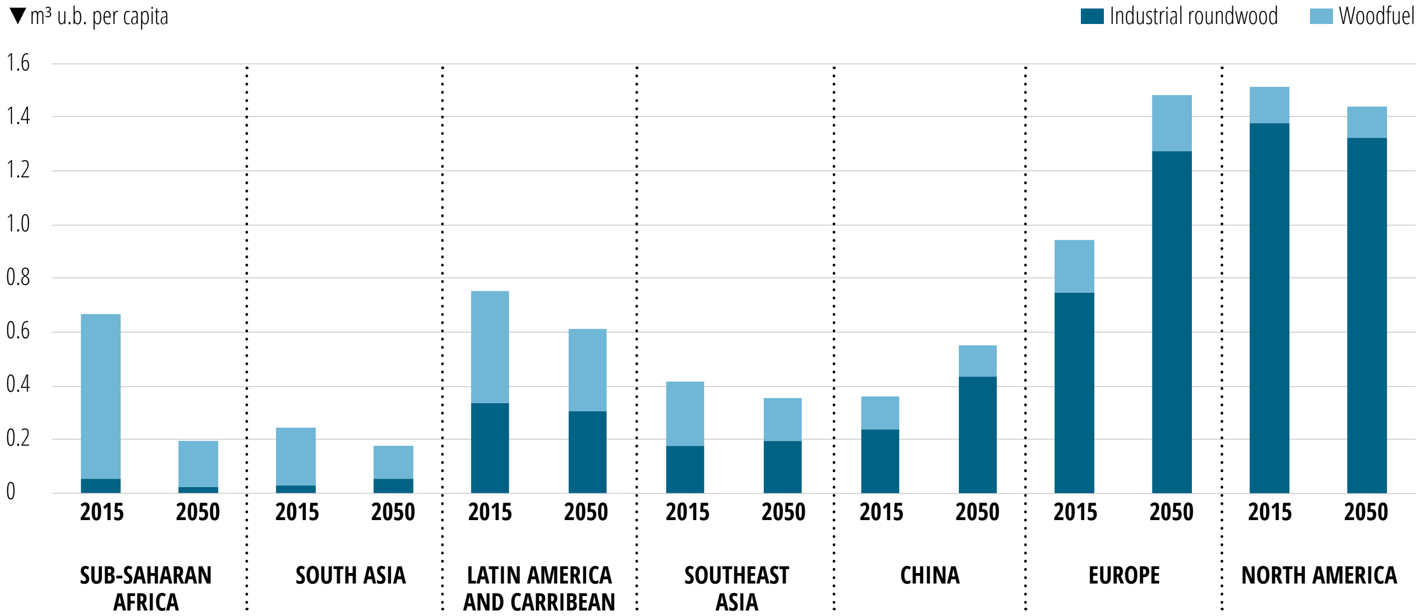


Figure 3.10: Per capita consumption of industrial roundwood and woodfuel in 2015 and 2050 by selected world regions in one scenario

Source: Held et al. (2021) [10] based on the Global Forest Products Model, corrected by the authors

Notes: Based on the IPCC Shared Socio-economic Pathway (SSP)2 scenario and showing reduced woodfuel and increased industrial roundwood production across the world by 2050. Updated modelling with a more pessimistic GDP outlook leads to adjusted results for woodfuel consumption in sub-Saharan Africa – there is still a drop in per capita woodfuel consumption, but it is not as strong as shown by Held et al. (2021) (personal communication with C. Held, results forthcoming in 2022).

Gaps in per capita consumption between countries may grow in the future, further decreasing equity and fairness.

Morland and Schier (2020): These scenarios do not depict realistic expectations, but rather explore the possibilities for how industrial growth in lignocellulosic-based products could impact other wood-based products. For example, in their "Change" scenario, industrial roundwood production increases by 120% and woodfuel decreases by 32%; in their "Drip" scenario, the trends are reversed (woodfuel increases by 30% and industrial roundwood decreases by 5%). Their "Islands" scenario shows moderate growth in both. Overall, they argue that the potential for growth in the textile and chemicals industries is coupled to the demand for woodfuel and paper [144] (see Section 3.2.4), underscoring that to meet human needs, the way in which markets develop (what products) is as important as the amount that is consumed (volume).

Held et al. (2021): This study by the International Tropical Timber Organization (ITTO) also uses the Global Forest Products Model. It assesses the future supply of and demand for tropical timber in the context of global trends using the "middle of the road" IPCC scenario (Shared Socioeconomic Pathway (SSP2). Held et al. (2021) predict a 13% increase in total global roundwood consumption (4.3 Gm³ in 2050). This relatively modest increase is a result of a decrease in woodfuel consumption. **The scenario shows a decline of 21% in global woodfuel use,** with strong decreases in tropical countries in particular (see Figure 3.10; e.g. woodfuel consumption in sub-Saharan Africa drops from 0.6 m³ per person in 2015 to 0.2 m³ per person in 2050). In contrast, industrial roundwood consumption is projected to increase by 45% globally (and by 24% in tropical countries) by 2050. Tropical countries are expected to be net exporters of industrial roundwood and **35% of industrial roundwood supply by volume is projected to come from plantations** (compared to 27% in 2015). The largest plantation expansion, including agroforestry systems, is projected for Southeast Asia and Latin America. To be able to increase capacities for industrial roundwood production (e.g. processing capacity for sawlogs and veneer logs), Held et al. (2021) project that **capital expenditures of around 40 billion USD would be needed by 2050.** If tropical regions were to produce more value-added products instead of exporting whole logs, their model showed that another 18 billion USD of investment in processing capacities would be needed [10].

Johnston and Radeloff (2019): This analysis looks at the carbon mitigation potential stored in harvested wood products and also uses the Global Forest Products Model to estimate future scenarios in IPCC storylines (SSP1–SSP5). The authors project **industrial roundwood consumption to rise by between 19% and 53% between 2015 and 2065**. Figure 3.9 shows the widest range of their results with regard to global timber consumption volume only, but does not automatically depict sustainability. The **SSP4 scenario "Inequality"** is characterised by high regulation and conservation in high-income countries and poor regulation with high deforestation rates in low-income countries. It would lead to declining levels of global roundwood consumption in terms of volume (3.7 Gm³) in 2050, but would be characterised by high levels of continued woodfuel use in low-income countries. In their scenarios, SSP5 ("Fossil-fuel Development"), is characterised by more intensive forest management and harvesting, causing stress to the environment and the highest overall consumption in forest products (just over 4 Gm³ in 2050). In contrast, SSP1 is the IPCC's "Sustainability" scenario, which would result in nearly 3.9 Gm³ of total roundwood consumed in 2050. It is characterised by a high level of recycling and efficient wood use accompanied by new bio-based materials and a rapid diffusion of best practices in forest management [135]. That means that, **although**

global demand for primary timber would be lower, consumption could increasingly stem from secondary flows and decouple from primary timber demand (circular bioeconomy based on cascades) to help secure supply. This sustainability scenario highlights the point that **it is not only how much, but what and how timber is produced and consumed that impacts overarching sustainability.** It implies that while footprints are needed to monitor scale, accompanying measures to monitor production across the life cycle are just as important.

Assessing the scenarios – the power of incentives

Assumptions about woodfuel trends have a large impact on the expected scope, scale and growth of future global consumption. However, these statistics are subject to much uncertainty. **For example, assessing forestry crimes, Nellemann et al. (2020) state that woodfuel and charcoal account for 80–90% of logging in Africa,** especially in the Congo Basin. They report that current trends in urbanisation and projected population increases (for another 1.1 billion people in sub-Saharan Africa by 2050) could lead to **a demand for charcoal that is at least triple the current use by 2050** [23]. The sector is also subject to massive illegal activity (see Section 3.1.2), creating perverse incentives for continued use. Net profits from dealing and taxing unregulated, illicit or illegal charcoal in East, Central and West Africa are estimated at 2.4–9 billion USD, compared to the estimated value of 2.65 billion USD for heroin and cocaine in the region [23].

Birch roundwood, United Papermills, Kuusankoski, Finland

© IMAGO/imagebroker/theissen

Second, growth in wood for energy purposes is also expected to meet renewable (not necessarily climate-neutral, see Section 3.1.2) energy targets, particularly in high-income countries. For example, the International Energy Agency's World Energy Outlook concluded in its "New Policies Scenario" that global bioenergy demand (including woodfuel and other biomass-based energy) is expected to **grow at an annual rate of 1.1% until 2040.** Using current FAOSTAT data and increasing woodfuel removals by 1.1% per year until 2040 would lead to a consumption level of nearly 2.5 Gm³ in 2040 (over 80% of the ecologically safe wood capacity (low-risk boundary) calculated in Section 4.3.3). Higher bioenergy demands could have a more dramatic impact. For example, in 2012 WWF's Living Forests Model showed that energy wood could reach +8 Gm³ in 2050 if it were used in larger amounts to meet ambitious carbon mitigation targets [145]. This level of consumption, which massively exceeds sustainability limits, should be interpreted as a warning, not a forecast.

All of the scenarios depicted in Figure 3.9 were based on the Global Forest Products Model. This is subject to limitations[69]. Other types of modelling – in particular integrated models – could provide a more holistic perspective that combine economic and ecological dimensions [146]. Nevertheless, key messages are unlikely to change. In particular, how wood energy use develops will have major consequences on the magnitude of consumption and the potential for industrial products to be supplied in a more sustainable way. Policies are the key driver towards incentivising increased consumption or supporting alternatives to reduce it. **These models show the power policy makers have to make changes now that have wide-reaching consequences for the future.**

69 Like all economic models, it has limitations for reflecting real-world dynamics, and should "be understood as a strong reduction of a complex reality in order to enable the envisioning of certain aspects of the future" [10]. Moreover, economic models are unable to take idiosyncratic shocks into account because they are built on the basis of past trends and relationships.

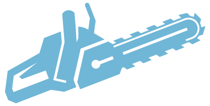
3.1.2 Wood from illegal sources

After counterfeiting and drugs, **environmental crime is the third largest crime sector in the world.** Environmental crime is the exploitation of, damage to, trade or theft of natural resources [9]. Forestry crime makes up, by far, the largest share of environmental crime. "The true value of the loss of forests is impossible to estimate, but measurable costs annually are likely in the range of… 51–152 USD billion a year" [9], [23]. **The quantities are massive,** with up to nearly one-third of globally traded timber potentially stemming from illegal sources (see Figure 3.11). In 2015 Hoare reported that, at a global level, progress to combat illegal logging had slowed [148].

"Forestry crimes, including illegal logging and deforestation for agricultural expansion, have become probably the single greatest threat to life on the planet, eradicating more species and numbers than any other human activity."
Nellemann et al. 2020 [23]

Forestry offences come in many forms. On the one hand, they include offences such as logging in protected areas, without a permit, with falsified permits or in excess of authorised quantities [23]. On the surface, such offences are often associated with poor citizens and may seem minor in themselves. However, if this exceeds the sporadic theft of wood for personal use, they add up to high ecological and economic damage [149]. **Organised crime** has been shown to instigate and make use of these poor citizens to engage in systematic illegal logging. The **transnational corporations ("white collar crime")** behind them profit from the cheap illegal timber and strengthen this destructive system through their demand[70]. The nature of organised crime and corporations becomes partly visible through targeted fraud, forgery, bribery, corruption, tax fraud, tax evasion, extortion, cybercrime, money laundering and smuggling [23]. The opportunity for **high profits combined with low risk** (low enforcement capacity) makes the sector attractive for criminal activities.

15 to 30%
of the volume of globally traded wood is estimated to be obtained illegally.[a]



Illegal logging and trade are valued in economic terms at
USD 51 to152 billion
annually.[b]

Forestry crimes are directly responsible for 50 to 90% of all logging and deforestation of tropical forests.[c]

Figure 3.11: The scale of forestry crime, illegal logging and sourcing of wood

Sources: a) Nellemann 2012 [147]; b) Nellemann et al. 2016 [9]; c) Nellemann et al. 2020 [23]

Some examples include [23]:

» **Endangered or high-value species:** Rosewood[71], which is used to make furniture or musical instruments, features frequently in illegal timber flows, in particular to China [23]. Teak from Myanmar's natural forest is used to make decking for super yachts[72]. High-value oak is used to produce flooring[73].

» **Woodfuel and charcoal:** Known as "Africa's Black Gold", these shadow markets "**fund terrorist groups** like Al Shabaab and a variety of insurgency groups around the world" [23]. Charcoal is used for local heating and cooking but also for barbeques in the USA or EU. Global charcoal production is expected to grow and it often contributes to forest destruction and deforestation [150], [151] (see also previous section).

» **Paper industry:** In Indonesia, this industry has been repeatedly linked to illegal deforestation for many years [152]. In 2016 a company supplying wood was ordered to pay a record fine of 1.2 billion USD for unlawful forest clearing [74,75]. There is some hope as the deforestation rate decreased. "But this decline might not last long, given that at least six new pulp mills have recently started operating, according to data from the Ministry of Industry, which points to an increase in demand for pulpwood and thus for new plantations to feed them."[76] In March 2022 palm oil and pulpwood companies were suspected of illegal deforestation in Papua, Indonesia[77]. **In 2015 a market survey** of paper products in Germany found that 20% contained tropical timber[78].

70 See, for example, The Guardian article "Romania breaks up alleged €25m illegal logging ring", 31 May 2018; https://www.theguardian.com/environment/2018/may/31/romania-breaks-up-alleged-25m-illegal-logging-ring; accessed March 202
71 See also "The Rosewood Racket" from the Environmental Investigation Agency; https://eia-global.org/reports/the-rosewood-racket. accessed March 2022.
72 See the article by Worth (2021) "Knock on wood: WWF Exposes Illegal Timber Practices in Germany"; available at: https://whistleblowersblog.org/environmental-whistleblowers/knock-on-wood-wwf-exposes-illegal-timber-practices-in-germany/; accessed March 2022.
73 See, for example, the 2016 article by the Environmental Investigation Agency "Lumber Liquidators sentenced for smuggling illegal wood in to the United States": https://eia-global.org/press-releases/lumber-liquidators-sentenced-for-smuggling-illegal-wood-into-the-united-sta; accessed March 2022; see also the 2019 Addendum article on oak from Ukraine: https://www.addendum.org/holzmafia/parkett-ukraine/
74 For example, see the Eco-Business article: "Indonesian logging firm fined a record US$1.2 billion for deforestation", 25 November 2016: https://www.eco-business.com/zh-hans/news/indonesian-logging-firm-fined-a-record-us12-billion-for-deforestation/; accessed March 2022.
75 https://news.mongabay.com/2021/03/indonesia-pulp-paper-new-investment-demand-deforestation/
76 Ibid.
77 https://news.mongabay.com/2022/03/palm-oil-and-pulpwood-the-usual-suspects-as-papua-deforestation-persists/
78 https://wwf.panda.org/wwf_news/?244971/WWF-files-charges-against-paper-retailers-suspected-of-violating-EU-Timber-Regulation; accessed 6 December 2021.

Forestry crime will continue as long as profits and demand remain high and risks and consequences low.

The international community is far behind in combating forest crime effectively. The resources allocated to international enforcement efforts "are **completely dwarfed by the income raised by organized crime** involved in natural resource exploitation" [23]. **Forestry crime will continue as long as profits and demand remain high and risks and consequences low.** Although the European Timber Regulation (EUTR) was adopted in 2013 to tackle illegal timber trade, it "has not so far been able to stop nor significantly reduce imports of illegal timber products or illegal logging that takes place within the borders of the EU" [36]. Sufficient political backing at EU and higher governmental levels are needed to harmonise efforts and increase the quality of implementation [153]. Positive examples depict ways to move forward. The successor regulation of the EUTR (deforestation-free[79]) should close loopholes and guarantee effective implementation combined with dissuasive penalties.

The EU Forest Crime Initiative[80] seeks to enable effective law enforcement through networks that are capable of detecting and responding to forestry crime. One example of a step in the right direction – even though it needs some improvement according to WWF – is the integrated electronic wood tracking system (SUMAL) established in Romania [154]. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)[81] includes activities to train forest rangers and specialised prosecutors, as well as moratoriums on logging and log export bans [80]. WWF (2021) found that, although some laws and tools to tackle forestry crime exist, several obstacles and gaps prevent their effectiveness. These include overregulation (excessive bureaucratic procedures in forest management) and a lack of clear, comprehensive and connected overarching strategies [148], [149]. The following conclusions can be drawn.

» **Increasing demand for timber products continues to incentivise illegal activities** [148]. This makes the type of monitoring proposed in this report all the more important. Timber footprints provide a baseline for understanding how high the pressures connected to – measurable – levels of consumption are (i.e. recorded in statistics).

» However, the scale of these crimes also make statistics less robust. It is unclear exactly where, how and to what degree illegal logging enters production and trade statistics. This could **imply that actual harvests are at much higher levels than indicated in statistical data.** This uncertainty adds to other inconsistencies in FAOSTAT statistics, where it is a well-known fact that forestry production and trade statistics contain data gaps and errors[82] [155]–[157]. **Both of these factors may mean that global consumption levels are actually higher than shown in this report.** This has consequences in particular for Section 4.3, where we compare consumption to sustainable supply capacities. If consumption is actually higher, it would mean the supply gap shown there is already larger, and we are in a phase of high risk with regard to the (over)use of forests for timber production.

Overall, the challenge for forestry is more relevant than ever: **"Forestry crimes may involve the greatest mismatch of government and intergovernmental resources spent on combating them relative to the crime profits that they generate"** [36]. In addition to undercutting the price of legal wood and relegating legally operating companies to the fringe, illegal logging also contributes to climate heating and species extinction.

79 The European Union is planning a far-reaching regulation to ensure that no materials or products originating from deforestation or illegal activities circulate on the European market. The regulation covers some major commodities and their products imported to the European markets. Currently, it concerns cattle, cocoa, coffee, oil palm, soy and timber. There is a draft regulation dated 17 November 2021, which is currently being heard. This is the regulation link: https://ec.europa.eu/environment/publications/proposal-regulation-deforestation-free-products_en.

80 wwf.de/eu-forest-crime

81 https://cites.org/eng

82 One study found that industrial roundwood consumption was under-reported in 57 countries and over-reported in another 44 [155]. FAOSTAT relies on country reporting and does its best to correct for errors; see "The story of forest product statistics: from numbers to information" at: https://www.youtube.com/watch?v=KsZDkJMt_MQ; accessed 6 December 2021.

3.2 Sectoral expectations

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Wood product markets are expanding. While there is widespread consensus that emerging bioeconomy sectors may become a key driver for timber supply and demand in countries like Germany [158], there is a limited understanding of the risks involved [159].

The modelling of global scenarios (like those presented in Section 3.1) is dependent on historical data, which limits the ability to capture dynamic and structural changes as well as novel products. For that reason, this section looks more closely at sectoral trends. Global developments are presented in the context of German and European markets in order to provide a snapshot of some of the recent developments and identify how they might evolve, dependently and independently of one other.

3.2.1 Energy

Two megatrends must be distinguished when looking at global woodfuel use. FAO statistics report that a little under half of all roundwood removals are for woodfuel. The vast majority of this occurs in "developing" countries where it is burned for household cooking and heating. **An estimated 2.4 billion people use wood-based energy for cooking** [160]. Bailis et al. (2015) estimate that over 275 million people live in woodfuel hotspots (places where harvesting rates are likely to cause degradation or deforestation): nearly 60% in Asia, 34% in Africa and 6% in Latin America [11]. **This "traditional" use of woodfuel can come at a high cost to human health** – in particular for women and children who spend much of their time near cooking hearths. The World Health Organization (WHO) estimates that household air pollution nearly doubles the risk of childhood pneumonia and is responsible for almost half (45%) of all pneumonia deaths in children less than 5 years old[83]. **Around 17% of woodfuel is converted to charcoal** [151], [160]. Charcoal production is associated with significant environmental impacts (including forest destruction and significant CO_2 emissions). Its use is expected to grow (especially in Africa; see Section 3.1.1), and it is associated with high levels of illegal activity (including money laundering for terrorist groups; see Section 3.1.2).

In 2016 the share of renewables sourced from forestry was already higher than envisaged in National Renewable Energy Action Plan projections for 2020.


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Child gathering fire wood, Ngoyla Mintom forest, Cameroon.

A multitude of efforts are under way to reduce the dependence on woodfuel in subsistence systems and help promote cleaner and healthier options[84]. Bailis et al. (2015) found that scenarios to disseminate 100 million state-of-the-art improved cookstoves could result in emission reductions in the order of 98–161 Mt CO_2eq per year [11]. To put this in perspective, Germany emitted 739 Mt CO_2eq in 2020[85].

India's State of the Forest Report found that average woodfuel consumption per capita fell from 294 kg per person and year in 2011 to 278 kg per person and year in 2019 [161]. Various government schemes promote alternative fuels [161].

83 For more information, see the WHO fact sheet on household air pollution and health: https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health; accessed 20 March 2022.
84 See, for example, the Clean Cooking Alliance; https://cleancooking.org
85 This was roughly 70 Mt (8.7%) less than in 2019 due to the COVID-19 pandemic; see https://www.umweltbundesamt.de/en/press/pressinformation/germanys-greenhouse-gas-emissions-down-87-percent; accessed 17 October 2021.

On the other hand, wood is actively promoted (to a certain degree) as an alternative to fossil fuels in high-consuming countries. The picture is not straightforward, in particular as countries aim to both promote wood as a renewable source of energy and count standing forests towards carbon mitigation[86].

Wood energy in the EU: current status, targets and mixed incentives

We present the framework in the EU to better understand these issues, as well as the debate, expectations and hazards surrounding this issue. **In the EU, bioenergy currently accounts for around 60% of renewable energy production. This comprises mostly wood: around 60% of biomass for energy is wood-based** [162]. According to estimates by Camia et al. (2021), nearly half of the wood-based energy was sourced from secondary sources (e.g. forest-based industry by-products and recovered post-consumer wood) in 2015 (222 Mm³ or 49%), whereas 37% (166 Mm³) was sourced from primary wood (e.g. stemwood, treetops or branches that were harvested directly from forests) and 14% (63 Mm³) was uncategorised. In 2016 the share of renewables sourced from forestry was already higher than envisaged in National Renewable Energy Action Plan projections for 2020. In contrast, the share of biomass energy generated from agriculture and waste was well below projected amounts [162]. **This does not bode well for the future.** The EU Commission's long-term vision for "a prosperous, modern, competitive and climate-neutral economy" would require between 214 and 322 Mtoe from bioenergy in 2050, depending on the scenario. In comparison, 140 Mtoe from bioenergy were reached in 2016 [163]. The vast majority of this increase is expected to be covered by waste and energy crops (such as switchgrass and miscanthus), whereas the contribution of wood is modelled to be between 60 and 65 Mtoe [163]. **This future scenario thus requires less energy from wood than that which was contributed in 2016,** implying the need to reduce wood energy consumption at the EU level. Many of the incentives in place at a country or operational level, however, still encourage the burning of wood to replace fossil fuels.

We need to "end subsidies and other incentives that today exist for the burning of wood."

The revised EU Renewable Energy Directive (RED II; Directive 2018/2001) contains criteria aimed at ensuring that timber harvesting practices maintain biodiversity, long-term productivity and forest regeneration. RED II also strengthens ties to the new land use, land-use change and forestry sector (LULUCF) criteria in which forest area harvests count towards countries' Nationally Determined Contribution (LULUCF Regulation 2018/841). In other words, countries must define a "forest reference level". Harvesting beyond that level would generate debits in their carbon accounting. This may lead to competing incentives for different policy groups – "RED II stimulates bioenergy demand by economic operators, while LULUCF disincentivises countries to harvest beyond certain limits" [95]. In an open letter to world leaders, 500+ scientists raised the point that: **"Making countries responsible for emissions from land use changes, although desirable, cannot alone fix laws that treat burning wood as carbon neutral because these national responsibilities do not alter the incentives created by those laws for power plants and factories to burn wood."**

The letter urged governments to "end subsidies and other incentives that today exist for the burning of wood whether from their forests or others"[87].

One of the key issues here is the concept of carbon neutrality. With respect to burning wood for energy the concept of carbon neutrality is highly debated. This is because there is a **significant time lag** between when wood is harvested and burned and when that forest grows back and traps enough carbon to offset that which was emitted. This time period is longer than we have to halt climate change (which must be addressed now). Moreover, old forests are better carbon sinks than newly planted and intensively managed forests, in particular due to the role of soil (see Chapter 2).

This further tips the carbon balance of burning wood towards unrealistic time horizons. Meanwhile, burning wood increases particulate matter emissions and raises carbon emissions over the short term [164]–[166].

It is also a question of scale. **This is reflected in a simplified thought experiment by asking** the question: how many trees would be needed to cover 100% of global energy demand? The answer: we would have to clear-cut nearly all of the world's forests to supply just one year's worth of energy[88]. In a similar simplification, a doubling of commercial wood harvests would be required to cover just 2% of global energy demands with wood. **Thus, at current use levels, substituting fossil fuels with biomass is not an option.**

86 For more information on the bioenergy criteria and forestry criteria in the EU taxonomy, see https://www.wwf.eu/?1151391/Bioenergy-mars-EU-Commissions-attempts-at-a-science-based-Taxonomy

87 See the letter and WWF response at: https://www.wwf.eu/?2128466%2F500-scientists-tell-EU-to-end-tree-burning-for-energy; accessed 17 October 2021.

88 This is massively simplified as an illustrative example using a global energy demand of 14,385 Mtoe (IEA 2019) and conversions (e.g. to steam in a commercial scale power facility and for just softwoods (50% moisture content)) to calculate 90% of standing stock.

Other high-income countries are also considering an increase in wood energy use

UNECE (2019) calculated potential wood energy production in North America that was estimated to be nearly three times higher than consumption in 2013 [167]. If this were to materialise, **it would greatly increase global wood consumption levels, well over the trends extrapolated in Section 3.1.1, and cause huge damage to forest ecosystems and biodiversity.** An assessment on the increased use of forest bioenergy in Canada found more modest potentials of between 5.5 and 20.4 Mm^3 by 2030, warning that "lessons learned from bioenergy policies worldwide have shown that increasing the use of bioenergy can impact the forest sector as a whole and that **the carbon impacts of bioenergy should be assessed holistically"** [168]. The UNECE study on wood energy expects that trade from North America and other UNECE members is likely to be the source of higher levels of wood energy consumption in the EU. A report by the US Department of Energy concluded that the "greatest potential for growth in renewable energy production in the OECD countries is in wind, solar, and wood pellets" ([167], [169].

Burning wood is not climate-neutral.

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Wood pellets – strategies and scales have significant implications for sustainability

The market for wood pellets has indeed boomed. Developments in different pellet markets illustrate that **the way in which the bioeconomy is implemented dramatically impacts its contribution to sustainability goals. Wood pellets comprised 15% of all woodfuel traded in 2012 and 23% in 2015.** Europe was the largest importer by far, and some countries relied heavily on imports (e.g. 94.7% in the UK and 81% in Italy) [162]. The use of pellets differs between countries. In the UK, pellets are generally burned in coal plants to produce, in some cases, just electricity. This practice has come under intense scrutiny [164]. A large proportion of the demand for pellets in the UK is met in the Southern United States, where 23 pellet mills were built over the past decade[89]. Proponents argue that this level of investment serves to make forests more valuable and promotes better forest management. Critics from science and environmental organisations argue that burning timber emits more CO_2 than burning coal over the short term; forest biodiversity and ecosystem services are being lost to wasteful energy consumers in rich countries; and subsidies to promote "renewable energy" should be better spent on effective solutions[90].

In Germany, the pellet industry emphasises that 90% of pellets are produced using mill residues (two-thirds of these are wood chips (Hackschnitzel) and one-third are sawdust (Späne). The remaining 10% is non-sawable timber. Most pellets used in Germany are produced within Germany (89% in 2019) and used in small-scale biomass combustion plants and households. **Around 10% of German households meet their wood energy needs through pellets.** Most private household wood energy consists of "logs from the forest" (66% in 2018) [170]. Pellet use is increasing rapidly, not least through government support programmes that promote the use of wood and help to offset the cost of replacing oil heating systems with "renewable energy" sources[91]. For example, the number of pellet boilers installed in Germany increased from around 200,000 in 2010 to slightly over 600,000 in 2021 [171] and the German Pellet Institute (DEPI) forecasts an additional doubling between now and 2030[92]. This is intended to help Germany meet its commitments to reducing its greenhouse gas emissions by 65% by 2030 (compared to 1990 levels). However, the actual contribution to climate change mitigation of burning wood is highly questionable due to the time lag in "offsetting" carbon emissions, which is highly dependent on what, where and how

89 Based on reporting in Politico by Grunwald in the cover piece "The 'green energy' that might be ruining the planet", https://www.politico.com/news/magazine/2021/03/26/biomass-carbon-climate-politics-477620
90 For example, the documentary Burned: Are trees the new coal?; Michael Moore's documentary on the biomass delusion (Planet of the Humans); and the report "The Black Book of Bioenergy: Good Intentions Gone Bad" [315] all highlight cases illustrating the dangers of bioenergy without effective constraints.
91 For example, the "Heating with Renewable Energies" programme was renewed in 2021; https://www.bafa.de/DE/Energie/Heizen_mit_Erneuerbaren_Energien/heizen_mit_erneuerbaren_energien_node.html
92 https://www.depi.de/pelletproduktion; accessed 17 October 2021.

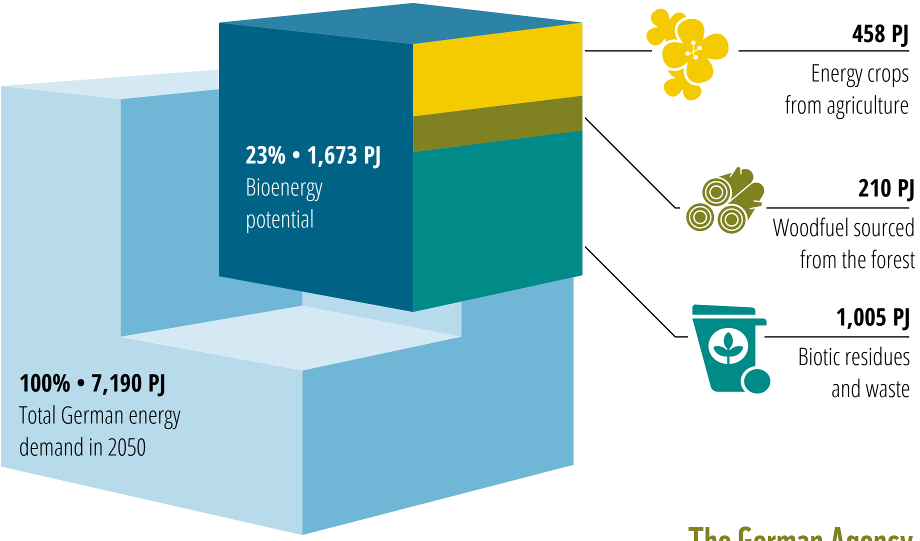
wood is burned and sourced. Moreover, scale matters critically. In the case of pellets in Germany, for example, a further doubling of demand could lead to an import dependency for pellets, raising questions about the source of the wood (including concerns regarding illegal harvesting) as well as overarching sustainability.

In 2021 the German Agency for Renewable Resources (FNR) estimated that bioenergy as a whole could potentially meet around 23% of Germany's total energy demand in 2050 [19]. The agency estimated that around 3% of total demand (210 petajoules (PJ)) could be covered by wood harvested for energy purposes (Figure 3.12). Approximately another 1.7% (about 119 PJ[93]) of forest harvest residues are included in the waste and residues category, of which 84 PJ represent a theoretically mobilisable potential. In 2016 it was estimated that 10% (697 PJ) of Germany's total energy demand in 2050 could potentially come from forestry [171]. This shows the dynamic nature of the state of research surrounding these questions. It also underscores the need to carefully evaluate political incentives for burning wood to avoid an overuse of forest resources, both within Germany and abroad. Luick et al. (2022) take an in-depth look at the issues surrounding climate protection, biodiversity conservation and the promotion of renewable energy in Germany.

They present at least three critical findings concerning the use of wood for energy.

Figure 3.12: Estimated potential for bioenergy in Germany in 2050 by the German Agency for Renewable Resources (FNR)

Source: FNR 2021 [19]



The German Agency for Renewable Resources estimates that around 3% of total German energy demand (210 PJ) could be sourced directly from the forest in 2050. Harvest residues could potentially supply another 1.7%. Waste wood (e.g. at the end of cascades) could also play a significant role here.

- » Using wood for energy and in short-life wood products **"usually leads to little or no reduction in GHG emissions compared to the fossil fuel benchmark"** [172].

- » In some cases, wood can be used for energy – but **only when wood cannot be used for anything else,** where it is based on residual or sawmill by-products and is burned **as locally as possible and only in efficient facilities.**

- » **"Wood that remains in the forest** in the form of living trees or deadwood can make at least as great and **often even greater a contribution to climate protection** than when it is used for energy and inefficient materials" [172].

The need to prioritise wood use

Heated debates on the sustainability of using wood for energy have and continue to take place in scientific journals, media and policy circles [173]. There is common ground on the potential benefits of some small-scale bioenergy systems, such as those under community ownership. Biofuelwatch argue that such systems for local energy needs "could still attract support, for example under Rural Development programmes … rather than from subsidies … which disproportionately boost large-scale industrial schemes"[94].

At the same time, the material use of wood for new and emerging bioeconomy markets is attracting more investment and is growing (see sections below). This will undoubtedly make questions concerning the sustainability of wood and forest use more complex. To this end, benchmarks constituting practical, robust and socially acceptable definitions of risk – like the one we present in Chapter 4 – would help to frame the debate. Such a benchmark shows the amount of wood available under sustainable management conditions. This underscores the fact that wood, directly sourced from the forest, is a limited resource. For that reason, there is a need to prioritise how wood is used in the economy. **Burning harvested wood is not a good use of our limited supply,** especially in light of the climate crisis and considering that burning wood emits carbon, whereas material use sequesters it. Nationally defined criteria are needed to limit the use of stemwood for energy purposes, in particular for electricity generation [172]. Wood products for a certain amount of time could continue to provide energy when reuse and recycling options have been exhausted (see "Cascades and reuse" in Chapter 5).

93 Based on own calculation of online data; https://webapp.dbfz.de/resources/?lang=en. See also the descriptions of FNR online: https://mediathek.fnr.de/grafiken/pressegrafiken/bioenergiepotenzial-2050-was-kann-bioenergie-leisten.html; accessed March 2022

94 Biofuelwatch and co-signatories, "Large-scale bioenergy must be excluded from the EU's renewable energy definition", in The Ecologist. 2016.

3.2.2 Construction

Among all sectors, the construction sector is the largest consumer of raw materials. Construction aggregates – such as sand and gravel – comprise up to around 85% of all mining and quarrying activities [174] and the scale of aggregate extraction is projected to double by 2060 (to around 55 billion tonnes (Gt)) [12]. Aggregates are mostly used for concrete production, which has grown significantly. For example, China's consumption of cement[95] increased by over 400% in 20 years [174]. **It is estimated that the building industry accounts for more than 50% of global energy and 35% of CO2 emissions** [175]. That is because cement is also carbon-intensive to produce. The cement industry causes 8% of global GHG emissions and 2% of German GHG emissions [321].

Many see wood as the resource of the future for greening the building industry. Part of the enthusiasm stems from new engineered wood products (e.g. cross-laminated timber; see Box 12) with structural properties that enable wood to replace steel and concrete – even in high-rise construction – in ways that were not possible even a decade ago[96]. The potential of wood for **prefabrication and modular design** – both significantly reducing on-site waste and enabling later reuse – is also promising. **Recyclable architecture** is now emerging [175]. This means designing for multi-use, reuse and resource-efficient construction in a way that takes changing needs over time into account, and wood is a lightweight material that helps to achieve this flexibility.

The carbon balance of building with wood – scale matters

Reducing CO_2 emissions by using wood in construction is a major focus of the environmental benefits discussed in the literature. However, **caution is needed here due to the issue of scale.** It is possible to save large amounts of embodied CO_2 emissions when single buildings are compared and steel and concrete are replaced with wood [38], [134]. **Large-scale substitution, however, may require more wood than can be sustainably harvested and lead to increased GHG emissions through fragmentation, degradation and deforestation.** This would be the case when wood consumption levels do not comply with the sustainable benchmark presented in Chapter 4.

Box 12: Production of mass timber products like cross-laminated timber

Mass timber products are engineered wood products that are laminated into larger structural components such as glue-laminated (glulam) beams or cross-laminated timber (CLT) panels. At the time of writing, they were not yet included in statistical monitoring (but will be soon). Verkerk et al. (2021) estimate that around 2.5 Mm^3 of cross-laminated timber is currently produced globally, based on estimates from known production capacities in major producing countries [38]. The EU is the largest producer, with **70% of global production stemming from Germany, Austria and Switzerland,** with a focus in these countries on supplying export markets. The USA and Canada are responsible for around 12% of global production, and Russia and Japan are investing in their CLT manufacturing capacities. **The sector is expected to continue to grow substantially**. It was valued at 603 million USD in 2017 and is projected to more than double to 1.6 billion USD by 2024 [176]. For the market volume to correspond to 0.1% of the total concrete market by mass, an estimated 40 Mm^3 of mass timber products would be needed [38], [177]. This, again, **underscores the importance of addressing the issue of scale when designing policies focused on substitution.**

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95 The trend for aggregates extraction can be estimated using cement production as a proxy (concrete is comprised of cement, water, sand and gravel) [174].
96 See, for example, the Tall Wood Building Demonstration Initiative (2021) launched by Natural Resources Canada, https://cfs.nrcan.gc.ca/publications?id=40337; accessed 24 November 2021.

In a theoretical example, Churkina et al. (2020) looked at the potential savings if 90% of urban buildings were built with wood (especially mass timber) over the next 30 years [178]. They found that emissions from manufacturing construction materials could be cut by around half compared to their business-as-usual scenario. However, this could require up to 5 Gm³ of roundwood per year (current global harvests are around 4 Gm³ per year for all end uses) and these estimates do not account for the changed carbon balance of forests. The study considers future projections for potential harvest rates generated from a climate model [179] that projects large gains in forest productivity due to climate change. **It thus relies on a wood supply scenario that dramatically exceeds the sustainable potential presented in this report** (see Chapter 4). Similarly, Oliver et al. (2014) estimate that "using wood substitutes could save 14 to 31% of global CO_2 emissions and 12 to 19% of global fossil fuel consumption" [180]. They see the greatest savings potential in the construction sector, but this would require using 5.8 to 17 Gm³. Indeed, Oliver et al. estimate a global availability of wood of 17 Gm³, which is nearly 4 to more than 5 times higher than our estimate of wood potential developed in Chapter 4. Their potential is based on estimates of net primary production, relies on sources more than 20 years old for tropical rainforests and does not appear to take any consideration of availability and accessibility into account. This makes their conclusions on the substitution potential of "using 34 to 100% of the world's sustainable wood growth" [180] highly suspect. On the other hand, a study focused on the USA [181] looked at an optimistic scenario for the uptake of mass timber products from the Softwood Lumber Board and found that such a scenario would increase current softwood lumber consumption by 17% by 2035. They found that this level of demand could be supplied within the USA (in total using 82% of their lowest level of projected forest growth) [181]. These theoretical examples show that scale and model assumptions matter to the interpretation of results and the policy implications.

Box 13: Wood foam

Wood foam is a product in pre-commercial stages of development. It is the result of a research project conducted at the Fraunhofer Institute and has a variety of potential applications. It is a lightweight, rigid foam with sponge-like pores that could be used for insulation, in packaging or as middle layers in sandwich boards for furniture and doors. In 2015 it won the GreenTec Award in the "Construction and Living" category. It is presented here as one example of the type of innovation and research currently happening in Germany.

Source: Wood foam developed by the Fraunhofer Institute for Wood Research/Wilhelm-Klauditz-Institut, https://www.wki.fraunhofer.de/en/departments/hnt/profile/research-projects/wood-foam.html

This wood foam board is an entirely natural product made from sustainable raw materials.

There is broad consensus that using roundwood for long-life applications rather than as a fuel would provide the most climate benefits, and that this is probably a low-hanging fruit. For construction, Peñaloza et al. (2018) found that the priority should be to substitute high-impact building types with several different approaches to gain optimal climate change mitigation results [182]. This means that wood substitution is one strategy, but it is not the only option, nor is it always the best option. The global mass timber impact assessment programme, initiated by The Nature Conservancy, aims to understand the potential benefits and risks of increased demand for mass timber products on forests and identify appropriate safeguards to ensure positive outcomes [183]. Results are expected in 2023.

Overall, the use of wood in construction, especially to replace concrete and instead of burning wood directly, shows positive environmental benefits on a case-by-case basis. However, scale matters critically.

Wood construction trends and incentives across the world

To date, wood construction is found mostly in the Nordic countries, North America, Australia, Japan and parts of southeast Asia[97]. It is a highly culturally dependent sector, and innovation is also notably slow in comparison to other sectors [184]. Tropical countries typically have low levels of wood construction, preferring concrete for high-rise buildings and bricks in rural housing [10]. There are also few, if any, policies in tropical countries that promote timber construction, for example in public procurement [185]. In Russia, the share of buildings with wooden walls is estimated to comprise around 10% of the total [127].

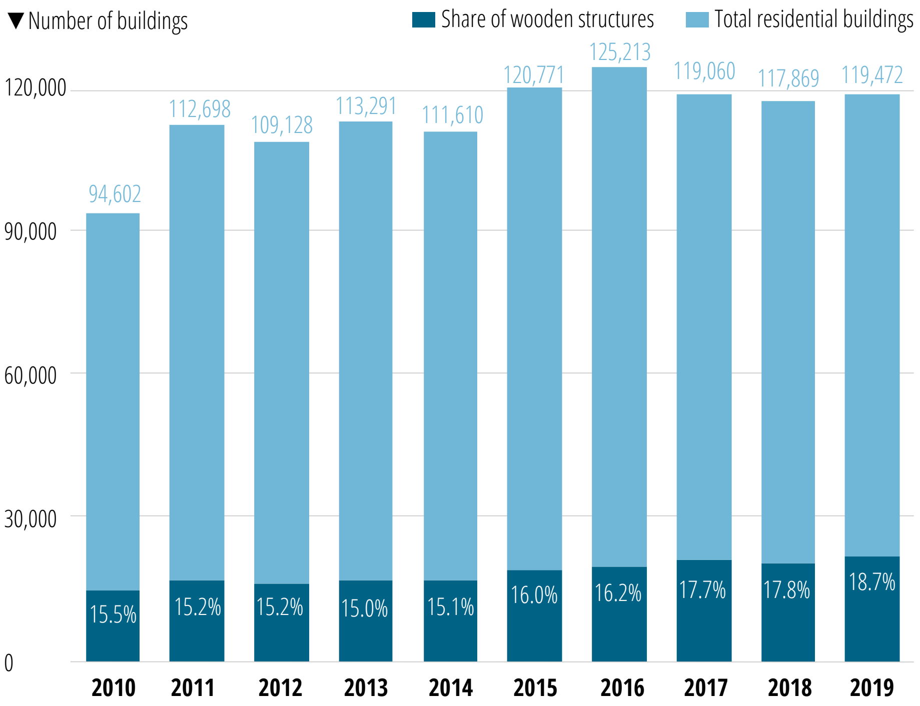

Figure 3.13:
Share of wooden structures in all approved residential buildings in Germany
Source: FNR 2021 [171]

Many governments across the world are promoting the use of wood in the construction sector. For example, in Japan, the Act for Promotion of Use of Wood in Public Buildings aims to promote CLT. In France, plans are under way to require that new public buildings are made of at least 50% wood or other sustainable materials from 2022[98]. In Finland, the Wood Building Programme[99] has enabled the construction of several wood-based buildings. The German government is also incentivising building with wood. For example, the funding programme "Climate-friendly building with wood"[100] (Förderung des Klimafreundlichen Bauens mit Holz) provides support to companies and cluster organisations for promoting digitalisation, automation and cross-company cooperation.

In Germany, nearly 19% of residential buildings approved for construction are made of wooden structures, and the trend has been increasing continuously since 2015 (Figure 3.13). The share of wooden structures in non-residential buildings was somewhat higher in 2019 (nearly 20%). Wood fibres comprised around 3.5% of insulation materials in Germany in 2011 (with mineral and fossil resources comprising 48% and 45%, respectively). A 2020 study on the potential for building with wood came to no clear conclusions on future capacities [187]. The study quoted data from 2012 as the most recent available estimate of wood use in the construction sector—namely 13.4 Mm³ of construction wood with 12.5 Mm³ stemming from primary sources (and the other share coming from sawmill by-products and waste wood). It also considered + 20% losses during construction, which would require 16.6 Mm³ of construction wood in total. In 2012, around 64% of the wood used in construction was used for renovation and 36% was used in new construction [188]. Based on the available literature, Wolf et al. (2020) could not deduce what rate of increase in timber construction would be feasible within the bounds of domestically available supply. However, **"an increase in the timber construction quota without imports but only with an increase in the domestic forestry area is estimated to be unrealistic"** [187]. Our results show that Germany's total wood consumption levels are already disproportionately high (compared to German supply capacities and global averages; see Section 3.3). For that reason, reductions in other sectors are vital to being able to, sustainably, increase the use of wood for construction purposes (especially renovation).

97 According to the article "Building in wood around the world" on the Swedish Wood website, available at: https://www.swedishwood.com/building-with-wood/construction/a_variety_of_wooden_structures/single_family_houses_and_multi_storey_buildings/building_in_wood_around_the_world/; accessed 30 November 2021.
98 See the article by Global Construction Review "New French public buildings must be made 50% from wood": https://www.globalconstructionreview.com/new-french-public-buildings-must-be-made-50-wood/; accessed 30 November 2021.
99 See the Ministry of the Environment website for more information: https://ym.fi/en/wood-building; accessed 18 March 2022.
100 Available at: https://www.klimafreundliches-bauen.de; accessed 30 November 2021.

3.2.3 Paper and packaging

Around 40% of industrially harvested wood is already used for paper production [13]. Global paper and paperboard consumption is expected to nearly double between 2010 and 2050 [14], [15]. This would have a significant impact on total wood demands. The predicted development will be a consequence of per capita consumption levelling off or even declining in high-income countries (at relatively high levels) and per capita consumption increasing across the world (at levels still below those in high-income countries) (Figure 3.14). Based on current trends, a recent study [189] came to similar conclusions about the amount of paper and paperboard that will be consumed in 2050, namely **878 Mt**.

Around 40% of industrially harvested wood is already used for paper production.

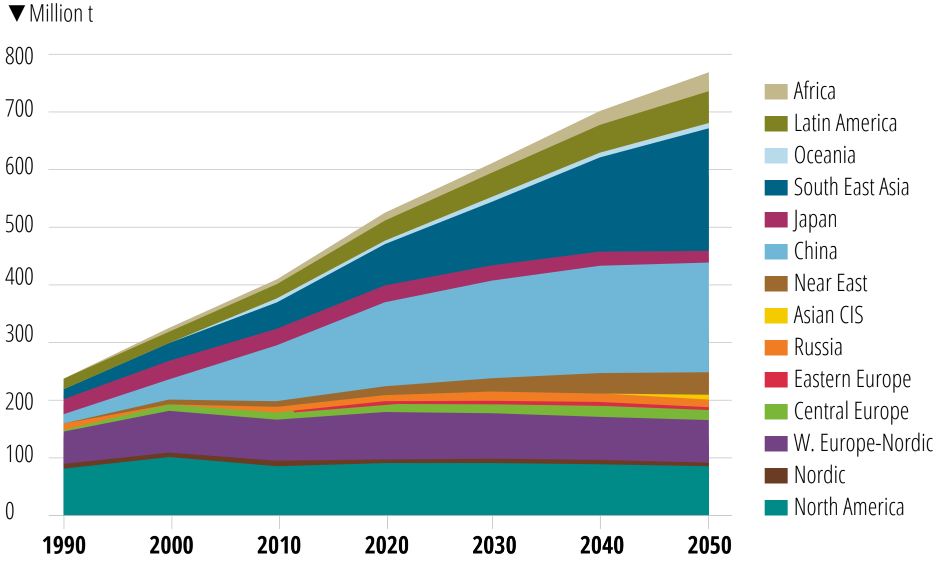

Figure 3.14:
Prospects in paper and paperboard consumption by region up to 2050
(Asian CIS = Asian Commonwealth of Independent States)

Source: Based on CEPI 2011 [14] and FAO (2011) [15]

“Paper consumption is at unsustainable levels and globally it is steadily increasing, particularly in Asia, while remaining at unequal levels of access in some parts of the world, particularly Africa.”
Environmental Paper Network 2018 [13]

This section looks at how much paper (from wood or recycled fibres) is being used and what it is being used for. It also touches on some of the environmental challenges associated with production and recycling. The focus is global, illustrative of the fact that high-consuming countries like Germany are already placing disproportionately high pressure on the world's forests – getting overconsumption under control in these countries could help make way for low-consuming countries to increase their consumption levels in an environmentally sound and socially just way. The challenges in this sector are also increasingly global, geopolitical and related to both socio-economic and environmental issues. Such challenges include deforestation, violations of Indigenous Peoples' rights, and shifts in production among countries in global markets.


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According to FAOSTAT, around 400 Mt of paper and paperboard were produced globally in 2020[101]. In that year, China was the world's largest producer (accounting for nearly 30% of production at around 117 Mt) followed by Europe (around 100 Mt) and North America (around 75 Mt). These are also the largest consumers. **Africa accounts for just 0.8% of global paper production.**

Global average consumption is 55 kg per person per year. After Luxembourg, **Germany was the world's second largest consumer of paper with a level of 251 kg per capita** ([13] based on FAO data from 2016). The African average is 7 kg per capita and the Indian average is 9 kg per capita. **This gap must be narrowed by lowering consumption in high-consuming countries.** There is a minimum level of paper judged necessary for living a decent life (providing high-utility items such as passports, medical records and legal papers).

Paper poverty line: 30 kg per year is the level of personal paper use judged necessary for education and democratic involvement in society [13].

101 https://www.fao.org/faostat/en/#data/FO

What are the main uses of paper?

Nearly 60% of global paper is used for packaging and wrapping, and there is a strong upward trend (Figure 3.15). Population and income trends are driving – and are expected to continue to drive – the continued increase in wrapping and packaging production and consumption. According to Verkerk et al. (2021): **"This is associated with the ever-growing consumption of goods and the need to package them for transport and sale"** [38]. E-commerce and take-away products are contributing to this growth. Sanitary paper is also expected to continue to grow significantly, and currently accounts for less than 10% of total paper consumption.

The picture for newsprint and printing and writing paper looks different. In the case of newsprint, global production increased steadily until 2004 (peaking at around 40 Mt), before falling to around 18 Mt in 2019. Printing and writing paper show a similar trend, peaking in 2007 (at 116 Mt) and falling to around 92 Mt in 2019. Figure 3.16 depicts regional trends for Asia, Europe and North America, which accounted for an average 95% of global production between 1961 and 2018. Digital media is cited as the main reason for declining trends in multiple sources [38]. Nevertheless, total paper production and consumption is increasing.

Nearly 60% of global paper is used for packaging and wrapping, and there is a strong upward trend.

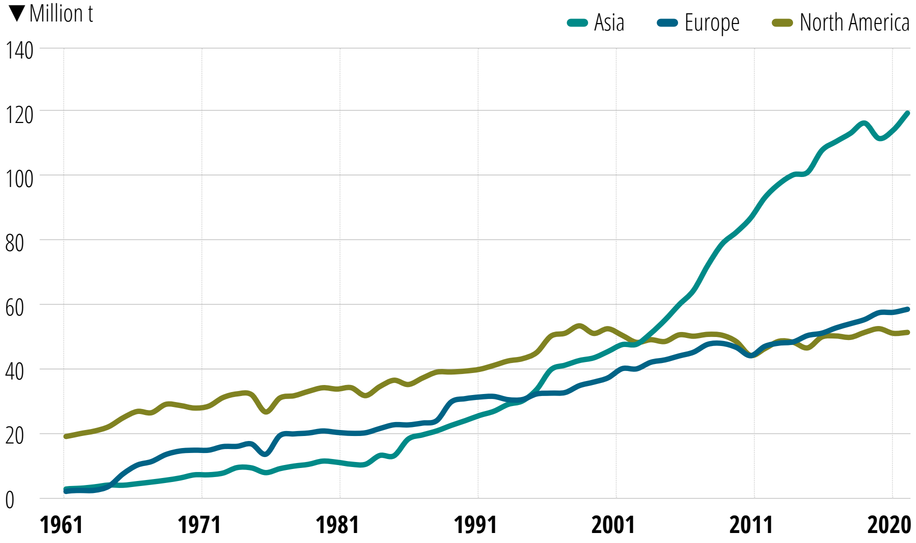

Figure 3.15: Trends in wrapping and packaging production in major world production regions

Source: FAOSTAT, accessed 19 March 2022

Note: This includes case materials (used mainly to manufacture corrugated board, such as the cardboard boxes often used in shipping; this comprised around two-thirds of the sub-category in 2020), cartonboard (used mainly in cartons for consumer products like frozen food and liquid containers; this currently comprises around one-fifth of the sub-category) and other wrapping and packaging [38].

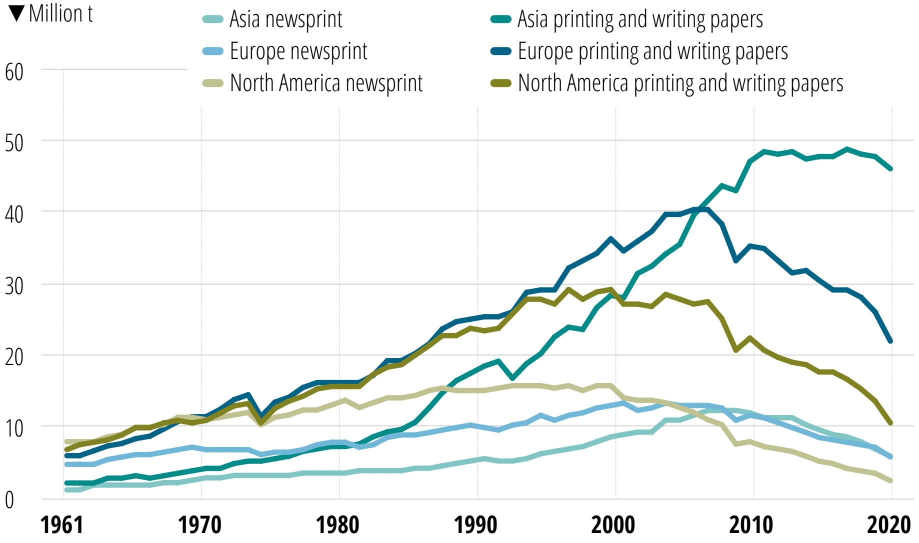

Figure 3.16: Trends in newsprint and printing and writing paper production in major world production regions

Source: FAOSTAT, accessed 20 March 2022

Note: The country assignments to country groups can be found under FAOSTAT (https://www.fao.org/faostat/en/#definitions); the exact FAO definitions of "newsprint" and "printing and writing papers" can be found at: https://www.fao.org/forestry/statistics/80572/en/

The environmental performance of paper

Pulp and paper mills rely on energy-, water- and chemical-intensive processes [13]:

- **On average, 10 litres of water are needed to make one A4 sheet of paper** ([13] based on [190]). In some countries, paper production accounts for more than 10% of all freshwater consumption [190].

- **The pulp and paper industry is the fifth largest industrial energy consumer in Germany**[102]. To date, it has covered most of its energy needs through combined heat and power generation using fossil fuels, mainly natural gas[103]. Paper drying accounts for up to 70% of fossil fuel energy consumption in the pulp and paper sector alone [13]. In the USA, pulp and paper manufacturing accounts for 6% of all delivered industrial energy consumption [191]. However, this only includes energy purchased by the mill and not the energy produced on site through the burning of by-products (black liquor). Including this could double the total energy consumption of the sector [13], [191]. For example, a pulp mill generates 1.7–1.8 tonnes of black liquor (pulp by-product) per tonne of pulp and represents a potential energy source of 250–500 Megawatts [192], [193], plus the heat energy generated by burning black liquor. Instead of burning it, black liquor may be increasingly desired as a raw material by the chemical industry in the future to replace mineral oil-based products (see below). Alternative energy sources like deep geothermal energy could become the future energy source for the pulp and paper industry instead of burning gas or black liquor[104]. This change in energy supply would lead to less pressure on forests elsewhere.

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- **Paper pulping and bleaching processes discharge toxic chemicals** into waterways; air pollutants are also released. While elemental chlorine bleaching is particularly problematic and declining, the trend in the use of elemental chlorine-free (ECF) bleaching and the use of total chlorine-free (TCF) technology is rare and declining.

The environmental performance of pulp and paper mills differs across the world. In general, North American mills generally lag behind European and South American ones (where newer mills exist). Southern Europe, North America and South America generally have mills that are more fossil fuel-intensive than those in Sweden and Finland [13], [194]. The export of paper or pulp with a considerable risk of illegality is estimated to be high in Indonesia (70–80%), Russia (10%), China (10%) and Brazil (2%) (according to a 2014 Chatham House paper). Indonesia signed a Voluntary Partnership Agreement (VPA) with the EU to stop illegal logging, but several publications and articles about illegal logging (also with links to the paper industry) in recent years suggest that the problem has not disappeared. **The pulp and paper industry is estimated to be supplied by more than 100 Mha of forest.** In South America, Asia and the Southeastern United States, most of the virgin fibre is grown in pulpwood plantations. It is thought that highly productive plantations [13] could have the potential to reduce pressures on natural forests. But, **widespread environmental harm has also been associated with pulpwood expansion, including the expansion of pulp plantations into peat swamp forests in Indonesia.** Moreover, **“Indigenous peoples continue to struggle to have their rights respected in all pulpwood-producing regions”** [13], [194], [195]. There is not only a need to ensure cleaner production (new technologies like DryPulp are possible), but also to include social responsibility as one of the pillars of more sustainable pulp and paper production. Nonetheless, the greatest gains would be achieved by reducing consumption in high-consuming countries.

102 The paper sector accounted for just over 6% of primary energy demand of German manufacturing sectors in 2019; see the German Environment Agency’s graph at: https://www.umweltbundesamt.de/daten/umwelt-wirtschaft/industrie/branchenabhaengiger-energieverbrauch-des#primarenergienutzung-des-verarbeitenden-gewerbes; accessed March 2022.

103 In Germany, see also the “Room for Improvement” project at: https://www.energyprofi.com/umwelt-news/branche-hat-noch-viel-luft-nach-oben-neues-energiekonzept-fuer-die-papierindustrie/; accessed March 2022.

104 See, for example, the “Kabel Zero” project at: https://www.energy4climate.nrw/themen/best-practice/kabel-zero; accessed March 2022.

What about paper recycling?

Paper recycling is key to reducing wood consumption and reducing the overall environmental footprint of paper production. Around 230 Mt of recovered paper were collected worldwide in 2018. Around 196 Mt of virgin pulp were produced in the same year [157]. A global paper recycling rate of nearly 58% was reported by the Environmental Paper Network [13] based on industry estimates. According to Verkerk et al. (2021), around 66% of paper and paperboard was recovered in the USA and Europe in 2018, with some countries reporting more than 80% [38]. Theoretically it would be possible to produce more paper with less wood. A scenario was presented in 2010 by the paper industry based on the assumption that the global recycling rate would increase from 53% to 70% (Figure 3.17).

This recycling scenario was not achieved and the goals were not reached. It was conceptualised more than a decade ago, but the idea behind it is more relevant than ever and should be renewed.

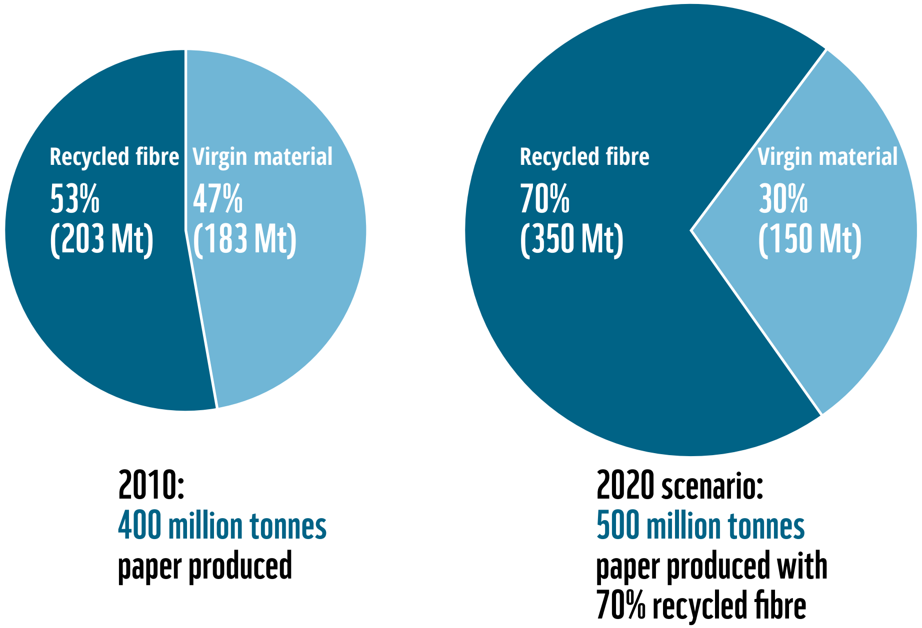


Figure 3.17:
Growth scenario showing how to increase paper production from 400 million tonnes to 500 million tonnes with less industrial roundwood/virgin material

Source: Modified by WWF in 2012 [145] based on personal communication with Voith Industries/Jaakko Pöyry Consulting in 2010 and FAO

But in reality, the recycling rate only reached 58%, which means that the consumption of wood for producing paper is increasing instead of decreasing (nearly 200 Mt instead of the predicted 150 Mt). There is an indication that recycling rates are increasing globally, but unfortunately much slower than predicted years ago (see Figure 3.17). The scenario in Figure 3.17 is 12 years old now and the goal was not reached, but the idea behind it is more relevant than ever and should therefore be renewed.

Not recycling paper also has negative implications: in many countries used paper ends up in landfill sites and produces landfill gases with negative effects on climate heating. There is therefore a clear need to stop landfilling paper, not just because we are losing a valuable resource but also because of climate change. Finally, profit-related incentives encourage the global trade of recovered paper [38], [196]. This may make reprocessing wastepaper less environmentally sustainable [38], [197]. In the past, for example, China imported enormous quantities of recovered paper [13]. It has since revised its import rules, requiring higher-quality materials.

The Environmental Paper Network (2018) found that recycled paper has half or less the climate impact than virgin paper [13]. However, recycling also requires energy. Ewijk et al. (2021) found more limited climate benefits of global pulp and paper recycling because they found that recycled pulp tends to be powered by fossil fuels and grid electricity, whereas chemical pulping of virgin timber is typically powered by burning by-products [189]. It is likely that diverting mill by-products into bioplastic production, for example, (see below) could impact such carbon balance calculations in future.

In conclusion, while efforts to make paper production cleaner and to increase recycling are important, there must be **a much greater focus on reducing wasteful consumption.**

Box 14: Biorefineries

A biorefinery is a processing plant where biomass is converted and extracted into a range of added value products. CEPI (2021) identified **139 biorefineries in Europe using forest-based biomass** [17]. The largest number were in Sweden, Finland, Germany, France and Austria. They produced mostly man-made fibres, biodiesel, bionaphta, lignosulfonate and tall oil products. CEPI (2021) classified biorefineries according to the following sub-categories.

Category 1: Biorefineries based on chemical pulping operations to produce various existing or emerging bio-based products (84% of European biorefineries fall into this category)

Category 2: Biorefineries using virgin pulp and/or recycled fibres to produce emerging bio-based products

Category 3: Other biorefineries using lignocellulose as raw material to produce various existing or emerging bio-based products

Around €2.7 billion were generated by bio-based products other than pulp and paper and, based on the amount of investment and research and development (R&D) programmes, **"it is justified to expect the share of emerging bio-based products to be substantially larger in the future"** [17].

Presentation of the planned biorefinery of UPM Biochemicals GmbH, Leuna.

3.2.4 Bioplastics

Over 400 Mt of plastic are produced each year, with more than 90% coming from fossil-fuel feedstocks. The sector is projected to grow to 1.1 Gt by 2050, at which time it would account for 20% of total oil consumption and 15% of the global annual carbon budget [198]. **Currently, around 36% of plastics are used in packaging** and more than 75% of global plastic production ends up as waste each year [38], [199]. A significant share of non-biodegradable plastic waste leaks into the environment. One study found that 19 to 23 Mt, or 11% of global plastic waste, entered our waterways in 2016 [200]. Governments are increasingly aware of the magnitude of this environmental disaster. For example, a UN Environment Programme (UNEP) study found that more than 60 countries had introduced bans and/or levies to curb single-use plastic waste [201]. However, a common strategy for plastic packaging is to replace it with paper and paperboard. UNEP (2018) stated: **"it is still controversial if paper bags should be considered an affordable and eco-friendly alternative to plastic"** [201]. Such substitutions could further increase demand for wood-based fibres in the paper sector (see above).

On top of efforts to ban single-use plastics, bioplastics are thought by some to provide an “eco-friendly” alternative to fossil-based plastics [202]. Some bioplastics are also biodegradable (Figure 3.18). While this does not “automatically” make bioplastics sustainable, there may be a role for biodegradable bioplastics in certain applications, such as in agriculture [203]. Currently, however, **the majority of bioplastics are used for packaging (nearly half of the market),** with an increasing level of use in catering products, consumer electronics, automotive, agriculture/horticulture and toys; there is also continuing diversification in this area. **Bioplastics comprise around 1% of the total plastics market.** Growth is expected to continue (Figure 3.18)[105].

Currently, most bioplastics are produced using primary biomass feedstocks (food and feed crops high in carbohydrates). In the forest industry, **future potential is seen in particular for industrial side streams from the pulp and paper sector.** “It is reasonable to assume that, by 2050, competitive cellulose-based plastic substitutes will be available on the market” [10]. While nearly 50% of bioplastics are produced in Asia, companies investing in wood-based bioplastics are mostly located in Europe (e.g. Finland, the UK, Belgium, the Netherlands) and in North America [38]. The focus is on tall oil, a by-product of the pulping process that has been traditionally used an energy source, from which naphtha can be derived. Further development of paper sludge (waste from the paper industry) is also being explored. Another potential feedstock from the wood industry is lignin, which has the advantage of taking longer to biodegrade than bioplastics made from e.g. corn or potato starch, making it more applicable to the agricultural industry [38].

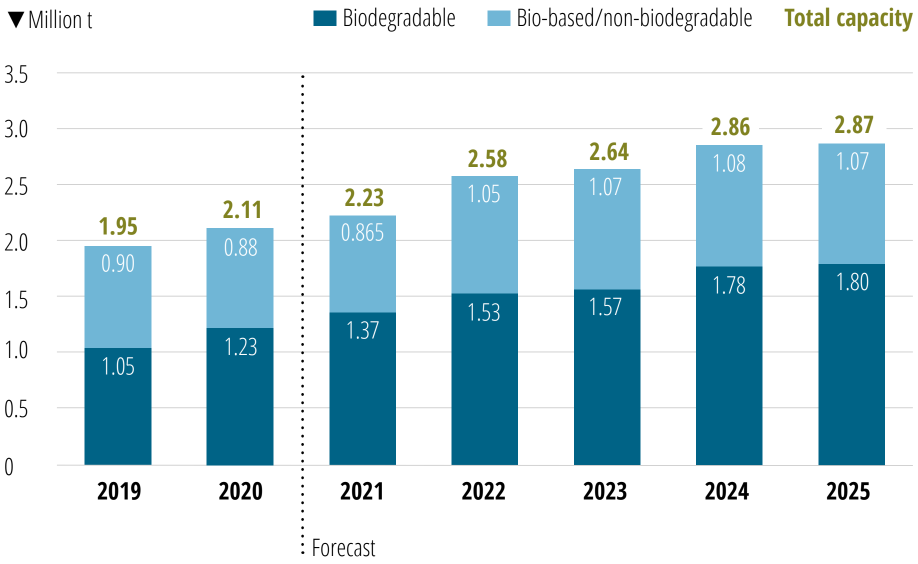


Figure 3.18: Global production and forecast for bioplastics

Source: European Bioplastics and nova-Institute 2020 [18]

Note: More information is available online at www.european-bioplastics.org and www.bio-based.eu

105 https://www.european-bioplastics.org/market/

3.2.5 Textiles

While around 7% of the global textile market was wood-fibre based in 2019, growth has exceeded comparative markets.

The market for man-made cellulosic fibres (MMCF; see Box 15) has expanded rapidly over the last decade. These fibres are mostly made of wood and historically include fabrics like viscose. In addition, new materials – such as lyocell and TencelTM – are responsible for much of the growth seen recently. These materials are better able to compete with cotton-based and synthetic fibres, and in some cases compare favourably in terms of environmental performance. For example, water and land shortages have implications for cotton (which may inhibit growth and lead to locally shrinking production volumes), and oil-based fibres lead to microparticle pollution. This situation takes place in a market situation where there is overall growth in the production and consumption of fabrics for fashion, building and other technical applications. It should also be mentioned that viscose and staple fibre production, for example, are highly chemical- and energy-intensive processes. The substances used in the process could be very hazardous to the environment and health. It can be questioned whether MMCF are natural fibres. They could possibly be a third class in addition to natural fibres and synthetics.

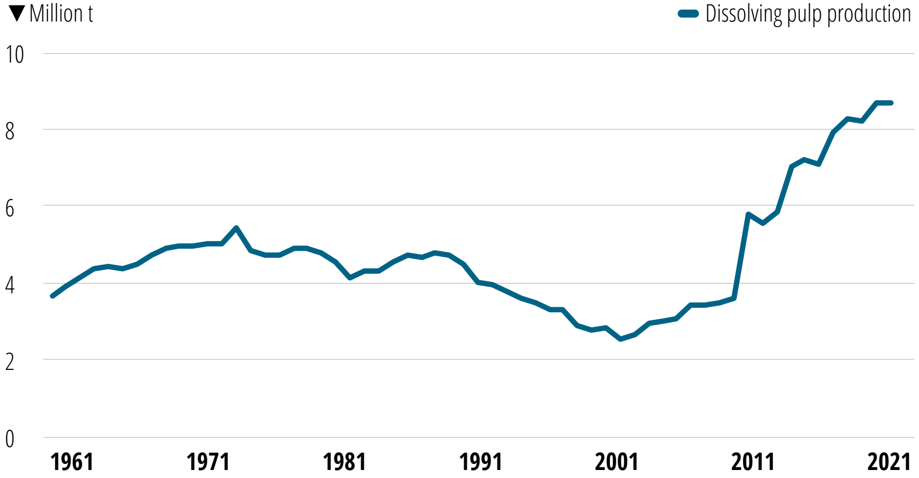


Figure 3.19: Global production of dissolving pulp

Source: Data from FAOSTAT, accessed 18 March 2022

Wood-based cellulose fibres are made from dissolving pulp (see Box 15); around 80% of dissolving pulp production is used for textile fibres. **While around 7% of the global textile market was wood-fibre based in 2019, growth has exceeded comparative markets.** The global production of dissolving pulp increased by around 6.3% annually between 2000 and 2018 (Figure 3.19), whereas annual cotton production growth was around 1.3% and chemical textile fibres growth around 5.1% over the same period [16].

Morland and Schier (2020) aimed to analyse how the expected industrial growth in the lignocellulosic-based products would impact other wood-based products in multiple scenarios. They used the Global Forest Products Model to depict a wide range of potential developments for dissolving pulp: from global consumption in 2050 staying relatively comparable to 2015 levels to increasing by more than 30-fold. The latter would be accompanied by a significant decrease in the consumption of paper (e.g. -40% for printing and writing paper) and woodfuel (e.g. by -30%). The study emphasises that **natural textile fibre markets are highly dependent on GDP and population developments, and that developments in the paper sector seem critical to resource availability** [144].

If current growth trends continue – and the consumption of fresh fibres for paper, packaging, etc., continues with the same consumption rates – it could add to the pressures on global land for fast-growing wood, unless reductions in other sectors "make space" for such "new" products.

Kallio (2021) presents scenarios for wood-based textile fibre markets based on different global GDP elasticities under different shared socio-economic pathways. The study found a slowdown in average annual growth rates (e.g. between 1.5% and 5.2% per year until 2030) compared to the 6.5% annual growth experienced over the last decade. Indeed, much of the recent growth has been due to paper pulp mill conversions. For example, around 20% of the wood-based textile pulp capacity in China in 2014 was based on mill conversions [16], [204]. This complicates forecasting in the market, as the profitability of the textile fibre production from wood is linked to the demand for textiles, the supply and price of cotton and polyester, and paper pulp production and demand. There could be the potential for synergies when production is coupled with solid wood processing, for example in cases where residues could be used. Ultimately, "it seems that factors affecting the textile pulp demand alone are by far more important drivers for its production than competition over wood" [16]. **If current growth trends continue – and the consumption of fresh fibres for paper, packaging, etc., continues with the same consumption rates – it could add to the pressures on global land for fast-growing wood, unless reductions in other sectors "make space" for such "new" products.**

Box 15: Definition of man-made cellulosic fibres and dissolving wood pulp

Man-made cellulosic fibres (MMCF)
are defined by the Textile Exchange as including viscose (rayon), modal, lyocell, acetate, triacetate and cupro. Feedstocks include virgin wood (highest share), reclaimed material including agricultural waste/by-products (e.g. straw) and pre-/post-consumer waste (e.g. citrus peel, cotton) or other feedstocks like flax. The cellulosic matter is processed into a pulp, dissolved and then regenerated into a staple or filament yarn through several chemical processes. MMCF are produced mostly in Asia (over 80%), with most produced in China (over 60%).[*1]

Dissolving wood pulp is defined by FAO as: "chemical pulp (sulphate, soda or sulphite) made from wood of special quality, with a very high alpha-cellulose content (usually 90 % and over). This type of pulp is always bleached and is specially refined or purified to meet requirements of its intended use. It is used for making regenerated cellulose, cellulose ethers and esters and products of these materials, such as plates, sheets, film, foil and strip, textile fibres and certain papers (filter paper, vegetable parchment, ...)". Around 80% is used for textile fibres.[*2]

*1 https://textileexchange.org/round-tables/mmcf-round-table/; accessed March 2022

*2 FAO's classification of forest products 2022, available at: https://www.fao.org/forestry/statistics/80572/en/; accessed 18 March 2022

3.2.6 Chemicals

The use of timber as a source for chemical compounds has a long history. Turpentine, for example, is a non-wood forest product that has been extracted from pine trees and used for multiple purposes in the chemicals sector – and the medical sector – for centuries. With evolving technologies in the context of the bioeconomy, the **range of potential products has become broader** [205]. The urgent need to substitute fossil fuels has led to **high expectations for the use of wood in the chemicals industry.** Research and development projects on the use of timber as a substitute for platform chemicals have multiplied across the EU. For example, the BIOFOREVER research project, which ran from 2016 to 2019, assessed the use of lignocellulosic feedstocks as a source for chemical intermediates and products and demonstrated feasibility in Europe[106]. Ethanol from waste wood was identified as the most economically feasible product in combination with a specific lignosulfonate as a substitute for coal tar pitch in carbon-based binders.

Of special interest is lignin, which represents up to 30% of lignocellulosic biomass and in addition to cellulose and chitin is the most abundant polymer in nature. **Lignin is also a by-product of the paper industry** and annually accumulates to around 50–100 Mt per year [206]. Lignin can be isolated via various chemical processes and then split into separate parts, which can be further modified. For example, it can be used as a colorant for coating or as a flame retardant [207]. A recent study by Liao et al. (2020) performed a techno-economic assessment, finding that about 78% by weight of birch wood could be valorised into four high-value products (phenol, propylene, oligomers and pulp) [208]. Due to its substitution potential, lignin has been referred to as "the new petroleum". However, upscaling to a large-scale commercial product has not yet taken place. Dessbesell et al. (2020) find that the current worldwide production of technical lignin (about 1.65 Mt per year) is **far from reaching its full potential** [209].

Due to its substitution potential, lignin has been referred to as "the new petroleum".

In Germany, the use of wood for the production of synthetic naphtha is considered in its 2050 chemicals roadmap (Roadmap Chemie 2050) [210]. A thought experiment calculation in the roadmap states that a **100% conversion of wood-based naphtha would require about 121 Mt of wood per year, which is more than the annual increment of the entire German forest area.** A realistic assessment of the sustainably available wood is therefore necessary to determine a meaningful application potential in the chemicals industry.

Synthetic kersosene for aviation could also be produced from timber – an additional potential mass consumer.

© freepik/bilanol

106 https://cordis.europa.eu/project/id/720710; accessed in November 2021

3.3 Timber footprints

There is a need for a public discourse on what "we" consider excessive, wasteful and appropriate in the context of sustainable consumption goals.

Environmental footprints are used to express the impacts and burdens of consumption and production activities on our environment. They have become **common monitoring tools.**

No universal definition exists, as each type of footprint addresses different impacts at different scales and for different systems [211]. One type of footprint – relevant for this report – can be used to answer the basic question: how much is used? In other words, how much land, water, carbon, biodiversity, raw material and so on is used in the production of a single product (product scale) or to supply the total consumption of a country (national scale)? **Per capita comparisons are used to depict the disproportionate contribution to resource use, for example across the globe.** Multiple footprints based on per capita calculations (see also [212]) and specific resource challenges have been developed, including ecological footprints [213] material footprints [214], [215], water footprints [216], [217], carbon footprints [218], land footprints [219] and biodiversity footprints [33], [220], [221].

Box 16: What are timber footprints?

The timber footprint is defined as the total volume of roundwood equivalents*1 used for final consumption in a country. It is calculated by adding the total amount of domestically harvested wood and the amount of wood harvested abroad to supply the imports for domestic consumption of products and services, and subtracting from this the amount of timber equivalents used for export [225]. The aim is to capture the amount of timber extracted annually, which is used as a proxy for the consumption of primary wood. Footprints do not reflect secondary flows of recycled material. Methods like the "wood resource balance"*2 [226] are complementary, but not comparable.

Material flow analysis is used to calculate timber footprints. This is a well-established method to assess resource flows through economies. O'Brien et al. (2018) assessed physical flows to calculate a "forest footprint" [5]. Another approach is to develop environmentally extended multi-regional input-output databases, like EXIOBASE [227], GTAP [228], WIOD [229] and Eora [230] (see the Annex). These databases combine economic and physical data to trace resource flows between countries. Such an analysis has the advantage that timber can be traced back to its country of origin at all stages of processing.

The timber footprint data shown in the following sections is based on an adapted version of the latest EXIOBASE database (EXIOBASE 3.8.1). The data used is updated based on earlier work done by Bringezu et al. [20]. Monetary flows of different timber product groups are tracked and then converted to harvested roundwood equivalents. The Annex contains a more detailed description of methods.

*1 Timber in all processing stages.
*2 The wood resource balance looks at flows within specific economies and can thus be used to assess rates of reuse, for example.

WHY FOOTPRINTS ARE USEFUL MONITORING TOOLS

Clearing a small patch of land is probably not a global threat in and of itself. It is this action, in the context of others just like it, that accumulate to pressures on the global scale. That means that approaches to monitor scale are needed. Consider as another simple thought experiment a children's birthday party as it is now sometimes celebrated. At this party, the table is set with disposable paper plates, cups, tablecloths, napkins and silverware; paper streamers and banners hang from the ceilings; plastic decorations and gift bags are set out on display. One such party is not overburdening the planet. There are around 2 billion children under 14 in the world. On that scale, does this party style become a problem? What if the plates are partly made of recyclable material and the plastic is biodegradable and made from renewable sources, like timber? Is it excessive? Is it wasteful? Or is it a norm we strive for as a society? There is a need for a public discourse on what "we" consider excessive, wasteful and appropriate in the context of sustainable consumption goals and grand challenges related to land, land use change and the health of our planet. From the perspective of a citizen 100 years in the future looking back: did it make sense to extract resources and manufacture them into products that are used once and then thrown away? This is not an easy discussion, nor should it be a shaming or blaming endeavour centred on guilt. Rather, what are the lifestyle implications of responsible and sustainable consumption goals that we can live with and what are the norms that society may develop for eliminating excess? Some behaviours have become unthinkable in countries like Germany (e.g. smoking in indoor public spaces, littering), as recognition of negative impacts became widespread.

Footprints of consumption can help to navigate and frame a discussion on overconsumption. They are the first step to identifying (a) if there is a problem and, if so (b) how much of a problem. For example, at a product level, footprints have gained widespread use to compare products with one another to identify potential hot spots (e.g. particularly resource-intensive products). As a consequence, producers are able to adjust practices, retailers may shift sourcing, and customers may change their purchasing behaviors. At a national level, knowledge on how much of a resource is consumed may be used in the same way. It would allow policy makers to identify "overconsumption" and adjust policy frameworks and incentives accordingly. When aggregated at higher levels of analysis (e.g. a country level), such footprints

Footprints help capture the impacts of consumption abroad.

may be integrated into existing monitoring frameworks and national accounting structures. Resulting policy interventions to incentivise sustainable use may take the form of tax adjustments, increased R&D funding, adjustments to subsidy structures, etc. The aim is not to propose prescriptive allocations for specific markets (we are not suggesting limiting the amount of birthday celebration decorations). **Instead, it is about incentives for use, reflections of true costs in the price of goods and services and simple principles for encouraging a resource-efficient and circular bioeconomy, including in the daily practices and social norms that people engage in.**

At all levels, a footprint indicator is useful for the following purposes.

» **Communicate** pressures in one aggregated metric ("headline indicator")

» **Relate footprints** of different countries, products, etc. to each other; for example, national consumption levels can be compared to global averages

» **Compare potential trade-offs** between one or more environmental pressures; for example, an investor may be able to better assess climate benefits versus land risks for developing their portfolio if multiple footprints are compared

» **Promote an understanding of the scale** of impacts connected to consumption in an easy-to-understand way

» **Overcome silo thinking:** focusing narrowly just on specific sectors instead of total economies when evaluating supply potentials or environmental impacts provides a distorted expectation of future capacities; national-level footprints offer a more holistic assessment of supply capacities within ecological constraints to put those sectoral prognoses into context

Key footprints have been calculated for the German bioeconomy in a pilot project (water, climate, agricultural land/biomass, forestry biomass, value added and employment)[107]. Researchers found that the German bioeconomy "has contributed substantially to land transformation in other regions and that it might continue to add to the scarcity of water in arid areas" [20]. The project confirmed the importance of such monitoring approaches for **capturing the impacts of consumption abroad.** Scaling up footprint monitoring from pilot projects to national statistical offices should be the next step.

Footprints are also very useful to investors, as they allow them to evaluate trade-offs from a systems perspective. In other words, a basket of footprints helps the investor to weigh the impacts of a certain decision with regard to the carbon footprint versus the material footprint, for example. There has been significant interest from the financial community in further developing biodiversity footprints [222]–[224]. This is particularly relevant for investors considering land-related investment decisions.

The calamities of recent years have led to unprecedented damage to German forests. A forwarder is loading timber, Lower Saxony, Germany.

107 For more information and data, see the SYMOBIO project website: https://symobio.de

German Timber Footprint of Consumption: 104 Mm^3 in 2021

The timber footprint shows that Germany's total consumption of wood and wood-based products is already higher than that which could be supplied by German forests.

RESULTS FOR GERMANY

Figure 3.20 depicts the German timber footprint. The period between 1995 and 2020 is based on historical data from FAOSTAT, whereas the period from 2020 to 2030 is a modelled projection based on business-as-usual historical trends (see also [269]). The projected data show an increase in exports over the next 10 years. The consumption of timber is projected to stay at a relatively constant level until 2030, whereas the total throughput of timber in the German economy is expected to increase. However, these trends are based on the economic GINFORS model[108] using historical trends. They do not reflect increases in consumption as a result of bioeconomy policies encouraging the use of wood (e.g. in construction). Thus, the future projections should be interpreted carefully, as bioeconomy policies and markets – depending on how they are implemented – could further increase consumption levels. This level of consumption is already higher than the global average in per capita terms. **Figure 3.21 shows that German per capita timber consumption is more than double the global average.**

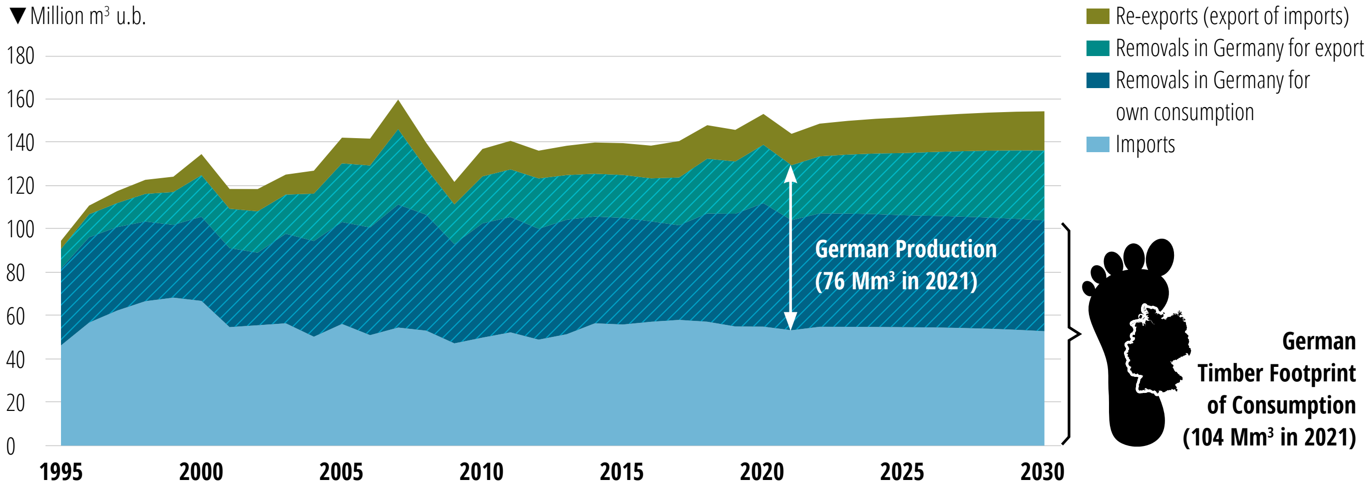


Figure 3.20:
Trends in German timber footprint, production and trade 1995–2030

Source: Updated data based on earlier work from [20][109], using the GINFORS model and based on an adapted version of EXIOBASE 3.8.1[110]

Note: Units are in Mm³ roundwood equivalents under bark. Future projections are based on historical trends and thus do not reflect potential increases resulting from bioeconomy policies incentivising the use of wood. Ongoing research is addressing such questions. See the Annex for a more detailed description of methods.

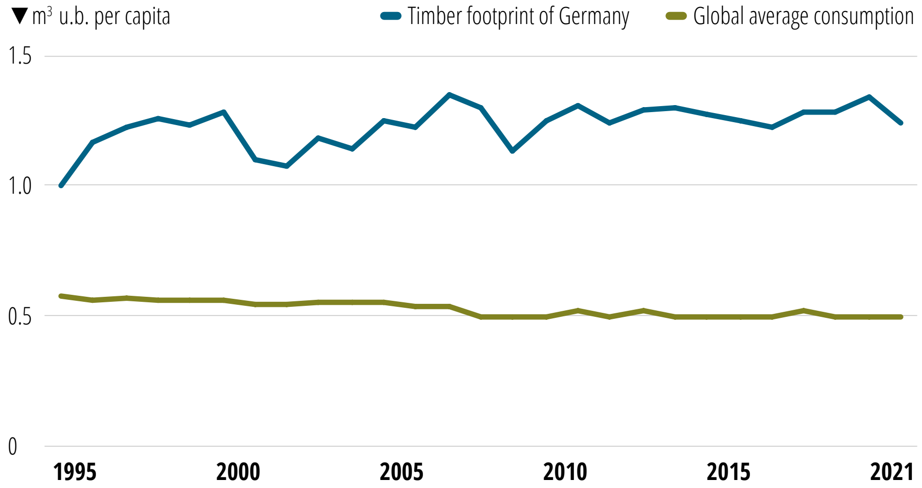


Figure 3.21:
German per capita timber footprint compared to global average consumption, 1995–2021

Source: Based on Bringezu et al. [20]; population data from Destatis[111] and global roundwood consumption based on FAOSTAT (see also Section 3.1)

Note: Units are in roundwood equivalents under bark.

108 The Global INterindustry FORecasting System (GINFORS) is an economy-energy-environment model with global coverage and a detailed sectoral disaggregation. It was developed by the Institute of Economic Structures Research (GWS) and is well suited to assessing the impacts of environmental policy. See also [316].

109 These results were first presented in a pilot report on the monitoring of the German bioeconomy generated in the SYMOBIO joint research project (www.symobio.de). The results have been updated to reflect current data by the authors. The English version of the pilot report is available at: https://kobra.uni-kassel.de/handle/123456789/13534?locale-attribute=en

110 EXIOBASE version refers to doi:10.5281/zenodo.4588235.

111 Federal Statistical Office of Germany: www.destatis.de. The population scenario refers to BEV-VARIANTE-02.

The timber footprint shows that Germany's total consumption of wood and wood-based products is already higher than that which could be supplied by German forests. Moreover, harvest rates, including bark and harvest losses, are expected to comprise around 85% of the net annual increment over the next decade. This exceeds the risk corridor for harvest rates (of 50 to 80%) that we defined at the global scale in Chapter 4.

Sustainability and self-sufficiency

In Germany, comprehensive national forest inventories were conducted in 1986, 2002 and 2012 [21], [232]. The fourth started in 2021 and data collection will be finished by the end of 2022. These inventories assess forest area, wood supply, wood increment and harvests, main tree species composition, age structure, deadwood, biomass and carbon storage. Based on the results of the third inventory, Oehmichen et al. (2018) derived one baseline scenario and two alternative scenarios for German timber supply capacities until 2052; these are known as the WEHAM scenarios [233]. They included a nature preference scenario and a timber preference scenario. Referring to the baseline scenario, a mean annual harvest potential of 78 Mm³ u.b. (around 98.7 Mm³ o.b.[112]) from 2013 to 2052 was calculated. This represents about 82% of the total annual increment of 121.6 Mm³. The nature preference scenario also shows a mean potential of 78 Mm³ (82% of increment), but with a different composition of tree age (more older trees) and a larger share of deciduous forest (with a focus on beech). A strict prioritisation of timber production, as seen in the WEHAM wood preference scenario, would require 134% of the annual increment and would significantly reduce German forest stock, age and quality for ecosystem services. This is not considered a viable option for long-term forest management.

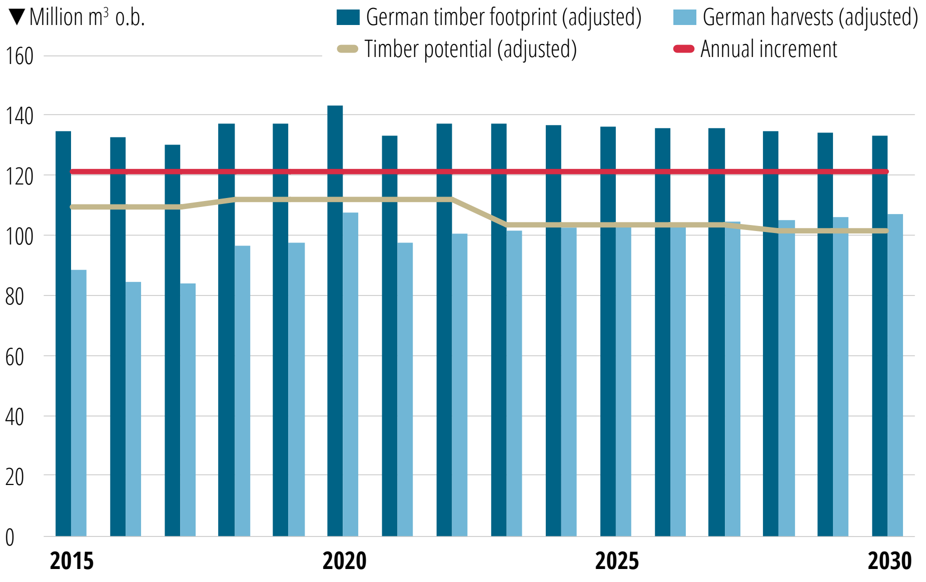


Figure 3.22: German timber footprint compared to timber supply capacity in Germany, 2015–2030

Source: German footprints and harvest levels are modelled with GINFORS based on EXIOBASE 3.8.1 and assume a continuation of historical trends (updated data based on Bringezu et al. [20]). The timber potential is from the WEHAM nature preference scenario [233], the annual increment is based on the third national forest inventory [21].

Note: Adjusted means that roundwood equivalents have been adjusted to include bark (+12%) and harvest losses (+10%) to make forest growth and timber consumption volumes comparable (see also the Annex). Adjusted units are roundwood equivalents over bark.

Taking these caveats into account, **the WEHAM nature preference scenario and the annual increment** calculated in the third national forest inventory can be used as **comparative indicators for German consumption levels.** Figure 3.22 compares trends in current and projected footprint and harvest levels (continuation of historical trends; see Figure 3.20) to the annual increment and the nature preference scenario. It shows the following two perspectives.

» **Production perspective:** The level of timber harvests in Germany is below the estimated annual increment. However, harvests are estimated to comprise on average 85% of net growth in the coming decade. **This exceeds the risk corridor for harvest rates that we defined in Chapter 4 (50–80%).** Moreover, if past trends continue, the modelled harvest rates would exceed the calculated roundwood potential of the WEHAM nature preference scenario in the late 2020s.

» **Consumption perspective:** The level of wood consumption is already above the level of annual increment. The level of consumption may grow as a result of bioeconomy policies and further increase this gap. **Figure 3.22 shows that already German consumption levels cannot be met by the current German forest area alone.** Germany is import-dependent to meet its consumption needs. It has a number of options: overharvest forests (not an option if it is trying to achieve sustainable development), expand forest area (noting that Germany is also highly import-dependent on agricultural land [35]) or reduce consumption.

112 The WEHAM roundwood potential is specified in m³ under bark; to be comparable with the forest increment, 12% bark and 10% harvest loss are added according to the method described in Box 20. Trees outside forests do not play an important role in Germany, so this adjustment is not made here.

In addition, **increasing tree mortality is likely to lead to a decrease in wood increment and thus also to sustainable wood potential in Germany, resulting in even lower supply capacities** (see Sections 2.4 and 4.3.4). The German timber sector is strongly based on the use of coniferous wood (approx. 73% in 2017), which is mainly used for material purposes. The remaining 27% consists of hardwood, which is mainly used (70%) as energy wood [234]. The focus on coniferous wood aggravates the dependence on imports. Securing the supply of roundwood from Germany's own forests requires a timber industry transformation that accounts for tree growth patterns and time spans. **Climate change is further increasing pressure** for such a transformation. For example, spruce has been a key industrial species in Germany, but as a shallow-rooted tree species it is particularly affected by extreme weather phenomena such as storms and drought.

Forest statistics – pressures may be higher than official sources indicate

The analysis of a country's timber supply in terms of self-sufficiency and sustainable timber harvesting is only as good as the statistics on which it is based. A comparison between the official production volume published by the German Federal Statistical Office and the "ex-post production analysis" conducted by the Thünen Institute[113] shows that this is also a problem in Germany (Figure 3.23). While the trend is the same, there is a large discrepancy between the results, indicating a continuous underestimation of the official figures. The main reason for this is that wood production in private forest areas is not officially recorded, but estimated and presumably used as woodfuel. Since small-scale private forest areas account for about 25% of the total forest area in Germany, the effect is large. Further in-depth data about German wood flows, use and final demand categories are reported by Mantau et al. [170]. Overall, this implies that pressure on the forest could be higher than official sources indicate.

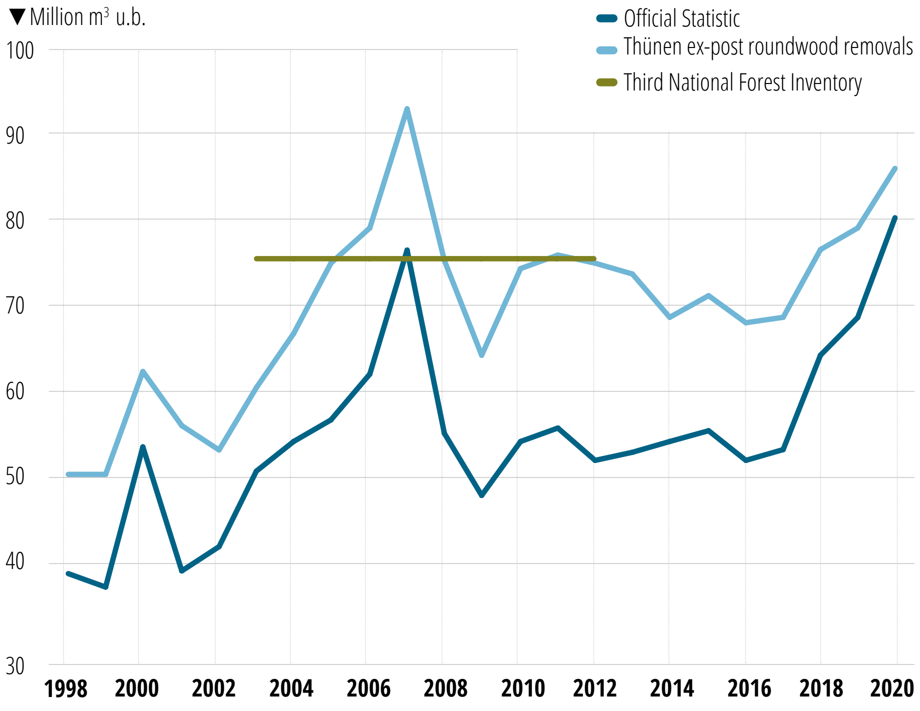


Figure 3.23: Comparison of roundwood production statistics in Germany, 2001–2020

Source: Adapted from Jochem et al. (2021) [235]

Note: The first of the two visible peaks is due to calamities caused by storm Kyrill and the second is due to a mix of drought calamities and increasing demand for roundwood abroad (especially in the USA and China).

We need to shift the focus from how to increase supply to how do systems of supply and demand interact and how can these systems be made more sustainable?

Ultimately, Chapters 2 and 3 have shown that there are a lot of complex issues on the supply side. It also matters what the wood is used for. We need to shift the focus from how to increase supply to how do systems of supply and demand interact and how can these systems be made more sustainable?

113 https://www.thuenen.de/en/wf/projects/recalculation-of-fellings/

4 Towards sustainable forest and timber use

For your Orientation

CHAPTER OVERVIEW

Balance between demand and sustainable supply capacity is the prerequisite for “do not harm” consumption. Chapter 4 is at the heart of this report. It aims to connect the trends seen in the global forest, as described in Chapter 2, to the trends seen in wood consumption, as described in Chapter 3. We ask: are consumption levels aligned with goals for sustainable forest management? To that end, this chapter is centred around three questions.

1. **How much wood can be sustainably harvested? We assess:**
   » What sustainable forest management means, in practice and across multiple scales and perspectives

   » How quotas for “allowable” timber extraction are determined in different countries, regions and contexts, and their applicability at a global scale;

   » Why and how the planetary boundary concept provides an appropriate context for benchmarks, and why operational benchmarks on multiple scales are useful for motivating change.

   We then develop an approach for determining a wood consumption benchmark by estimating the forest area available for wood supply, the productivity of that area and the amount that can be removed (risk corridor) to maintain multiple ecosystem services over the long term.

2. **How does current and future consumption compare to the benchmark for sustainable supply?**
   We look at consumption in 2020 and a trend extrapolation until 2050. In the case of future supply, we also consider the impact that deforestation, restoration, productive forest expansion, plantation expansion and climate change could have on supply capacities.

3. **What are the considerations related to equity and the implications for targets?**
   The role of targets, the issue of fair shares in light of unequal forest area distribution and the potential orientation a future timber target could take are discussed.

KEY MESSAGES

1 Sustainable forest management is about finding a balance between environmental, social and economic aims. It goes well beyond optimising tree growth calculations for timber supply. The forest has value in and of itself. Ecosystem services are also natural assets.

2 Nearly half of the global forest area is found to be available for wood supply (with wide regional variation). Harvesting at levels equivalent to 50% (low-risk boundary for sustainability) to 80% (high-risk boundary) of growth results in a current global supply capacity of between 3.0 and 4.2 Gm^3.

3 Global consumption already overshot the harvest potential in the risk corridor by 3% (high-risk boundary) to 67% (low-risk boundary) in 2020. It is likely that this overconsumption will continue and grow in the future.

4 What-if future considerations showed that there is limited potential to significantly expand global supply capacities, and these are far from sufficient to meet growing global demands.

5 Targets support policy orientation and awareness raising. The challenge for forestry is how and whether to take regional variability into account when considering per capita targets for consumption levels based on concepts of “fair shares”. A gradient of orientation levels (national to regional to global) is discussed with the aim of starting a broader discussion on the need for a benchmark on wood consumption based on sustainability. For example, under business-as-usual trends German consumption could exceed global per capita supply capacities by around 230% to 350% in 2030.

6 There is a connection between how people consume wood products and what happens in the forest. High-level goals for sustainable consumption or substitution must be translated into actual change in consumption practices.

4.1 Concepts of sustainable forest management

Sustainable forest management is defined by the United Nations as a "**dynamic and evolving concept [that] aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations**"[114] [236].

There are massive mobilisation efforts across the world addressing what sustainable forest management means in practice at the stand, landscape, national and international levels. The definition recognises that the concept has been and continues to be strengthened by experiences and research from all over the world. These activities are widespread, with multiple organisations[115] and programmes[116] working towards developing criteria and indicators[117] [236].

At a national and international level, the essential elements of sustainable forest management could be characterised as monitoring and managing for multi-functionality, protection, forest biodiversity and ecosystem services maintenance in a balanced way. The Global Forest Goals Report [80] provides an initial overview of progress towards achieving the six Global Forest Goals[118] and their 26 associated targets as contained within the United Nations Strategic Plan for Forests 2030.

"The market for wood can motivate good forest stewardship that safeguards a critical resource and protects forest values; or it can destroy the very places where wood grows."
WWF 2012

What does sustainable forest management mean in general for forestry operations that are focused on timber extraction?

At the level of forest stand management, operation processes can be classified according to their intensity: at one end, "passive, nature-driven" forestry and "low, close-to-nature" forestry and at the other end "intensive, short-rotation" forestry [237]. Here, similar to the macro level, managing for multi-functionality is recognised as a core element of sustainable management. In other words, an **exploitative model of forestry is being replaced by regenerative forest management practices which aim to minimise trade-offs between forest timber production, climate change mitigation and biodiversity conservation.** The type of sustainable silviculture practices envisioned require integrating biodiversity conservation across all forests.

The key issue is that **sustainable management goes beyond aims directed only at optimising timber supply.** To this end, Garibaldi et al. (2020), propose a **minimum habitat restoration target** for working landscapes (e.g. farming, ranching and forestry) of at least 20% of the area (depending on local conditions). Such restoration can "enhance the effectiveness of protected areas by offering corridors and stepping stones interconnecting wild populations across landscapes that might otherwise form barriers or sinks" [238].

Integrated forest management may also have another effect: "a commercial interest in maintaining wood supply can help protect vulnerable forests from illegal logging, encroachment or conversion to farmland" [145]. While pursing low-intensity harvesting may reduce short-term revenues by decreasing roundwood removals per harvesting cycle, it **increases forest resilience.** This is because low-intensity harvesting decreases the vulnerability of tree species to disease, drought, wind and fire and improves long-term productivity by sustaining ecological, carbon, nutrient and water cycles. However, as WWF (2012) points out, this is a double-edged strategy as "more commercial species may make illegal logging more alluring" [145].

For forest managers, **various guides for practitioners have been developed.** For example, WWF has produced guides for Russia [239], the Democratic Republic of the Congo[119] and Germany [240]. These are geared towards enhancing the sustainable management of those distinct forest types in their socio-economic contexts. According to the European Environment Agency (EEA) (2016), "understanding trade-offs and developing optimised management strategies are critical issues for forest management" [241]. For example, research increased rapidly in the EU on the **trade-offs between the removal of logging residues** (e.g. tops, branches, stumps for energy) **and forest impacts** (e.g. on biodiversity, soil, erosion, climate) in light of the EU bioenergy targets. A meta-analysis by Camia et al. (2021) highlights multiple facets to consider, including high risks associated with stump removal as well as the safeguards built into some management and certification regimes for staying below estimated ecological thresholds [95].

114 For more information on the definition and context, see: https://www.fao.org/forestry/sfm/85084/en/; accessed October 2021.
115 For example, the African Timber Organisation and the International Tropical Timber Organisation (ITTO).
116 International programmes, notably REDD+; Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); and the EU's Forest Law Enforcement, Governance and Trade (FLEGT) programme and its Voluntary Partnership Agreements (VPAs), helped support a shift towards sustainable forest management.
117 For example, the Montreal Process on Criteria and Indicators for the Conservation and Management of Temperate and Boreal Forests, the Pan-European Forest Process on Criteria and Indicators for Sustainable Forest Management (the Helsinki Process or Forest Europe).
118 1) Reverse forest cover loss; 2) Improve forest benefits and livelihoods; 3) Protect forests and use sustainable forest products; 4) Mobilise resources; 5) Promote inclusive forest governance; 6) Cooperate and work across sectors; see also the UN Forum on Forests at: https://www.un.org/esa/forests/index.html
119 https://www.wwf-congobasin.org/what_we_do/forests_and_forest_carbon/sustainable_forest_management/

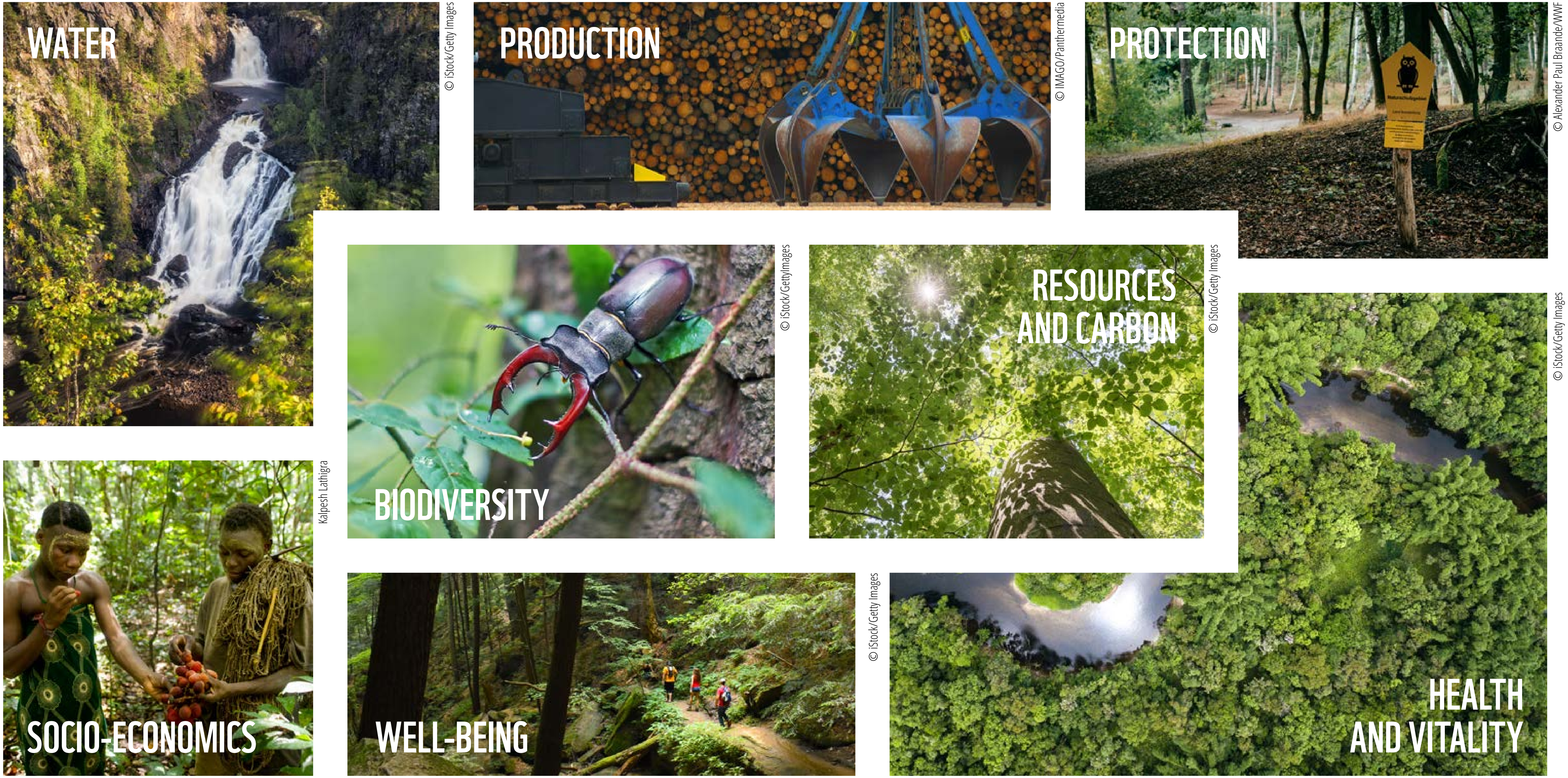


Figure 4.1: Essential elements of sustainable forest management

Source: Guidelines for the Development of a Criteria and Indicator Set for Sustainable Forest Management, Geneva Timber and Forest Discussion Paper 7; modified by WWF

RECOGNISING THE INTRINSIC VALUE OF FORESTS

The use of forests for supplying timber – and other non-wood forest products – is an undeniable part of human existence. However, how and how much forest is used for this purpose speaks to the heart of our sustainability challenges. **In addition to social values, the value of nature itself must be recognised in the struggle to find balance.** New Zealand, for example, has granted a forest (Te Urewera) the same legal rights as a citizen. The Act states that "Te Urewera has an **identity in and of itself,** inspiring people to commit to its care. […] The purpose of this Act is to establish and preserve in perpetuity a legal identity and protected status for Te Urewera for its **intrinsic worth,** its distinctive natural and cultural values, the integrity of those values, and for its national importance" [242]. This Act changes the prevailing perspective of human sovereignty over the environment to reflect the Māori relationship with the land. In an interview, Ruru (2016)[120] stated: "From the Māori perspective ... our landscape is personified, we see the earth, our lands as our earth mother Papatuanuku", To represent the legal interests of the forest and river in the sacred Te Urewera area, a board composed of Māori has been established.

"This new act that moves Te Urewera land from the national park regime puts it into its own place because it owns itself. Māori don't own, the New Zealand government doesn't own this land. It is its own person, it cannot be owned." Ruru (2016)

Te Urewera has legal recognition in its own right, with the responsibilities for its care and conservation set out in the law of New Zealand.
(Te Urewera Act 2014, Public Act 2014 No 51)

120 Professor J. Ruru quoted in Calderwood, K.: "Why New Zealand is granting a river the same rights as a citizen", available at: https://www.abc.net.au/radionational/programs/sundayextra/new-zealand-granting-rivers-and-forests-same-rights-as-citizens/7816456; accessed 2 December 2021.

Stone (1972)[121] argued, convincingly, for establishing legal rights for natural objects. He postulated that this would be an extension of the granting of rights in the legal framework seen across history: “Corporations cannot speak either; nor can states, estates, infants, incompetents, municipalities or universities. Lawyers speak for them.” He argued that the legal system in the USA granted payments for environmental harm, but only when these impacted human-made conceptualisations of value (the fisher who lost income due to pollution) and that there is **“a good case to be made for taking into account harm to the environment in its own right”.** As the number of – seemingly minor – pressures accumulate across the world to result in thoughtlessly degraded forests, this argument may be worth reconsidering.

In Germany, legislation was passed in 2002 that requires protection of the living environment. Article 20a of Germany’s Basic Law states: “Mindful also of its responsibility towards future generations, the state shall protect the natural foundations of life and animals by legislation and, in accordance with law and justice, by executive and judicial action, all within the framework of the constitutional order.”[122] As early as 1990, the German Federal Constitutional Court[123] passed judgement that state forests should be managed to serve the environmental and recreational functions of the forest – in particular ensuring ecosystem services – and not the sale and utilisation of forest-based products.

Altogether, sustainable forest management might come down to how forest managers, policy makers and consumers see their role and impacts on forests: as separate entities or as part of the natural system; **as entrepreneurs or as guardians and stewards; or as a mixture of all of these roles.**

Box 17: Forest Certification

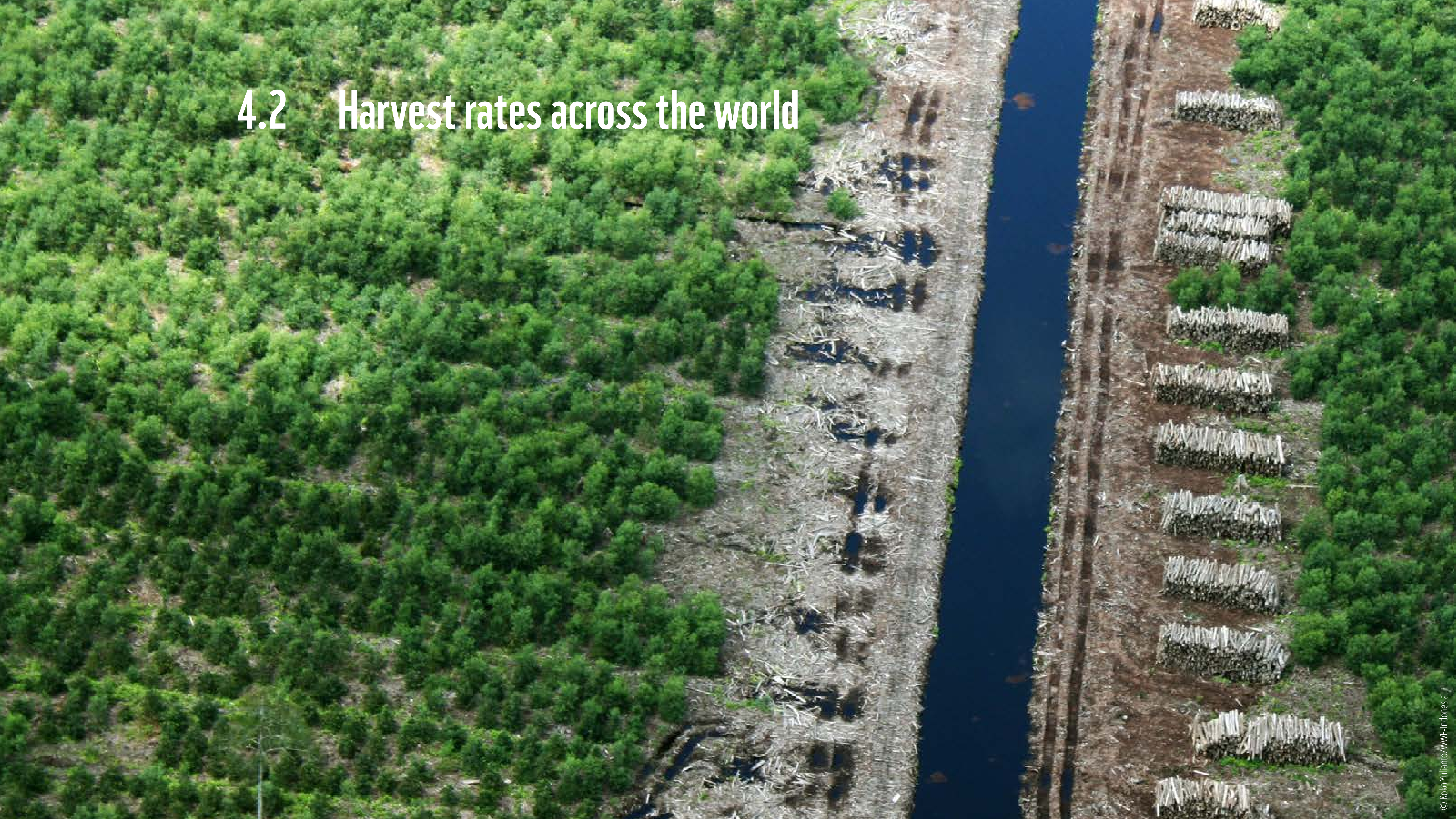
According to FAO, forest certification covered 426 Mha of forest (around 11% of the total forest area) in 2019 [4]. Canada (167 Mha), Russia (54.1 Mha) and the USA (38.1 Mha) account for more than 60% of the world’s certified forest area [4]. Together, South America and Africa held around 10% of the globally certified forest area in 2014 [243]. Around the turn of the century, certification expanded rapidly, indicative of efforts to increase transparency and accountability for consumers. There are now a large number of different certification systems with varying degrees of quality with regard to system requirements, including audits, transparency and large differences in forest management requirements. WWF recommends only the Forest Stewardship Council® (FSC). **The effectiveness and quality of certification have also come under scrutiny in some cases**[*1] [244], [245]. While certification can provide a useful label for end consumers and there are good examples of implementation, there are also loopholes – depending on the system – that currently make certification rather weak and ineffective in practice.

*1 See also the WWF Forest Certification Assessment Tool, which has been developed to test the strength of certification systems and their standards, available at: https://wwf.panda.org/?246871/WWF-Forest-Certification-Assessment-Tool-CAT

© FSC Germany

121 “Should trees have legal standing? –Toward legal rights for natural objects” in the Southern California Law Review 45 (1972): 450-501.
122 Basic Law for the Federal Republic of Germany, available in English at: https://www.gesetze-im-internet.de/englisch_gg/englisch_gg.html#p0116
123 Judgement of 31 May 1990, NVwZ 1991, 53.

4.2 Harvest rates across the world



The demands on sustainable forest management differ widely across the world. Countries are increasingly taking wider sustainability considerations into account when determining their harvest limits.

This section presents short examples of how quotas for "allowable" timber extraction are determined in different countries, contexts and scales. **These examples do not always imply strong ecological and social sustainability per se; their purpose is exploratory. The aim is to explore what kind of tools are used in different contexts** (e.g. geographical scope, forest type). This is not meant to be comprehensive, but instead illustrative of the multitude of approaches in place. Ultimately, we are interested in tools that could potentially be operationalised at a global level to determine how a planetary boundary for global forest productive capacity – in balance with ecological systems – could be defined as a benchmark for sustainable consumption levels.

Logging of selected oak trees which could be used for high-quality products with a long life

© IMAGO

European Union

According to the European Environment Agency (EEA): "The **balance** between increment and fellings highlights the sustainability of timber production over time as well as the current availability and the potential for future availability of timber. For long-term sustainability, the **annual fellings must not exceed the net annual increment, agreed to be less than 70% over the long term.**"[124] The ratio of forest felling to increment is relatively stable and remains under 80% for most countries across Europe. This utilisation rate has allowed the forest stock to increase. However, **a felling-to-annual-increment ratio of approximately 70% is recommended to ensure the sustainable management of forests.** This should ensure, at least partially, the maintenance of all ecosystem services and allow the forest to fulfil its full life cycle, which includes deadwood and decay phases. According to the most recent data available, about one-third of the countries in the EEA region[125], including Austria, Switzerland and Sweden, do not fall within the recommended 70% mark.

United States of America

In the USA, states apply different approaches to determine their harvest thresholds. For example, the Minnesota Department of Natural Resources [246] analysed a range of **scenarios to show trade-offs** between forest resources at different harvest levels and determined their 10-year sustainable harvest level based on these scenarios and **discussions with stakeholders and the public.** They determined a "theoretical biological potential" taking just legislative restrictions into account (approx. 4.08 Mm^3 annually). However, this "potential likely exceeds what is actually available and certainly exceeds what is commercially viable". On the other hand, considering biodiversity, water quality and old forest habitat more inclusively led to an annual sustainable harvest level of approx. 2.17 Mm^3. The department **selected a value in between these extremes** as its 10-year sustainable timber harvest level (3.15 Mm^3), i.e. **its theoretical biological potential is 30% higher and its prioritisation of non-timber values is 36% lower than its end result.** The study also found that forest inventory data collection must be improved – even at this more "local" level of management – to enable more accurate scenarios [246].

124 From the website of the EEA on "Indicator Assessment" for Forest: growing stock, increment and fellings: https://www.eea.europa.eu/data-and-maps/indicators/forest-growing-stock-increment-and-fellings-3/assessment; accessed 2 November 2021.
125 Comprises 32 countries within Europe. For a list, see: https://www.eea.europa.eu/countries-and-regions

Australia

In Australia, “the sustainable annual yield of **high-quality sawlogs from multiple-use public native forests** is the **yield that can be removed each year while ensuring maintenance of the functioning of the native forest system as a whole and the supply of wood products in perpetuity.**” This level **declined by 53% between 1992 and 2016** (see Figure 4.2; note that it only refers to a subset of Australia’s forests). It is expected to continue to decline until the period 2030–2034, at which time it may increase slightly, if risks from wildfire, disease and climate change are successfully managed. The reasons for these declines include the “transfer of multiple-use public native forests into nature conservation reserves, increased restrictions on harvesting, revised estimates of growth and yield, and (especially in Victoria) impacts of occasional, intense broad-scale bushfires” [247]. The Forestry Corporation states that “it takes 30 to 40 years to grow a tree that will produce high quality timber and we harvest about 1% of the areas we manage each year to maintain forest health, habitat and a sustainable supply of timber … certain trees are selectively harvested for timber while others are set aside for habitat, seed generation and future timber production and then the harvest area is regenerated.”[126]

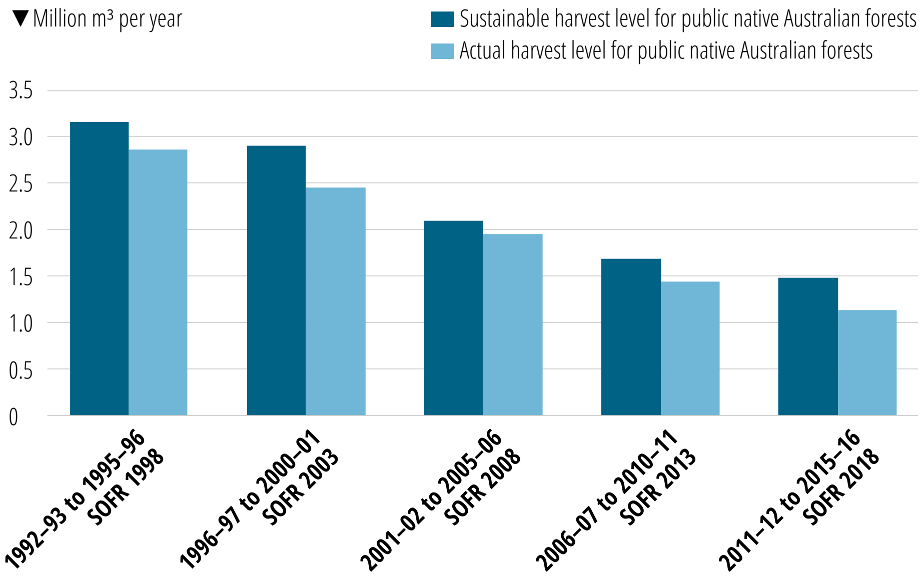


Figure 4.2: Comparison of the actual and the sustainable harvest level defined from an Australian perspective for sawlogs from multiple-use public native forests in Australia

Source: Australia’s State of the Forests Report 2018 [247]

Note: SOFR refers to State of the Forests Report. Data includes harvests from private and leasehold native forests where timber rights are owned by the Crown.

126 See https://www.forestrycorporation.com.au/sustainability/timber-volumes-and-modelling; accessed 14 November 2021.

Canada

A trend of declining sustainable yield levels is seen in Canada (Figure 4.3). In Canada, sustainable wood supply is “the volume of timber that can be harvested annually … while meeting environmental, economic and social objectives” [248]. Inventories of the composition of tree species in forests, their age, and their structure are used to determine this volume. For example, in 2018, forests contained an estimated 45 Gm³ of wood and the estimated sustainable wood supply level was 217.9 Mm³. In other words, **the sustainable supply level was just under 0.5% of Canada’s total standing stock.** Figure 4.3 shows that, historically, harvest rates have been below the sustainable supply potential, but that the difference between them narrowed in 2018 (e.g. around 72% of sustainable supply potential was harvested). **Sustainable wood supply is expected to decline over the next several years “in response to the impact of the mountain pine beetle and severe wildfires, further narrowing the gap between harvest and wood supply”** [248].

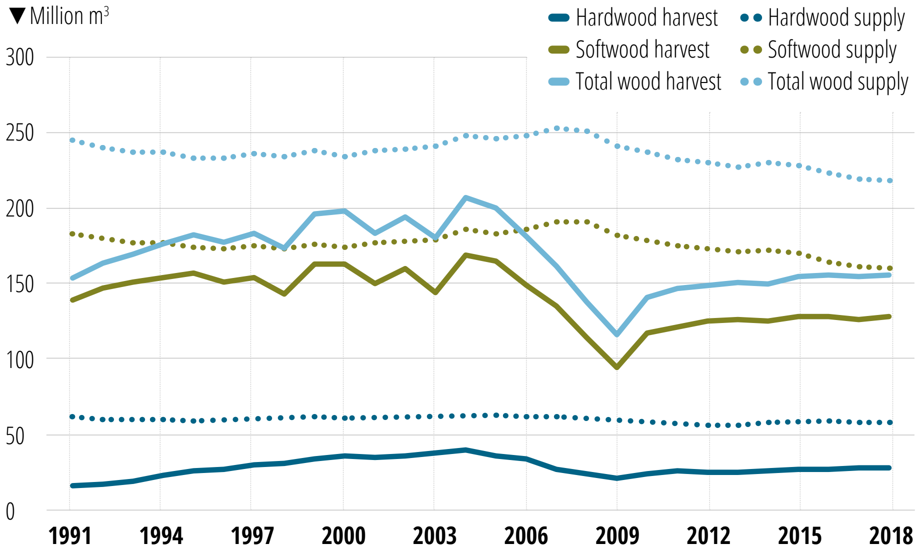


Figure 4.3: Annual harvest versus supply deemed sustainanable for harvest in Canada, 1991–2018

Source: National Forestry Canada [248]

Russia

The annual allowable cut (AAC) is the official norm for sustainable wood harvesting in Russia and is defined by Russian law. **It amounted to the equivalent of 0.85% of the total growing stock volume indicated in the State Forest Registry in 2016.** The AAC has varied from about 690 to 750 Mm³/year over the last 15 years. However, because it does not consider the economic accessibility of forests, **"many scientists argue that the official AAC overestimates the real sustainable harvest level by about two-fold"** [127]. Russia has a vast amount of forest, including huge areas of primeval forest. The challenge is adapting clear-cut practices to embrace sustainability principles. Leskinen et al. (2020) pointed to **a trend towards delayed or failed forest regeneration after harvests** [127]. On a hopefully more positive note, the 2015 "Concept of intensive use and restoration of forests in the Russian Federation" was implemented in pilot regions. It aims to preserve the biological functions of forests via reforestation, tending of young stands and thinning. Another critical challenge for Russia is combating illegal logging, which some estimate to comprise a level equivalent to 20–30% of official harvests, while official estimates place this figure at around 1% [127].

Siberia's forest areas are continuously degrading due to high harvest levels.

© IMAGO/Panthermedia

China

China's forest sector is in a **stage of transition,** characterised by major afforestation in the first decades of the 21st century [249], a 2015 logging ban in natural forests [250], and increasing recognition of the need for multifunctional forest management to further develop healthy, stable and resilient forest ecosystems [251]. The 9th National Forest Inventory in China indicates that nearly 80 Mha of plantations have been established. These are mostly monocultures dominated by Chinese fir, populus and eucalyptus (the area of young forest covers around 23 Mha) [252]. This has shifted the dynamics of timber production, reducing the share of wood coming from natural forests from an estimated average of 81% in the period 1994–1998 to around 2% in 2016, with mixed ecological and social impacts [96], [249], [250]. With regard to sustainable harvest levels, the National Report on Sustainable Forest Management indicates the general principle of **keeping harvest volumes below net growth** [253]. For example, the proportion of logging volume to net increment was around 68% in "timber forests" in the 7th National Forest Inventory (2004–2008). A World Bank report published in 2019 reviewed models of promising sustainable forest management practices in China and **recommended amending harvest and quota-based prescriptions and relaxing the logging ban.** The report concluded that thinning and harvesting "should be based on the prescriptions of an approved forest management plan for the area" and that "the existing technical regulations governing forest harvesting should also be revised to favor natural regeneration and replace clearcutting with the selective cutting of individual trees" [251]. This will have impacts on the long-term sustainable supply potential of China's forests. Hoffmann et al. (2018) report on official figures that give an optimistic timber supply capacity of 300 Mm³ in 2020 [249]. However, a major gap between national supply capacities and demand will continue to characterise China's forest industry (China's imports already surpassed domestic timber supply in 2011 [254] with ecological impacts in export countries).

4.3 Towards global benchmarks for consumption

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Companies often lack the tools, knowledge and incentives to innovate their business models toward better alignment with the Sustainable Development Goals[127], and people lack the information, motivation and options to implement meaningful change at the scale needed. Global goals may be too abstract to be effective for inspiring change at the level of daily practices. For this reason, there is increasing recognition of the need to make planetary boundary indicators operational and meaningful at the level of action – in other words, where the change to more sustainability has to happen. Efforts to translate these boundaries are immense and ongoing [255]–[257]. For example, Willett et al. (2019) examined how food systems could both supply the world with food and stay within planetary boundaries [100]. The Science Based Targets Network is working on guidance for business with “measurable, actionable, and time-bound objectives, based on the best available science that allow actors to align with Earth’s limits and societal sustainability goals” [258]. The Earth Commission is assessing what a safe and just corridor for human development means [259]. This report aims to look at what applying a planetary boundary framework could imply for forests and wood consumption levels.

The scale of consumption is linked to pushing key planetary systems beyond their tipping points.

Forests are at the heart of multiple and interconnected planetary boundaries (see Chapter 2). The scale of consumption is linked to pushing key planetary systems beyond their tipping points. In other words, it is the amount of greenhouse gas emissions aggregated at a planetary scale that leads to climate change. High emitters in particular are called on to lower their emissions. In the same way, the overuse of forests for sourcing wood changes the whole forest ecosystem. Aggregated to a planetary scale, this has detrimental impacts on biodiversity and the climate. Those with high consumption levels are called on to lower their levels of wood consumption.

International agreements to promote sustainable and responsible consumption exist since 1992 (Agenda 21 [260]). It is past time to make the changes needed.

The impacts of consumption extend beyond borders. Market demand for more timber may incentivise forest clearing and/or more intensive management, as well as forest crime. We argue that countries must do better to monitor and adjust their levels of consumption toward sustainability. International agreements to promote sustainable and responsible consumption exist since 1992 (Agenda 21 [260]). It is past time to make the changes needed. To that end, a reference value (benchmark) for evaluating the sustainability of consumption is required. Countries need a mechanism to compare their consumption levels with the global capacity for sustainable supply.

This consumption-oriented approach complements production-oriented approaches in the overarching framework of sustainable development. Combining both provides a better basis for informing policy decisions. For example, Dieter et al. (2020) apply a production-focused perspective to argue that major leakage effects could be associated with implementing the EU Biodiversity Strategy [261]. They argue that if EU roundwood removals are reduced to meet conservation aims, this reduction is likely to be compensated by imports from non-EU countries, where environmental protection measures are potentially not as strict [262]. Adding a consumption approach provides a fuller picture. This is because the same argument holds true for increasing imports to cover rising demands for biomaterials and bioenergy. **The “solution” does not necessarily lie in focusing mainly on the productive capacity of the forest, but rather also on how wood is used, reused and recycled within the economy.** Monitoring underpinned by benchmarks may help to make this case clearer. The conservation of forests, nationally or abroad, is central to preserving biodiversity. These efforts should not be prevented by arguments based on consumption preferences, nor on fundamental assumptions that take high consumption levels as a matter of course. A systemic perspective is needed, as **well as strong political leadership to put long-term interests before short-term ones.**

This report argues for benchmarks that are based on the economic principle of supply and demand. A focus on only how much of increment can be extracted may lead to mindsets concentrated on exploitation, just within limits of biomass regrowth. Promoting this kind of calculated “increment harvest” is not the aim of this report; it is also an outdated approach. Rather, **we propose benchmarks on supply capacity as a necessary monitoring tool to put consumption levels into the perspective of planetary boundaries.** These benchmarks could be developed toward targets for the same purpose, depending on the need and role such targets should and could take in steering a sustainable bioeconomy transition (see Section 4.3.4). The overshoot of our benchmark requires rethinking practices to better align business models, investment practices and forest management with the principles of regeneration[128] and ecosystem resilience.

127 https://sdgs.un.org/goals
128 For nine principles of regeneration, see the Doughnut Economics Action Lab. Its focus is on creating social change that helps to better align economies with dynamic ecological processes; https://doughnuteconomics.org/stories/140

APPROACH TO DEVELOPING GLOBAL BENCHMARKS

Our aim is to instigate a conversation about what level of wood consumption is sustainable, in particular for high-consuming countries like Germany. The most practical approach to determine a benchmark for global supply capacities would be to apply the same approach countries use to define their own sustainable harvest limits and scale this up. However, there are two central challenges that need to be considered.

First, forests around the world are in poor condition (Chapter 2). For example, the German National Forest Report found that almost all tree species in Germany show a loss of vitality and four out of five trees suffer from crown damage [126]. A paradigm shift in the forest industry to redefine how harvests limits are calculated is needed. Until then, **our report represents a first step** to see where we stand based on existing definitions of "sustainability". Second, the data used reflects the best available data. This is improving rapidly (see Chapter 5 on monitoring advances). As such, **the results here may be taken more as preliminary results.**

Workers from the Strîmbu-Băiuț Forest Management Unit harvesting FSC-certified beech trees, Maramures, Romania.

© James Morgan/WWF

For these reasons, we apply simple assumptions and choose a "broad strokes" approach. **Our method focuses on the balance between increment and fellings on forest available for wood supply and is characterised by a precautionary approach to environmental limits.** It is based on the approach presented by O'Brien and Bringezu (2017a, b), both of which discuss in more detail the context, rationale, weaknesses and needs of the methodological development of such benchmarks for forestry [263], [264]. Each of the following sections contains a short description of methods, and more detail on the data and approach is given in the Annex. The following steps were taken.

1. Determine how much forest is available for wood supply (Section 4.3.1).
2. Estimate the net growth of available forests (Section 4.3.2).
3. Develop a risk corridor based on the share of net growth available for harvests and a gradient of risk levels (low to high) as regards ecological sustainability (Section 4.3.3).
4. Compare results to literature and alternative methods (plausibility check) (Annex).
5. Compare the results to consumption, adjusted to be comparable (Section 4.3.3).
6. Check the effect that "what-if" options and impacts (sensitivity analysis and simple thought experiments) would have on future global wood supply capacities (Section 4.3.4).
7. Explore the challenges and potential for developing per capita benchmarks for forestry (Section 4.3.5).

Overall, we urge a societal discourse that will address the question: how should we best use forests to ensure long-term sustainability for ecosystems and people? In keeping with the concept of a "safe operating space" this should be based on (a) a precautionary approach in light of scientific evidence and (b) "societal" agreement on the amount of **acceptable risk.** Such a discussion on the value of the world's forest and the consequences of greater conservation versus greater expansion of timber-producing areas as well as higher versus lower levels of harvest intensity must happen to generate robust benchmarks. For example, the amount of forest considered theoretically "available" for commercial harvesting depends on how protected, conserved and Indigenous and community conserved areas are taken into consideration (now and in the future). In addition, the amount of timber which could be annually extracted when applying an integrated approach to forest management (e.g. prioritising biodiversity) could be lower than in a forest managed for maximising timber production. Much more consideration must be given to how forest health and ecosystem function on the one hand, as well as degradation and fragmentation on the other, can be addressed in the benchmark. These questions should be addressed while keeping the aim of the benchmark at the forefront of discussions and future research. In Germany, for instance, the aim is to determine what level of consumption constitutes overconsumption (in connection with rising pressures on global ecosystems and unjust levels of pressure on planetary boundaries). For that reason, Germany (and/or other high-consuming countries) may consider accounting for global sustainable supply using a more conservative approach (like the one presented here). What-if scenarios, such as those used in the US Minnesota example (see Section 4.2), could provide the basis for such a discussion. This is complementary to approaches on sustainable forest management (Section 4.1).

Our aim is to start a conversation about sustainable wood consumption levels in high-consuming countries like Germany. Our approach is not "set in stone" but rather illustrative of the kind of approach we think is necessary to strengthen monitoring and guide development towards sustainability goals (like the SDGs) and governance.

4.3.1 Forest available for wood supply (FAWS)

FAWS refers to the area of forest (in hectares) **theoretically** available for supplying wood. See the definition in Box 18. **This is not the area used for timber harvest.** We use it to develop a theoretical indicator of sustainable harvest volumes. This information is reported especially in Europe [267] and was collected at a global level by FAO in its 2000 Forest Resources Assessment [268]. The FAWS in this study is estimated based on a combination of different sources (see also [269]).

GIS[129] analysis: Spatially explicit maps for 2015 from two sources are analysed to combine their information. First, the land cover maps produced by the European Space Agency – Climate Change Initiative [270] show the extent of forest area. Second is "the global forest management layer" map produced by Lesiv et al. (2021) [22]. The combination of these maps is used to show forest area in countries that demonstrate either no significant traces of human intervention (classified as primary forest) or forest areas that are distinguished by signs of human intervention (classified as "currently used forest area"). Short-rotation plantations are also distinguished in the latter (as part of "currently used forest area"). See the Annex for more information on the GIS analysis.

FAO Global Forest Resources Assessment (FRA) 2020: This is a comprehensive FAO dataset based on self-reported country-level data on various forestry-specific indicators like forest extent and designation. The latter includes management objectives (ranging from production to protection to multiple-use management) [4]. For this study, we look especially at forest area designated for production.

(Country-)specific FAWS studies: Some country- or region-specific comprehensive studies assessing FAWS or based on their own statement of "sustainable supply capacities" are already available [29], [127], [248], [271].

129 Geographic Information System

Box 18: What is forest available for wood supply (FAWS)?

FAWS was defined by the UN (2000) as "forest where any legal, economic [e.g. accessibility] or specific environmental restrictions do not have a significant impact on the supply of wood. [This] includes: areas where, although there are no such restrictions, harvesting is not taking place" [265].

Social constraints on forest area, such as Indigenous or cultural sites, should also be included in the definition in the future. See also [266] for further considerations regarding the definition.

In this paper, FAWS comprises production and plantation forests and excludes protected areas.

Each of the available data sources has its advantages and disadvantages. Data gaps and inconsistencies in national reporting make it difficult to rely on FAO data alone. For example, if only FAO data was relied upon, Mexico's productive forest area would be about 1.5% of total forest area. However, GIS results show that more than 80% of Mexico's forests show signs of use. Relying on GIS data alone could also be misleading as this data may miss forests whose growth could theoretically contribute to potential supply (under sustainability constraints). This would be the case in countries with extensive forest areas, like Russia, in which "currently used forest area" based on GIS could be smaller than theoretical FAWS area based on country reporting.

For these reasons, data was compared and adapted at a country level. In those countries where direct estimates of FAWS already exist, these values are used [29], [272]–[274]. This refers to forests in European countries. Data for the "Big 5" are presented in the Annex. Protected areas (see the definition in Section 2.4, it includes IUCN classes I–IV for example) are not included in forest available for wood supply. The percentage of protected forests in the total forest area is taken from FRA 2020 [4] and applied to the total forest area as determined by the GIS analysis. Primary forests, which currently show no significant traces of human intervention, are also not included in FAWS. For calculating the current potential in 2020, these areas are clearly unavailable (mainly inaccessible with no roads). For calculating future supply, we also consider their potential contribution to be limited due to the **need for intact forests to maintain biodiversity and mitigate climate change.** There is a high risk associated with expanding infrastructure into primary forest, potentially setting into motion the destructive pathway of fragmentation, followed by degradation and deforestation.

As regards plantations, the GIS analysis tends to underestimate the plantation area, since only plantations with rotation times of less than 15 years are detected. As such, the proportion of plantations to total forest area reported in FRA 2020 is applied to the GIS-based forest area analysis. This leads to somewhat lower values than those given in FRA 2020. The total plantation area used in this study as a base value for 2015 is 108 Mha (about 13% smaller than the corresponding FRA 2020 value). O'Brien (2016) calculated an area of fast-growing plantations of 57 Mha for data relating to 2005 [275].

Results

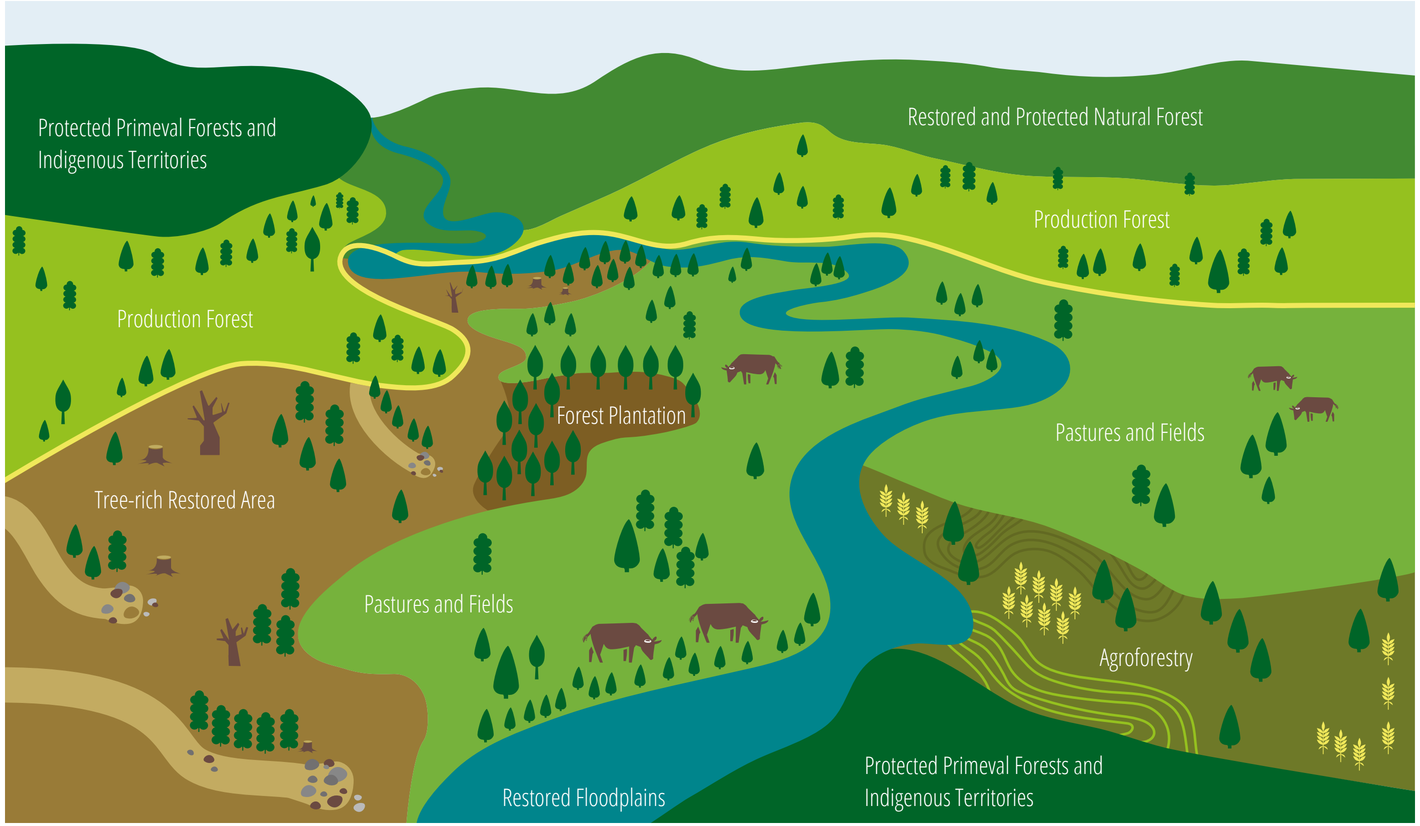
The results for the current forest status are shown in Figures 4.4 (global FAWS) and 4.5 (world regions and “Big 5” forest-rich countries). **Each figure distinguishes four forest classes: productive forests, plantations, primary forest and protected forest.** FAWS comprises the former two. The term “current” refers to a mix of information from various sources, indicating their latest available information.

Globally, 46.5% of forest area is classified as FAWS, consisting of about 1.86 Gha of production forest and around 113 Mha of forest plantations. The remaining 53% consists of 620 Mha of protected forest area and 1.5 Gha of forest area that currently shows no signs of human intervention.

Europe has by far the highest share of FAWS, with about 84% (160 Mha). This is because almost no primary forests are left and strictly protected area is relatively small (strictly protected areas do not allow harvesting; in contrast, conserved areas with integrated management do permit harvests – under sustainability criteria – and may be included in FAWS – see Section 2.4). The share of FAWS in Asia is 62% and in Africa is 50%. The lowest shares of FAWS are found in Latin America and Russia, where a large share of the total forest area is primary. Latin America has the highest share of officially protected forests. At about 10%, Asia has the highest share of plantations of all the regions. A large part of this area (40 Mha) is located in China.

The “Big 5” are the countries that host half of the world's forests and are important global producers. Brazil, Canada and Russia have the largest forest areas, which are also difficult to access, so their FAWS area is rather small. China and the USA have a FAWS share which is much higher and similar to the average European FAWS.

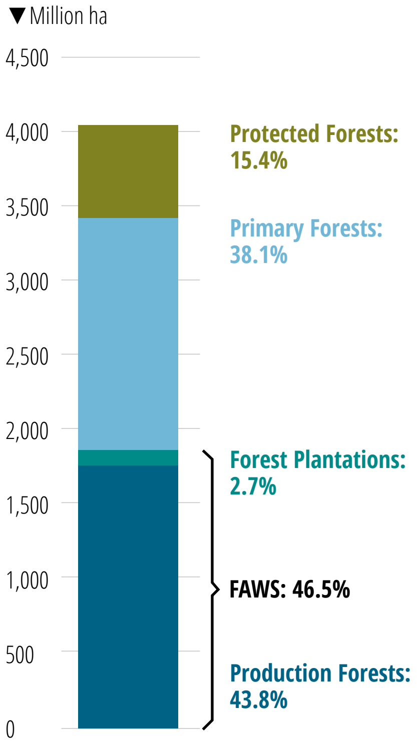
Wide-scale and mosaic restoration opportunities (schematic representation).

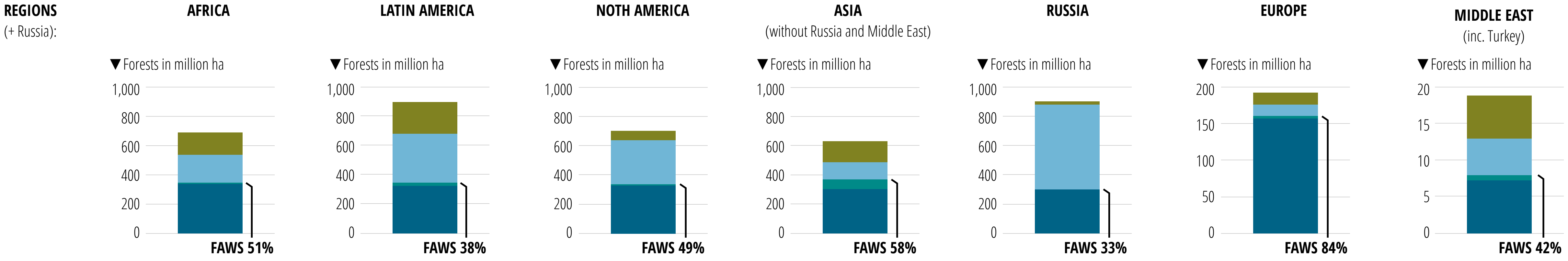


© IUCN & WRI ROAM 2014, modified

Figure 4.4:
Global forest use structure and FAWS

Note: The total share of protected forests and plantation forests in the figure differs from the share reported by FRA 2020 due to the merging of assessment approaches based on different total estimates of forest area (remote sensing versus country reporting). “Protected areas” comprise strict IUCN classifications and are excluded from FAWS, whereas some conserved areas with integrated management may be included in FAWS (e.g. some Natura 2000 sites in the EU, see also Section 2.4).





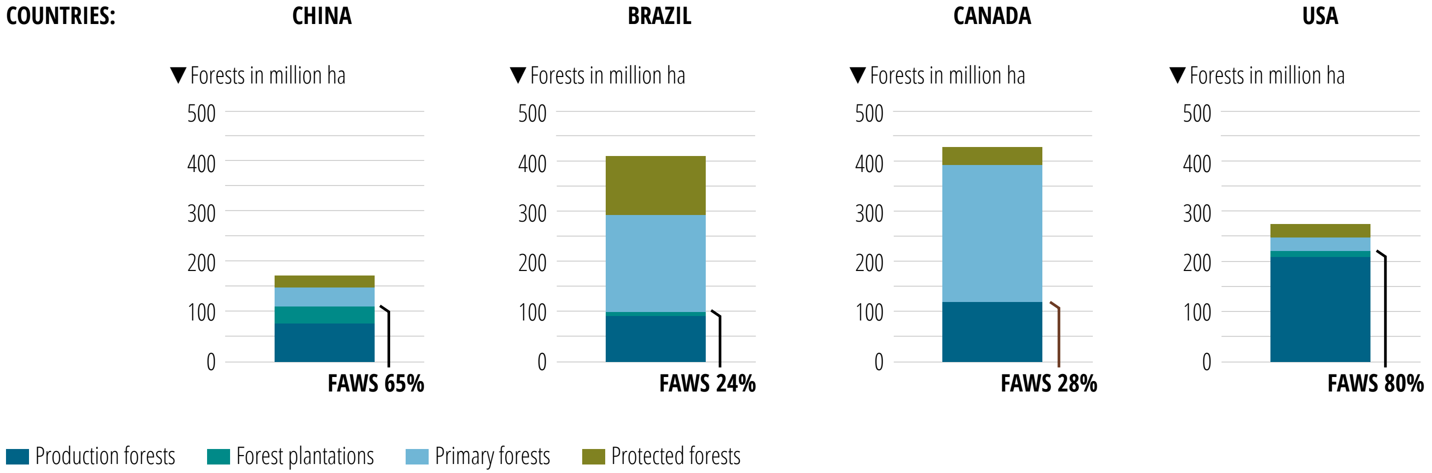


Figure 4.5: Comparison of the forest use structure and FAWS of different geographic world regions and the five countries with the largest forest area

The FAWS area reported in this report does not represent the forest area used annually for timber harvest, but rather shows a theoretically usable potential for timber supply (nearly half of forest area).

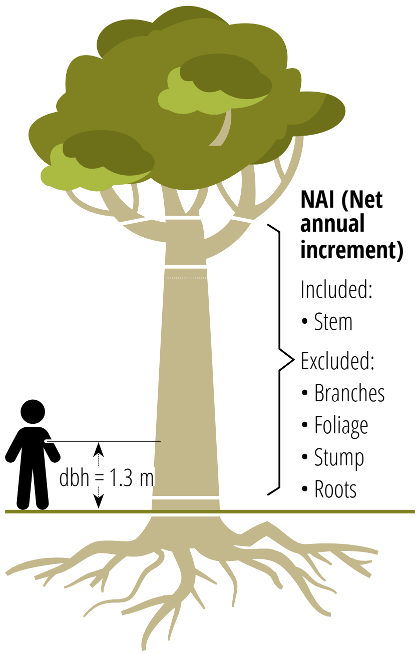


Figure 4.6: What and how NAI is measured in EU national forest inventories

Source: Diameters in different countries based on [284]

Minimum diameter at breast height (dbh=1.3m) for trees to be included in the NAI assessment of different countries:

0.0 cm (DK, EE, FI, LT, SE); 2.1 cm (LT, LV); 5.0 cm (AT, NO, RS); 5.6 cm (RO); 6.4 cm (BE); 7.0 cm (DE, CZ, HU, IE, SK); 7.5 cm (ES, FR, PT); 10.0 cm (SI); 12.0 cm (CH)

Figure shows the different size specifications of tree parts assessed in EU national forest inventories. This highlights the challenge of compiling forest inventory data due to different methods of measurement, increasing uncertainty at a global level.

4.3.2 Net annual increment (NAI)

NAI is an indicator describing tree and forest growth. It looks at total growth minus natural losses to determine net growth (see Box 19 and Figures 4.6 and 4.7). MAI is a similar indicator used for plantations (see Box 19); it is applied to reflect their shorter rotation periods and harvesting practices [275].

Recent estimates on the NAI of EU forests are available [29]. International data on NAI has been collected by FAO [268], [278], [279]. Sources [278], [280], [281] on countrywide MAI for forest plantations are based on O'Brien (2016) due to a lack of more recent calculations [275]. Compiling these sources, we estimated the NAI and MAI for each country in the world (see further information in the Annex as well as [269]).

Box 19: How are net annual increment and mean annual increment defined?

Net annual increment (NAI)

NAI is used as an indicator of forest growth for natural forests. It is defined as the "[a]verage annual volume of gross increment over the given reference period less that of natural losses on all trees, measured to minimum diameters[*1] as defined for 'growing stock'" [276]. Natural losses include aspects like fire, disease, pests and drought (see also Section 2.5 on mortality and disturbances). The unit of NAI is m³ per hectare per year (m³/ha*y).areas.

GROSS INCREMENT				
NATURAL LOSSES	NET INCREMENT			
	Fellings			Net change
	Bark	Logging residues	Roundwood removals	

Figure 4.7: Components of gross and net forest increment

Source: Based on [29]

Mean annual increment (MAI)

MAI is used as an indicator of forest growth for plantations. It is defined as the average annual timber volume growth per unit area. It is the 100% potential rotation-age harvest volume per hectare divided by the harvest age for plantations [277].

*1 The diameter is defined differently in the different national forest inventories and therefore the subject of research in order to harmonise reporting [284]. Currently a value of 10 cm diameter at breast height (dbh) is used for international statistics.

Results

The NAI averages all tree growing conditions within a country. The global average value includes all forests, from the slow growing trees in the boreal (cold) and dry forests, to highly productive tropical forests. The average global NAI of production forests is **2.5 m³/ha*y.** The average global MAI of forest plantations is **9.3 m³/ha*y.** The high value for plantations is due to the restricted regional occurrence of plantations with even-age stands, often favoured climate conditions and sometimes fertilisation. In areas with favourable growth conditions, the NAI of production forests can be as high as the average MAI. See also the Annex for more information.

Using country-specific average NAI values from global statistics, as was done in this report, provides a comparison at the international level, but at the expense of detail. **NAI values are strongly influenced by climate and will change in the future.** The way these values are changing is subject to much research. For example, higher CO_2 levels in the atmosphere can have a fertilisation effect, increasing productivity and raising the gross increment. However, higher levels of mortality due to climate change reduce the net increment. How these factors affect one another is unclear. Reyer et al. (2017) show that disturbances in European forests cancel out productivity gains in most cases. Rising tree mortality rates seem to be especially crucial [282]. Senf et al. (2021, 2018) show an increase of about 25% in the average canopy mortality rate between the late 20th century and the early 21st century for different European countries [122], [283]. Although these results are specific to European forests, coupled with the expected impacts of climate change (see Section 2.5), they suggest increasing challenges at a global level for forest management and harvest capacities.

4.3.3 Global wood supply capacity and different levels of risk

The guiding principle of forest management for timber supply is that harvest rates should be below growth rates. This is because a ratio of nearly 100% has been shown to lead to a loss of standing stock in the medium to long term. Several studies therefore suggest lower ratios. For example, Heinonen et al. (2018) show that a harvest level equivalent to around 80% of NAI does not lead to a reduction in standing stock in Finland [285]. Many European countries currently harvest their forests around this level. The EEA recommends a maximum harvest share corresponding to 70% of NAI[130]. A Greenpeace study suggests that 50% of NAI can be economically exploited without harming the environment [286].

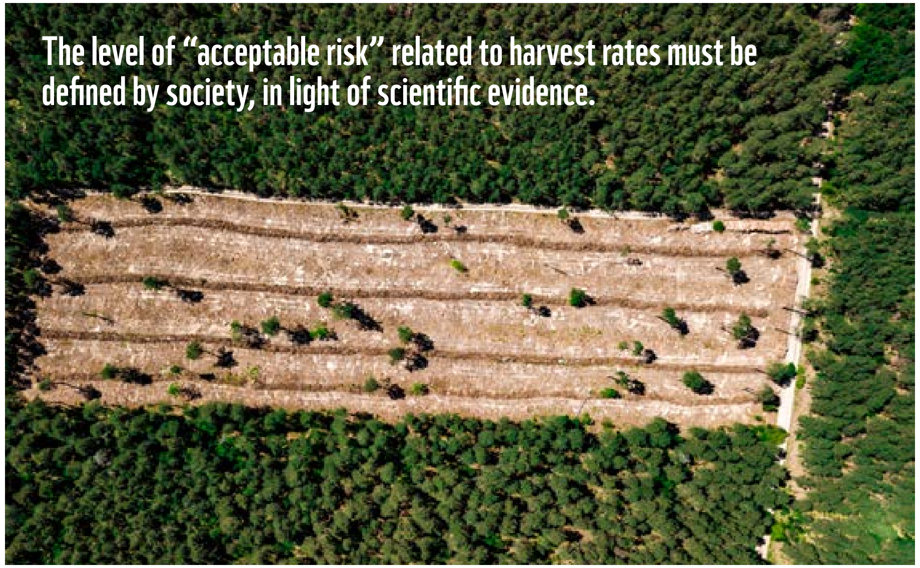
This study thus estimates a corridor between 50% (low risk) and 80% (high risk) of NAI on available productive forest area (see Section 4.3.1 on FAWS). This "risk corridor" refers to the planetary boundary for global wood consumption. It is calculated as a corridor to account for uncertainties in the data and to reflect different levels of risk. In particular, the 80% share is a quantity-based use boundary focused primarily on the maintenance of standing stock. It is not sufficient to be able to make a holistic assessment of the extent to which the calculated corridor is used in a "sustainable" way. Perspectives that go beyond timber supply alone are needed to achieve holistic sustainable forest management and stewardship. The low-risk boundary (50% of NAI) allows greater incorporation of ecosystem services and could be considered to align more with an "ecologically safe wood capacity". With regard to plantations, in our calculation all growth contributes to potential theoretical supply. Further "restrictions" aligned with multi-purpose plantation management could be added in the future to better incorporate ecological services here also.

The supply capacity refers only to the amount of wood available that would allow the forest area to be maintained for generations to come. How this amount is both managed and harvested – in light of ecological and social considerations – determines whether it actually contributes to sustainable forest management and stewardship.

Results

Our sustainable supply capacity is 3.0 Gm^3 and below (Figure 4.9). Our risk corridor ranges between 3.0 Gm^3 and 4.2 Gm^3. Figure 4.9 also compares results to global consumption levels. These reveal that overconsumption is already happening at a global level (with consumption 3% to 67% higher than supply capacity). If everyone on Earth were to consume at the same level as Germans, the world would overshoot its sustainable supply capacity by a factor of at least 3 to more than 4.

It should be noted that global consumption levels differ from those presented in Chapter 3, as they are adjusted here to make consumed volumes comparable to the volume of trees growing in the forest (see Box 20). The Annex contains a plausibility check to compare results to both an illustrative alternative calculation and literature sources.



© iStock/Getty Images

130 From the website of the EEA on "Indicator Assessment" for Forest: growing stock, increment and fellings. See: https://www.eea.europa.eu/data-and-maps/indicators/forest-growing-stock-increment-and-fellings-3/assessment; accessed 2 November 2021.

Box 20: Adjusting roundwood consumption statistics to comparable units of forest supply capacities

Due to the current state of the data, conversions are needed to make wood consumption levels (i.e. roundwood equivalents) comparable with our benchmark for sustainable supply capacities (i.e. trees growing in the forest) (Figure 4.8).

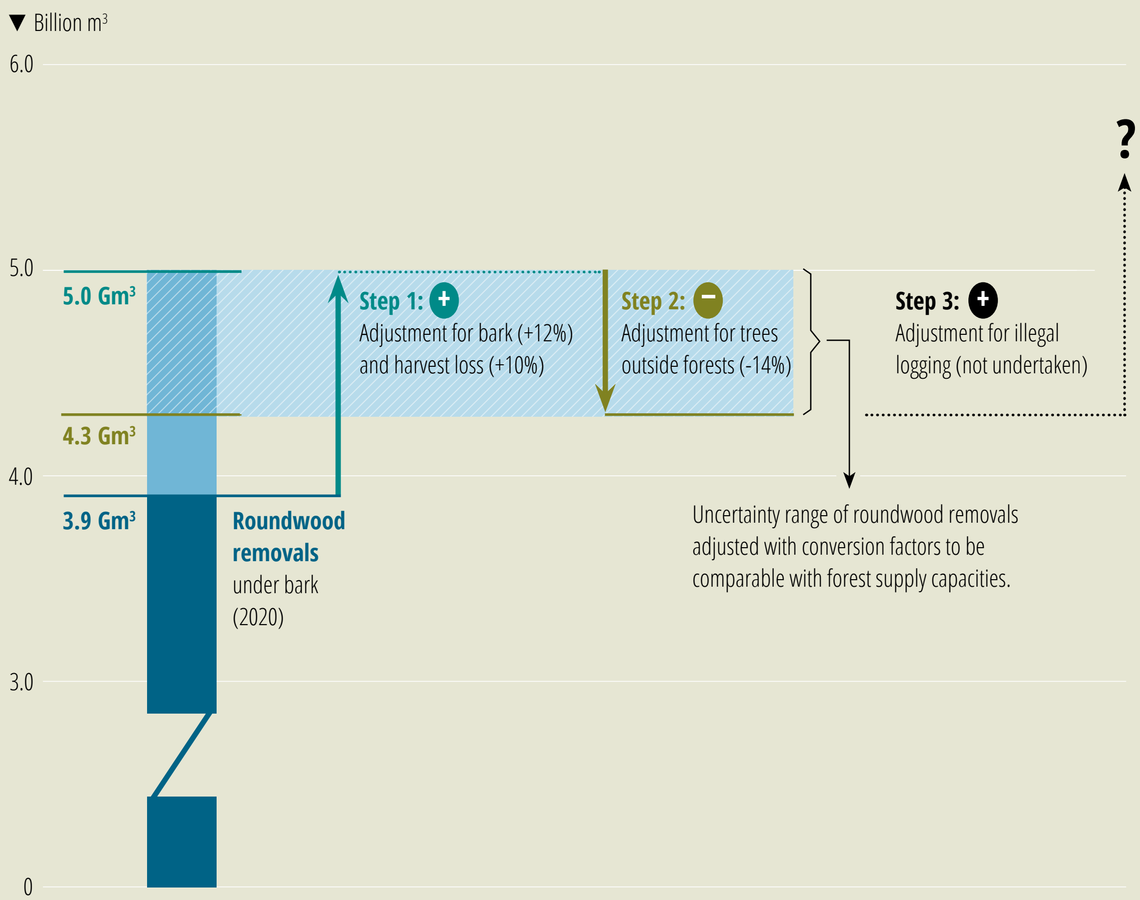


Figure 4.8: Step-by-step adjustment method for converting roundwood consumption to units that are comparable to forest supply capacities

Step 1: In the first step, bark and harvest losses are added. With regard to bark, roundwood removal statistics are reported by FAO in units under bark (see Box 8). Forest growth statistics (NAI) are reported over bark. With regard to harvest losses, timber that makes it out of the forest and into production/consumption statistics is accompanied by a certain level of timber that is left in the forest. We added +12% bark following FAO et al. [287] and +10% harvest losses following Englert et al. [288]. A recent study by Pilli and Grassi (2021) calculated with an average of 27% “irretrievable losses”, accounting for bark and harvest losses [289]. Harvest losses, in particular, depend heavily on the harvesting method and therefore vary widely around the world. Our conversion is a rough attempt to increase comparability on a global scale.

Step 2: Roundwood consumption statistics also contain a certain share of trees from sources outside the forest (trees outside forest, ToF) (see the definition of roundwood in Box 8). This is especially relevant for woodfuel, in particular in low-income countries, where woodfuel may be gathered, for example, by the roadside (see Section 3.2.1). The share of roundwood removals from trees outside the forest is not well documented. This is a well-known problem in statistical reporting [290], and efforts are ongoing to improve the picture [291]. As we aim to compare wood consumption levels to sustainable supply capacities of the forest, we made an initial attempt to adjust consumption downward to reflect that not all global consumption stems from the forest. The total adjustment applied for trees outside the forest is -14%. This number is obtained by following the approach used by Smeets and Faaij (2007) [295] and applying exploratory adjustment values for woodfuel for all of Africa (-50%) and all of Asia, excluding China (-60%) and India (-49%) [281], [292]–[295]. These adjustments at the global level should not detract from the main message of the study, which is about the already high consumption levels of high-consuming countries like Germany (see Figure 4.9).

Step 3: Large quantities of traded wood come from unofficial and illegal sources. Nelleman et al. (2020) present estimates that approximately 190–565 Mm³ under bark could be cut illegally every year [23]. Looking at FAO statistics, Buongiorno (2018) found that industrial roundwood consumption was under-reported in 57 countries and over-reported in 44 countries [155]. Taking Germany as an example, Figure 3.23 shows that officially reported roundwood removals differ from an ex-post analysis of roundwood removals in all the years assessed; it shows that there may have been significant under-reporting (e.g. more than a 40% discrepancy around 2014), with more recent years showing a smaller discrepancy [235]. A third step could therefore be an adjustment for unregistered, illegally harvested roundwood. We did not perform this step quantitatively here as it is unclear from an accounting perspective if, when and how much of these, in particular illegally sourced timber flows, enter roundwood removal statistics (if at all). We assume that global consumption is, in practice, higher than global statistics indicate. The range shown in Figure 4.9 thus serves to illustrate the level of uncertainty in global consumption statistics, to provide transparency about the conversions undertaken and to call attention to the level of illegal activities, which could comprise an estimated 15–30% of globally traded wood by volume [147].

Figure 4.9:
The planetary boundary for global wood consumption: comparing the sustainable[*1] supply capacity and the risk corridor to consumption levels

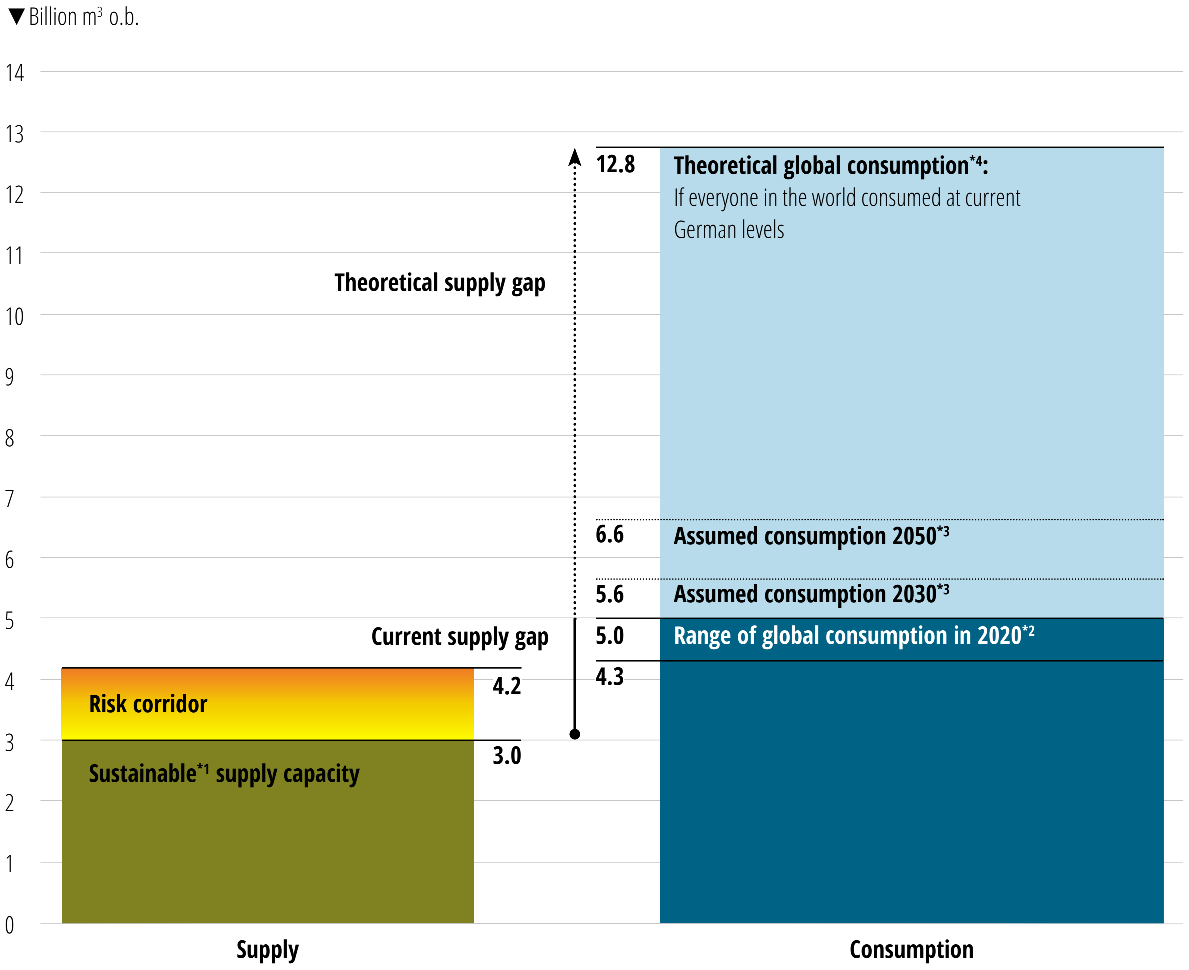
Notes:

[*1] Sustainability here refers to quantity considerations, which is only one consideration when aiming for holistic forest management.

[*2] Global consumption in 2020 is depicted as a range to depict uncertainty in conversion values (e.g. adjustments for bark and harvest losses), share of global consumption that stems from the sources outside the forest (e.g. roadsides), illegally sourced timber and statistical data uncertainty.

[*3] The global consumption values in 2030 and 2050 depict the highest boundaries respectively and are based on an extrapolation of historical trends over the decade 2010–2020.

[*4] The average annual German consumption level between 2015 and 2020 was taken as a reference for calculating "current consumption" because calamities (including massive beetle outbreaks) caused a spike in German harvests in 2020.



Kalpesh Lathigra /WWF

4.3.4 What-if future considerations

This section asks the question: **how might supply capacities develop in the future as a result of trends and targets?** To begin to answer that question we performed a simple sensitivity analysis that isolated five parameters: 1) halting versus continued deforestation; 2) achieving forest landscape restoration targets and continued afforestation; 3) expanding plantation areas; 4) expanding FAWS; and 5) possible negative impacts linked to climate change. These parameters are not shared projection scenarios from integrated models. **The purpose is to demonstrate – in an illustrative way – the effect that change, alone, would have on the risk corridor** estimated in Section 4.3.3 up to the year 2050. This is useful to compare potential future supply capacities with consumption projections (e.g. in Chapter 3) to check how these align. The assumptions behind each of the five parameters are described in the following sub-sections. Our assumptions should not be interpreted as future projections, but rather as **what-if questions** and **thought experiments** to investigate the potential scale of impacts associated with different trends. Some of the what-if questions, for example regarding increasing supply capacities by expanding plantation or FAWS areas, are very complex due to the potential for trade-offs and increased harm with natural systems. We attempt to ask how supply potential could be increased, taking a higher degree of sustainability constraints into consideration and based on the literature. However, much more detailed research (e.g. on the potential of degraded land) is needed.

Results are illustrated in Figure 4.10. **Overall, we found that there is limited potential to expand supply capacities, and these are far from sufficient to meet rising demands.** Our results clearly illustrate a growing divergence between potential supply and extrapolated demand. There is limited potential to sustainably extract more on the supply side, and this is judged as a mid-to-high risk strategy for small to moderate gains. **This means that reduction in consumption is the only option.**

We performed a simple sensitivity analysis that isolated five parameters:

1) halting versus continued deforestation,

2) achieving forest landscape restoration targets and continued afforestation,

3) expanding plantation areas,

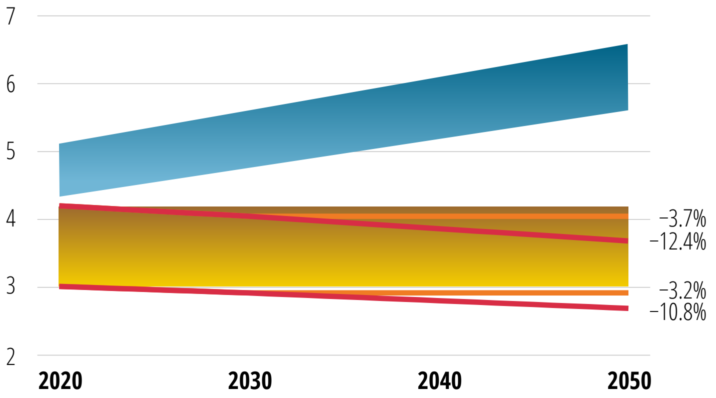
4) expanding FAWS, and

5) possible negative impacts linked to climate change.

Planting native tree species to transform pine monocultures into more natural deciduous forests to increase sustainable wood supply, Germany.

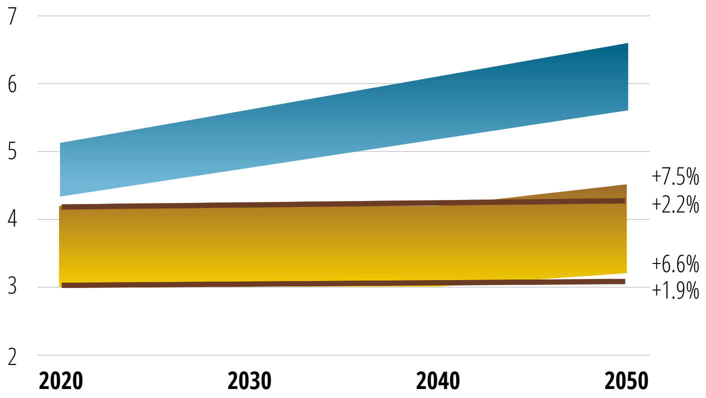
Figure 4.10: What-if sensitivity analysis 2020–2050: The highest gains can be achieved by reducing consumption

A) Halting deforestation saves forests and maintains supply capacity



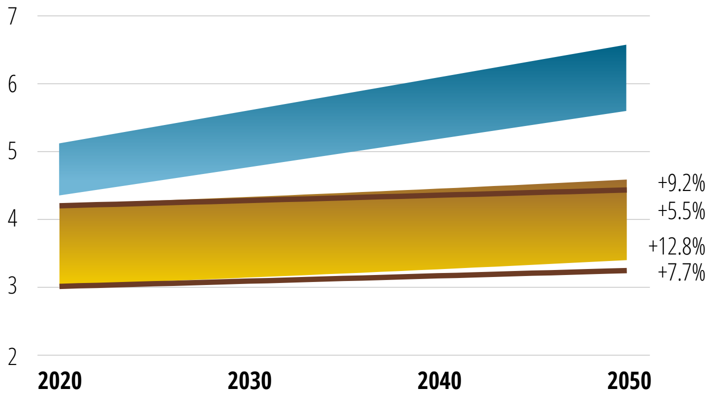
Halting deforestation starting in 2021 (yellow corridor) or in 2030 (orange lines, 5-year trend) compared to continued total deforestation trend to 2050 (red lines, 5-year trend) and assumed same share of FAWS.

B) Meeting reforestation targets and afforestation



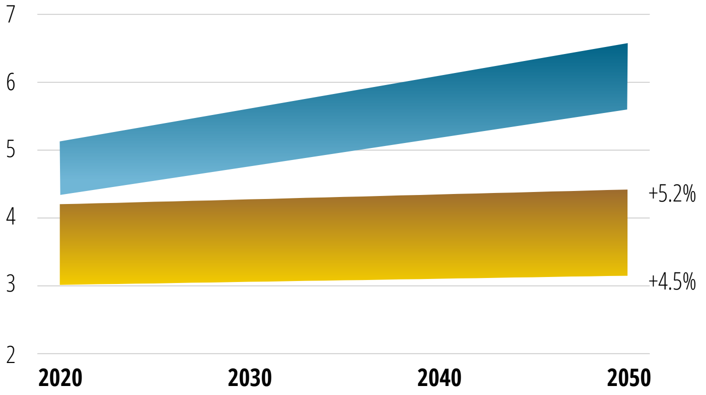
Achieving the Bonn Challenge with half the area (+175 Mha) entering theoretical production forest supply capacity starting in 2040 (yellow corridor) and FAO afforestation trend extrapolation (brown line).

C) Plantation expansion



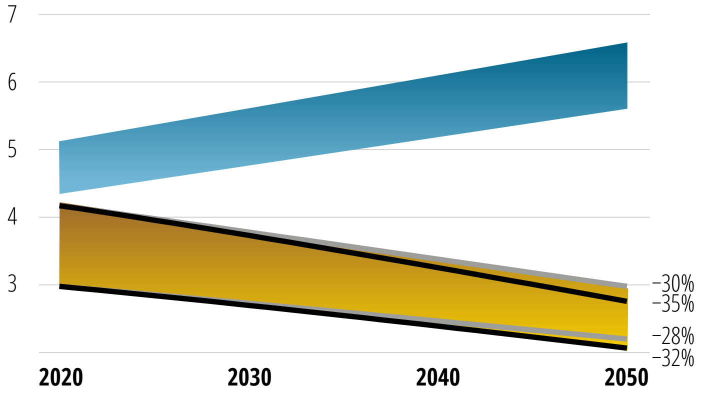
Increasing plantations by 20–35% (to cover 133–150 Mha) (yellow corridor) and halved-trend extrapolation (brown line), noting that land constraints must be carefully considered.

D) Expanding forest available for wood supply (FAWS)



+20% FAWS only in countries with a FAWS share under 50%. This would mean FAWS would cover 2.04 Gha in 2050 (+9% FAWS expansion).

E) Mortality increases as a result of climate change



Trends are illustrative based on light (grey lines, 80% NAI) to moderate (black lines, 50% NAI) mortality increases in a trend scenario for Europe.

Risk corridor
Global consumption (10-year trend extrapolation)
Trend extrapolation (10-year forest area trend)

Note: Consumption is based on an extrapolation of past trends (see Chapter 3.1). It is adjusted for bark, harvest losses and trees outside the forest (see Box 20). It is depicted as a gradient to illustrate the range of uncertainty in statistical conversions. Nonetheless, this depicts a continuation of past trends; a higher growth rate would further widen the gap.

1. Halting deforestation prevents further losses and saves forests (Figure 4.10a)

If deforestation is occurring at the same rate in 2050 as in 2020 this would lead to a supply loss of 10.8% (-324 Mm^3) in the lower boundary of the risk corridor and 12.4% (-519 Mm^3) in the upper boundary.

Our development of sustainability is guided by halting deforestation to protect biodiversity- and carbon-rich forests in order to stop biodiversity loss and mitigate climate change. The impact of halting deforestation today and in 2030 on global timber supply is assessed. For that reason, the what-if option (shown in Figure 4.10a) shows what could happen if halting deforestation targets are not met (in comparison to meeting them). This is based on the annual gross deforestation of 10 Mha worldwide reported by FAO [4] for the period 2015–2020. The time frame 2015 to 2020 is taken to reflect slowing annual trends. Figure 4.10a just shows total deforestation, without the "counterbalancing[131]" trend of afforestation in terms of timber supply as these are separate trends happening in different world regions. **The same share of FAWS is assumed in 2030 and 2050 as in 2020**. This means the share is the same, but the absolute size of the area decreases and therefore also the area of harvesting. This makes it a **theoretical calculation** indicative of the fact that permanent forest loss should have impacts on wood supply capacities. The "remaining" forest area is still needed for wildlife and ecosystem provision.

This trend shows that global timber supply could shrink by 153 Mm^3 (-3.7%) in the upper boundary of our risk corridor and by 96 Mm^3 (-3.2%) in the lower boundary of our risk corridor if deforestation is stopped in 2030. FAWS would then cover 1.76 Gha, which is 5.4% less than the 2020 value. If deforestation is occurring at the same rate in 2050 as in 2020 this would lead to a supply loss of 10.8% (-324 Mm^3) in the lower boundary of the risk corridor and 12.4% (-519 Mm^3) in the upper boundary. Such a loss would not only impact wood supply, but also biodiversity and climate.

With regard to consumption, a linear extrapolation of the 10-year trend (see Chapter 3) would result in **global consumption of nearly 6.6 Gm^3 in 2050** (adjusted for bark and losses and at the highest point of the consumption range calculated for 2050; see above). **This level of consumption would already be 56% to 118% higher than the supply capacity if deforestation is stopped today.** If deforestation were to continue unchecked, the gap would grow (overreaching supply by 79% to 144% in 2050).

Deforestation of the Amazon rainforest, 2020, Maués, Brazil.

131 This compensation effect is deceptive, especially with regard to the forests being lost compared to those being gained – planted forests and plantations cannot replace primary (tropical) forests, as these are much more important for carbon storage and biodiversity.

2. Forest landscape restoration targets and afforestation (Figure 4.10b)

In line with the **Bonn Challenge and New York Declaration on Forests,** 350 Mha of degraded or deforested area should be restored by 2030 (see Section 2.2), in addition to halting deforestation. **The aims of restoration are not focused on wood production, nor should they be.** To reflect this, we roughly assume that 50% of the restored area (175 Mha) is available for production in 2050 and 50% consists of strictly protected areas or trees in the landscape (such as fruit trees, tree lines, small copses and tree groups). In addition, growth in restored areas are first considered to contribute to theoretical growth availability in 2040 in order to reflect the fact that short-rotation plantations are not the goal of restoration. For this reason, the country-specific NAI of natural forests is used.

Community mangrove restoration in Madagascar.

© WWF-Madagascar

Under these conditions, total supply in 2050 would be 198–317 Mm^3 higher than in 2020 (low to high boundary). This corresponds to an increased supply capacity of around 6–7%. The corresponding FAWS increases by 9.4% to cover 2.04 Gha in 2050. This implies rather low potential for immediate gains – in part due to our assumptions. However, restoration could lead to a more **long-term** supply potential while also supporting global efforts towards climate mitigation. Bastin et al. (2019) argue that there is room for an additional 900 Mha of tree restoration potential, excluding agricultural and urban areas, and that this would contribute significantly to effective climate mitigation [85]. Others find more modest potentials (Sections 2.2 and 2.3).

We also consider the trend extrapolation of afforestation from FAO data [4], using a linear extrapolation of the 2010 to 2020 trend at the individual country level (only positive values). It must be noted that this trend should be separate to restoration goals, but both are shown together in Figure 4.10b for the sake of simplicity. For the extrapolation, supply increases by about 58–93 Mm^3 (+1.9% to 2.2%) corresponding to 1.90 Gha of FAWS (+2.2%) in 2050.

3. Plantation expansion is limited by land availability and competition (agriculture); it must be done right to reduce risks (Figure 4.10c)

When planted and managed in keeping with ecological and social principles, plantations are thought by some to have strong potential for contributing to future timber supply. We present modest scenarios (closer to [296] – based on growing land constraints [101], [219] related especially to agriculture [100]) and emphasise the risks associated with getting this wrong (see Section 2.3). The impacts of two different projections of plantation expansion on global timber supply in 2050 are assessed. One is from a recent global ITTO report [10] and the second is a linear projection of half the positive annual plantation expansion rates reported by FAO [4] for the period 2010–2020.

Results indicate that the upper boundary of total supply capacity could increase by 5.5% (to 4.43 Gm^3) in 2050 for the halved-trend extrapolation and by 9.2% (to 4.59 Gm^3) based on the ITTO projection. In the case of the lower boundary, supply increases by around 7.7% (to 3.25 Gm^3) and by 12.8% (to 3.40 Gm^3) in the respective scenarios. In terms of area, total global plantations increase by 19.3% (to 135 Mha) and by 34.8% (to 153 Mha) worldwide. Total FAWS area thus increases by 1.17% to 1.89 Gha for the FAO halved-trend extrapolation and by 2.1% to 1.90 Gha based on the ITTO projection.

4. Expanding FAWS is a risky strategy with low gains for timber supply (Figure 4.10d)

The share of FAWS could expand to meet increasing demands for timber. Some studies see widespread potential here. However, expanding FAWS leads inevitably to further loss of primary forests and forest fragmentation through the necessity of forest roads. This is problematic since:

"The capacity of the surviving forests and other natural habitats to sustain biodiversity and ecosystem services will hinge upon the total amount and **quality of habitat left in fragments, their degree of connectivity, and how they are affected by other human-induced perturbations** such as climate change and invasive species" Haddad et al. (2015) [2].

Climate change: Forest fires even reach the humid zones along the river.

© iStock/Getty Images

At a minimum, Key Biodiversity Areas (KBAs) and especially those identified by the Alliance for Zero Extinction (AZE) must not be harmed by a FAWS increase. **Scientists increasingly argue that current protected areas are insufficient to halt biodiversity loss.** For example, the post-2020 protocol of the Global Biodiversity Framework Conference calls for protecting and conserving at least 30% of the planetary area (terrestrial and aquatic) by 2030, with a focus on KBAs [115]. Some scientists go even further by advocating the idea of "Nature Needs Half", implying that 50% of the global area should be unavailable for productive measures [106], [116], [117]. While this approach has been criticised as being of "questionable feasibility and justness" [118], other teams have contributed to its core scientific basis [100]. For these reasons, our theoretical FAWS expansion scenario was performed by only expanding the share of FAWS in countries with a FAWS below 50%. In these countries, FAWS was expanded by 20% by 2050 (corresponding to less than 1% expansion per year).

In this "scenario", FAWS would cover 2.04 Gha in 2050 (an increase of 9.4% compared to 2020). This would lead to an increase in production of around 135 to 217 Mm³ in 2050 (+4.5 to 5.2% compared to 2020). The timber supply in this section is calculated using a top-down approach with a global average NAI. This is the reason for the supply difference vis-a-vis the reforestation section and underlines the need for integrated modelling.

5. Increased mortality could have serious consequences for potential wood supply capacities (Figure 4.10e)

Climate change will impact forest growth patterns. It is unclear how (see Section 2.4). More robust and realistic data is needed to investigate potential productivity gains, noting that these may be counteracted by increases in mortality [282]. Due to the importance of increased mortality observed in very recent years, **we depict potential impacts in an indicative way to show the magnitude of potential challenges.** Our trend is based on data from Senf et al. (2018), for which the average change in canopy mortality is given from 1990–2015 for six European countries [122]. This trend is then projected to 2050 using a logarithmic function for the moderate increase and a linear trend projection for the light increase. **A light increase in mortality could lead to a loss of -28 to -30% in timber supply capacity in 2050 and a moderate increase in mortality could lead to a loss of -32 to -35%.** These scenarios dramatically increase the supply gap in 2050 – with a gap of up to 4.5 Gm³ between the assumed upper boundary of consumption in 2050 and the lower boundary of the supply corridor under moderate mortality. It should be noted that these results could potentially be mitigated somewhat by higher growth rates. Nevertheless, an increase in mortality rates due to climate change may lead to significant timber supply shortages worldwide.

4.3.5 Fair shares for wood consumption: A discussion

The concept of “fair shares” is based on an equitable per capita distribution. It is a transparent and simple method for comparison that can be easily communicated and used to support the global governance of environmental limits [297]. This section looks at the role of targets, their applicability for wood consumption and the results of our calculations on a per capita basis.

The role of targets

Targets help to **raise awareness** about the need for change. Increased awareness paves the way for **public acceptance** of new policy interventions and also helps to support the development of **eco-innovative business models,** and their markets [298]. Targets may serve as both a **rationale for policy intervention** and as **guidance** for developing evidence-based policies. A bundle of key targets for global resource use (e.g. footprints) linked to the concept of safe operating space could also help to make European policy more coherent across sectors and policy areas and help to prevent problem shifting between planetary boundaries [219]. One strength of the 2 degrees Celsius (preferably 1.5 degrees Celsius) limit, for example, seems to be that it is clear and easy to communicate (the numbers are rounded). When developing targets, this raises the question of the kinds of targets needed and whether these should prioritise directionally safe, simple and easy-to-communicate headline values or be more focused on scientifically robust and precise data – perhaps implying a target range in the case of poor data.

Different levels of orientation for sustainability

Potential targets for wood consumption in a country like Germany could embrace different levels of strength toward achieving global fair shares (Figure 4.11). These range from a national focus on self-sufficiency to a global focus on sustainable fair shares. While self-sufficiency does not seem to be appropriate in light of global sustainable development goals, also calling for massive reductions to reach a globally equitable distribution of wood would meet with resistance in forest-rich countries. The wide distribution of forests means that places have formed a different **cultural identity** towards the use of forests and wood products over time. Cultural, religious and community-wide significance are different in forest-rich and forest-poor countries. In some places, trees may be planted and cultivated with the needs of grandchildren in mind. This makes **the challenge for targets in relation to forestry more nuanced, both in terms of time span and distribution, than comparable efforts,** such as for cropland[132].

In light of our results, the question is: How can the importance and urgency of using wood and wood products in a smarter way best be communicated to society?

On the other hand, overuse of global timber resources crosses a planetary boundary with universal consequences. The concept of a “safe and just operating space” [259], [299] suggests that limited natural resources critical to meeting basic human needs (including shelter and energy) must be shared in a humane way. An international, multi-stakeholder discussion is needed on the “validity” of the concept of “fair shares” for different types of resources. A disproportional distribution of use could be suitable in some cases, as long as cultural practices with low or high wood consumption are within – at least – national supply constraints and do not harm the capacity for attaining a dignified quality of life for all. **At its core, the challenge for forestry is how to take regional variability into account when considering global capacities,** and to this end a social discourse is absolutely necessary [263], [264].

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Increased awareness of forests paves the way for public acceptance of new policy interventions, COP26, United Nations Climate Change Conference, 2021, Glasgow, United Kingdom.

132 For example, Bringezu et al. (2012) look at per capita distribution of sustainably available global cropland under safe operating space conditions [317]. They argue that per capita consumption reference values are the most viable option – despite different resource endowments of countries regarding e.g. fertile soils, rainfall and growing conditions – as people across the globe should be entitled to a fair share of food security. In a similar exercise, Willett et al. (2019) find that it would be possible to provide healthy diets for an estimated global population of about 10 billion people by 2050 within their safe space framework derived from planetary boundaries (with globally zero future land conversion of natural ecosystems into farmland, for example) by striving for sustainable systems of production and consumption [100].

What is a sustainable level of wood consumption, now and for future generations?

It is about smarter – more balanced – consumption. Keeping in mind the climate challenge and the need to reduce fossil fuel use in a smart way, the issue to be addressed is about finding a middle ground between two extremes: 1) problem shifting induced by excessive demand and 2) a protectionist type of market with no trade. In Figure 4.11, a focus on national self-sufficiency does not mean that imports and exports would stop. Instead, it means that the goal, at a bare minimum, should be to keep consumption at a level that could be supplied nationally. **Germany has already exceeded such a minimal target** (see Section 3.3 and Figure 4.12).

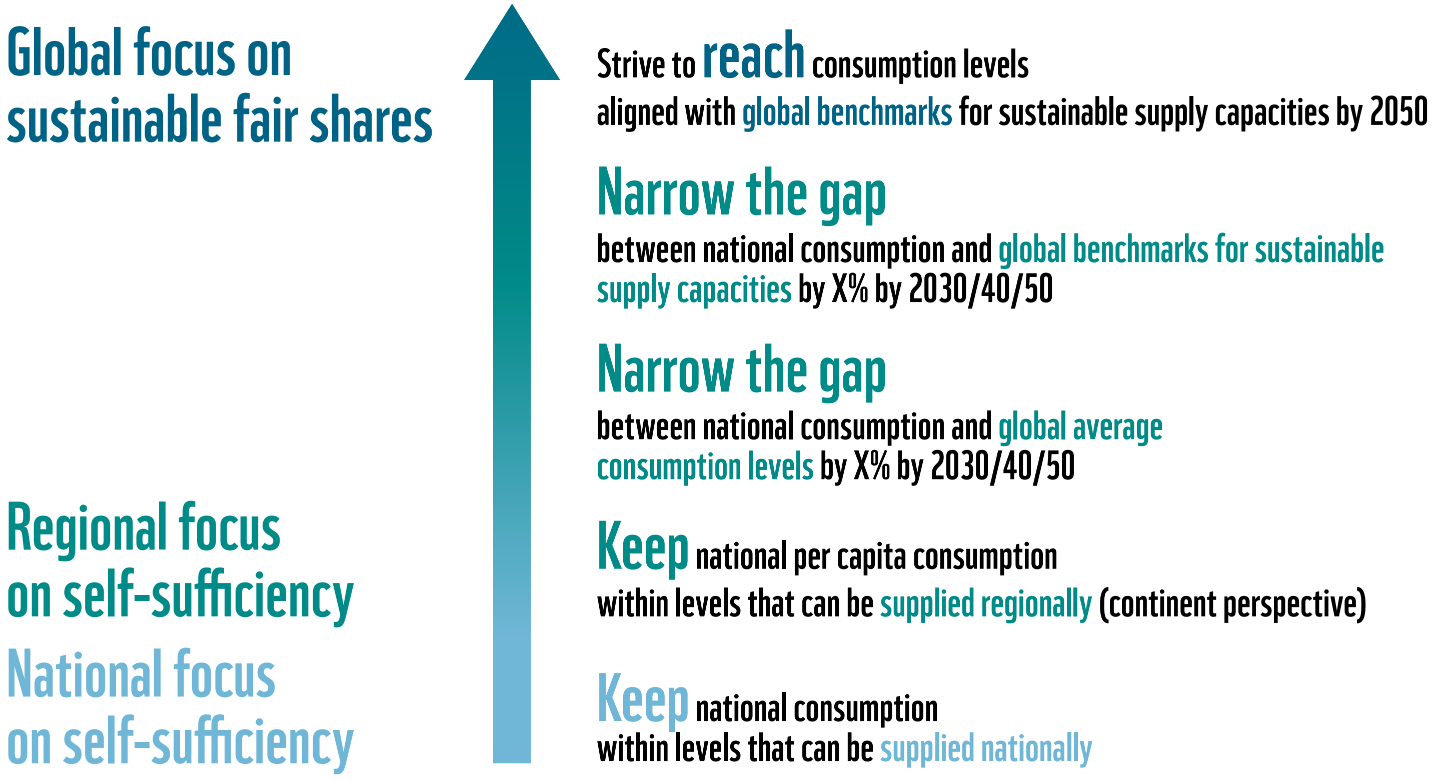

Figure 4.11: Gradient of target orientations to promote sustainable levels of wood consumption

Per capita comparisons of supply and demand against a backdrop of population growth

We applied an illustrative approach similar to that adopted in Section 4.3.4 to depict the **impact of population growth over time on the per capita global supply capacity and the implications for a gradient of target orientations.** To this end, we performed the following calculations.

- **The global risk corridor** that we calculated in Section 4.3.3 was divided by UN medium population forecasts. No changes to forest area were made due to both the uncertainty regarding future trends and to effectively communicate the effect of a growing population on equitable distribution.

- **The EU27 risk corridor** was calculated using the same method. The population data from the EUROSTAT baseline projection[133] was used. We assumed that a minimum of 10% of forest area was under strict protection (as per the EU's Biodiversity Strategy) and thus capped FAWS at 90% of total forest area (i.e. 130 Mha). The total calculated supply corridor is 386 to 602 Mm³, of which the upper boundary is close to the range of available supply calculated by other scientists[134]. It must be emphasised, however, that the upper boundary is based on harvest shares with higher levels of risk and which may no longer meet the criteria of being ecologically safe[135].

- **The German risk corridor** was calculated using the annual increment in the third German forest inventory (see Section 3.3) and the same method applied in Section 4.3.3 (e.g. 50 to 80% harvest shares). The increment was then divided by the German population forecast[136] until 2050.

133 https://ec.europa.eu/eurostat/de/web/population-demography/population-projections/database
134 For example, Verkerk et al. (2019) [318] calculate a range of 622–699 Mm³ [318]; Jonsson et al. (2018) [319] calculate a value of 636 Mm³; di Fulvio et al. (2019) [320] calculate a value of 506 Mm³; and O'Brien (2016) [275] calculates a range of 600–700 Mm³ in 2020 (all sources use an 80% share of NAI).
135 According to the demands of forest ecology for biodiversity and climate and as reflected by the request of a further 20% of protected areas for nature maintenance and no more than extensive harvests.
136 Using the middle variant scenario G2L2W2 from Destatis. For more information, see: https://www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/Bevoelkerungsvorausberechnung/Methoden/Erlaeuterungen/VariantenListe.html

Supply capacities were also compared to both **global per capita consumption** (10-year trend extrapolated to 2050) and **German per capita consumption** (to 2030 as described in Section 3.3). **These consumption trends are based only on a trend extrapolation and thus may be considered to be more indicative of business as usual.** They do not include the rising demands of the bioeconomy indicated by Chapter 3.

Results

Results are shown in Figure 4.12. Three key messages can be derived.

» Global per capita risk corridor: This decreases over time as a result of rising population pressures. In 2020 the risk corridor ranges between 0.39 and 0.54 m^3 per capita, and in 2050 it ranges between 0.31 and 0.43 m^3 per capita.

» Global consumption: While total global consumption is shown to rise by around 30% between 2020 and 2050 (see Figure 4.10), per capita consumption increases only slightly (by around 3%). This is a result of population growth, but does not imply that distribution becomes more equitable over time (only that the average remains relatively stable).

» German consumption: It is clear that German per capita consumption far exceeds both global consumption levels and all risk corridors (global, German and EU). It exceeds the upper boundaries of the German risk corridor and the EU27 risk corridor in 2030 by 37% and 20%, respectively

All in all, according to these calculations, global consumption would exceed per capita supply capacities by 33–86% in 2030 and German consumption would exceed global per capita supply capacities by 226–354% in 2030.

Our simple calculations should be interpreted as a call to engage more deeply in developing such benchmarks – with society, policy and science.

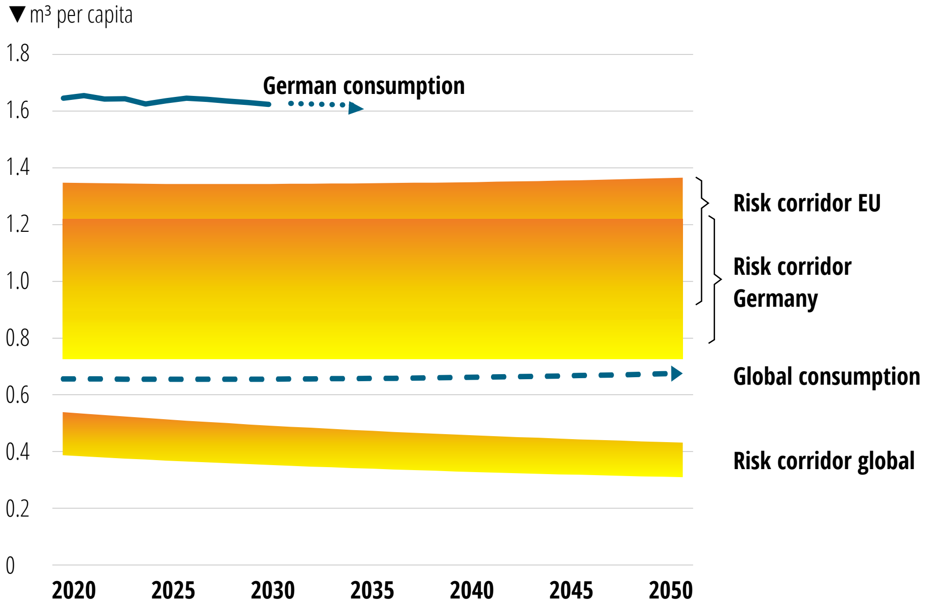

Figure 4.12: Per capita risk corridor (global, EU and Germany) compared to per capita consumption trends (global, 2020–2050 and Germany, 2020–2030 and 2050)

Notes: Consumption is cubic metres over bark (o.b.) and consumption levels are adjusted to include both a bark conversion (+12%) and harvest losses (+10%). At a global level, only the upper boundary of the consumption corridor is shown (see Box 20), i.e. the trees outside the forest adjustment corridor is not depicted here for the sake of simplicity. German consumption is based on the footprints presented in Section 3.3; global consumption is based on trends presented in Section 3.1; and the risk corridor is based on the approach described in Section 4.3.3.

5 Innovation and good practices

How can the limited amount of freshly harvested wood be used within the economy to contribute to meeting sustainability goals?

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For your Orientation

CHAPTER OVERVIEW

Chapter 5 initiates a conversation about this issue. The aim here is not to promote prescriptive policies, but rather to foster innovations which prioritise long life, reuse and recyclability.

Multiple resources showcasing positive examples of innovation exist (see, for example, the WWF report Business Model Innovation for Sustainability [300] or visit the Doughnut Economics Action Lab[137]). Indeed, **the business model is at the heart of efforts to transform economies to make them more sustainable.** Not least because business model innovation may help to shift the focus from selling more (intimately linked to rising consumption levels) to providing value. **Product design** is also critical to harnessing end-of-life potential. This is relevant to all types of products, including homes. In Japan, for instance, there are examples of buildings in which refurbishment and repurposing options are already considered in the plans for the building.

This chapter presents a few short examples focused on different aspects of the overarching challenge. **The aim is to initiate a discourse about how wood is used in a balanced bioeconomy.** These are the kinds of assessments needed to help policy makers identify, prioritise and foster smart wood consumption.

137 https://doughnuteconomics.org

KEY MESSAGES

1. Changed consumption practices – and the business models and social innovations that accompany them – are fundamental to reducing pressure on forests. **The question is: what is wood used for? Reductions in excessive, wasteful and inefficient consumption** would help to make way for increased substitution of fossil and mineralbased feedstocks with wood.

2. Grassroots innovations aimed at sharing, exchanging, repairing, reusing and minimising, provide examples of alternative ways to “consume” wood. However, these are the exception rather than the rule (to date).

3. Cascading use is widely recognised as a key solution, but around 30% of harvested wood is still used directly for energy in Germany.

4. Recognition of the ways in which forests are interwoven into the fabric of our daily lives and how interdependent we all are on the ecosystems of the world's forests is the first step towards holistically addressing and mitigating deforestation. Cities4Forests is a platform dedicated to this purpose from a city perspective.

5. The issue is not only about how much wood is used and what it is used for, but also what kind of forest and what kind of wood is used to supply industry. Was the forest sustainably managed and harvested? To this end, customers, companies and financial institutions need accurate and reliable data. The Deforestation Risk Toolset aims to support businesses to achieve deforestation-free supply chains. Such measures complement footprints.

6. Near real-time alerts from remote sensing systems are being used to combat deforestation and detect disturbances (wildfires and increasingly even beetle outbreaks). Detailed remote mapping of forests enables a better assessment of potential wood supply that complements data generated by inventories on the ground. Combined, these data sources will enable more robust estimates of sustainable supply capacities. Nevertheless, the time to act is now – we need to address consumption.

Innovative solutions beyond the forest

The German National Bioeconomy Strategy states: “What we need are sustainable solutions that provide alternatives to established forms of production and consumption patterns by taking into account systemic relationships” [37]. Changed consumption practices – and the **business models and social innovations** that accompany them – to reduce pressure on forests are fundamental to making way for increased substitution of fossil- and mineral-based feedstocks with wood (e.g. for bioplastics, textiles and construction). Only reductions in total demand will allow future needs to be met – in a sustainable way – with wood[138]. As the Environmental Paper Network (2018) states: **“The answer to the question ‘paper or plastic’ must more often be ‘neither’”** [13].

Less consumption is even better than recycling valuable resources.

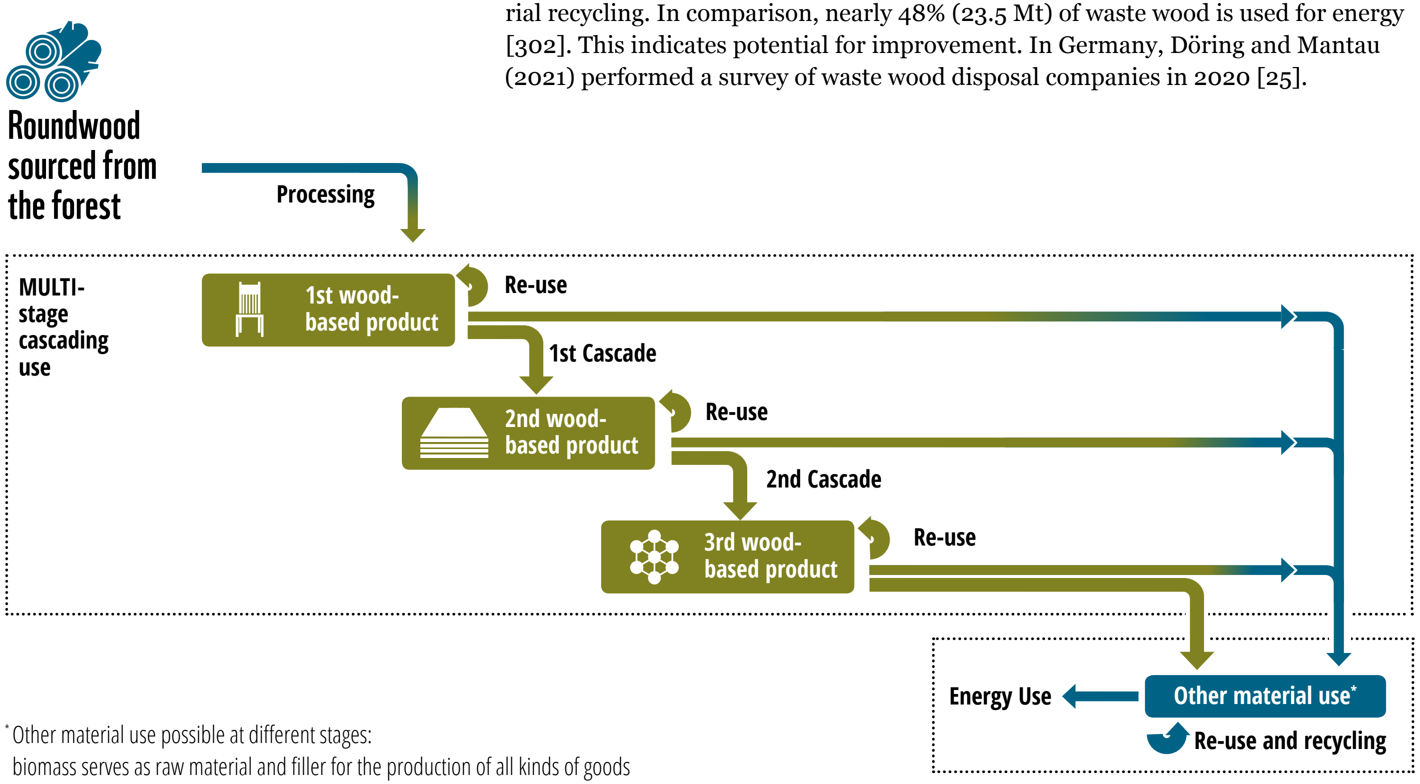
© iStock/Getty Images

Examples of social and **grassroots innovations** to reduce the scale and impact of consumption are widespread and increasing. The **“minimalist lifestyle movement”** and the booming trend in “tiny houses” in Western countries are just two examples. **Reuse and repair cafes** can be found across the world. **Exchange platforms** for used goods have become mainstream (e.g. eBay classified ads, craigslist). Communities are coming up with clever ways to share products **(“sharing economy” and “collaborative consumption”).** Urban planning is reducing the need for car-based **mobility,** as daily needs can increasingly be met within short distances. Cities across the world are investing in making bike lanes safe, fast and convenient **alternatives for achieving mobility,** as e-bike sales and innovations (like cargo bikes) have boomed. Although perhaps small in scale, cup deposit and reuse schemes in cities across Germany have trigged **widespread changes in behaviour** – from single-use throw-away paper coffee cups to customers bringing their own or sharing reusable ones. Such acceptance of behaviour shifts could be a hopeful signal for the future. The use of information and communication technology, especially as seen in the COVID-19 pandemic, offers viable **alternatives to business travel.** It remains to be seen whether changed behaviours remain after the pandemic. Smart homes and further **energy efficiency gains** through digitalisation may help to reduce energy demand. However, there is also a high risk of rebounds and some have found that: **“The hopes set on digitalisation reducing energy consumption have not yet been justified”** [301]. Researchers in Germany have found that the additional demand for energy caused by increased digitalisation has been greater than the energy-reducing effects [301]. This underscores the need to address the scale of consumption, including increased knowledge on why and how people reduce their ecological footprints, and most importantly, how such behaviours can be incentivised and mainstreamed.

138 If not, the bioeconomy may become part of the problem instead of delivering “solutions”. See also the paper by Gerhardt on “Forests under pressure: why the bioeconomy threatens our ecosystems”, available at: https://english.denkhausbremen.de/2020/06/11/forests-under-pressure-why-the-bioeconomy-threatens-our-ecosystems/

Cascades and reuse

Reuse and recycling extend the lifetime of harvested wood in the economy. According to Eurostat [302], around 41% (20 Mt) of waste wood in the EU is used for material recycling. In comparison, nearly 48% (23.5 Mt) of waste wood is used for energy [302]. This indicates potential for improvement. In Germany, Döring and Mantau (2021) performed a survey of waste wood disposal companies in 2020 [25].



*Other material use possible at different stages: biomass serves as raw material and filler for the production of all kinds of goods

Figure 5.1: of the circular and cascading use of wood

Source: adapted from Höglmeier et al. 2015 [162]

Note: Multiple cascades are possible.

They estimated that around 10.3 Mt of waste wood were collected in Germany in 2020. Large quantities of waste wood were also traded in 2020 (around 1.5 Mt were imported and 1.4 Mt exported). In total, nearly 7 Mt (around 70%) of waste wood was burned in Germany (the vast majority in large firing systems of at least 1 megawatt) and around 1.4 Mt (around 15%) were used for particleboard production [25].

The cascading use of wood is defined as "the **efficient utilisation** of resources by using residues and recycled materials for material use to extend total biomass availability within a given system" [303]. It means using wood at least once – ideally multiple times – in products before using it for energy. The goal is high-quality recycling. An example is presented in Figure 5.1 where a circular and cascading use is depicted between the extracted roundwood from the forest and the end-of-life incineration. Cascading use not only reduces pressure on forests by lowering the demand for primary material, it is also beneficial for climate protection. Brunet-Navarro et al. (2017) show that increasing the average lifetime and recycling rate of sawnwood, wood-based panels, and paper and board in the EU by around 20% each could increase CO_2 savings by about 17% [304].

The potential for a circular and cascade utilisation has been recognised by the EU. A theoretical potential volume of about 50 Mt per year was estimated for the EU (24 Mt from municipal waste, 19 Mt from demolition and construction, 6 Mt from industry)[139]. The figure provided by the Wood Circus project[140] is even higher: about 70.5 Mt of waste wood generated annually. The German Forest Strategy and the second German Resource Efficiency Programme explicitly mention the cascading use of wood, but without formulating clear targets and the Forest Strategy is not legally binding, it is just a recommendation. A number of research projects[141] are under way to strengthen the knowledge base on what, how and why cascades are implemented and on their scale-up potential. Nevertheless, **around 30% of wood** in Germany **is used directly for energy purposes,** with a big difference between coniferous (10% direct energy use) and deciduous (60% direct energy use) wood [24].

139 See the summary report of the workshop "Wood products in the sustainable bioeconomy" from the 10th and 11th of December 2019 as part of the Iniative "Sustainable Wood for a Sustainable World2; http://www.fao.org/forestry/50086-08f3427df3cbc8c4060c4e94e367ef58c.pdf
140 https://woodcircus.eu/index.php/about/; good practices are also depicted.
141 See, for example, the "Working Group for Monitoring of Residue Potential" and open data from the German Biomass Research Centre (https://webapp.dbfz.de/?lang=en) and the SYMOBIO project (https://symobio.de).

Cities4Forests

Cities4Forests is a coalition of more than 60 cities from all parts of the world. It helps cities to “recognize their interdependence with the world’s forests and use their political, economic and cultural power to protect and manage those forests for human well-being”[142]. Technical support, capacity building and peer-to-peer learning are all aspects of the platform. It focuses not only on inner-city forests, but also aims to reduce pressure on forests in far-away places. For example, its Partner Forest Program lists 10 ways in which cities can reduce deforestation[143].

1. Inventory your city’s tropical forest footprint and incorporate into climate and sustainability goals.
2. Upgrade municipal procurement policies to reduce deforestation.
3. Communicate the impacts of consuming forest-risk commodities to city residents.
4. Reduce waste to reduce consumption of forest-risk commodities.
5. Increase accessibility of alternatives to forest-risk commodities.
6. Create a Partner Forest Program to support community forest conservation.
7. Incentivize forest-positive innovation in local businesses and entrepreneurs.
8. Regulate forest-risk products using bans, taxes, and incentives.
9. Encourage national/state governments to legislate on deforestation risk commodities.
10. Incorporate nature-based solutions as offsets in climate change mitigation strategies.

The Deforestation Risk Toolset

According to the Accountability Framework report published in 2020, at least 411 companies have committed to achieving deforestation-free supply chains [74]. There is much room for growth with regard to both the number of corporate commitments and the effectiveness of existing ones. To this end, companies and financial institutions need accurate and reliable data and knowledge to be able to assess and manage risks. They also need monitoring systems to track and report change. The Deforestation Risk Toolset is one initiative that aims to fill this gap[144]. It comprises three publicly available resources – Global Forest Watch Pro, Trase and the Accountability Framework. They aim to effectively eradicate deforestation and ecosystem conversion from supply chains and, to this end, provide tools to link critical data to the guidance needed for effective reporting. “The toolset provides an affordable and credible way to map supply chains, assess risk, manage suppliers, and monitor and report results”. The toolset offers:

» Capacities to assess deforestation exposure, tailored to the needs of the organisation

» Near real-time monitoring of deforestation, fires and other environmental impacts

» Historical exposure to deforestation to inform full delivery of responsible sourcing commitments, plus identification of high-risk areas for supplier engagement and audits

» Holistic supplier management support, including supplier engagement and management of supplier non-compliance

» Reporting on progress.

142 https://www.wri.org/our-work/project/cities4forests
143 https://www.partnerforests.org/forest-footprint-action-plan
144 Resources and initiatives are increasing rapidly. For example, the Consumer Goods Forum launched the Forest Positive Coalition to accelerate systemic efforts to remove deforestation and forest degradation from key commodity supply chains. More information is available at: www.theconsumergoodsforum.com/environmental-sustainability/forest-positive/; accessed 1 December 2021.

The Accountability Framework is an initiative that provides a roadmap for companies to set goals, take action and demonstrate progress towards ethical supply chain goals. It also defines best practices for implementation and reporting. Trase and Global Forest Watch Pro support companies in key implementation processes, including supply chain mapping, risk assessment and monitoring. **With its focus on supply chains, the method is complementary to footprint approaches assessing the issue of scale.**

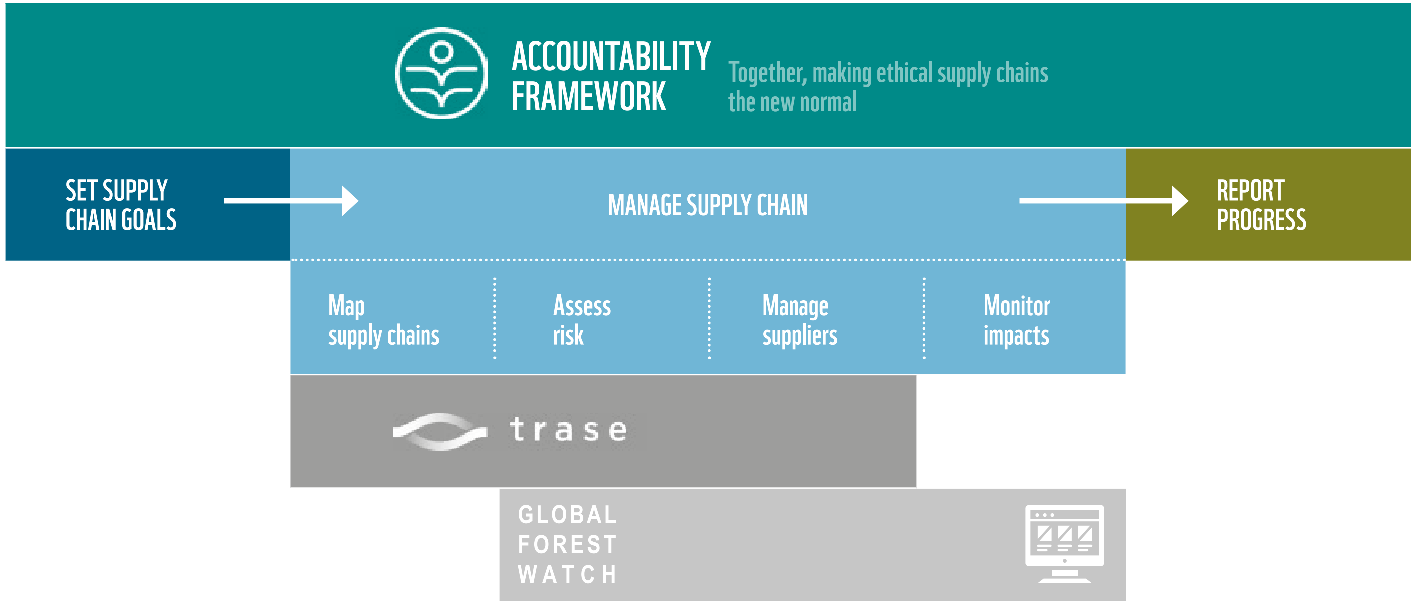


Figure 5.2: The Deforestation Risk Toolset

Source: Available at: https://accountability-framework.org/deforestation-risk-toolset/; accessed 1 December 2021

Monitoring with remote sensing – production and forest-oriented approaches to strengthen the available data

Earth observation technologies are changing the face of forest monitoring. They provide near real-time data to deliver early warning systems on disturbances and to combat deforestation. They are also being used to harmonise data on forest extent, stocks and change, enabling analysis of trade-offs between ecosystem services [305] and supporting the implementation of forest and climate policies [306].

The Copernicus Atmosphere Monitoring Service (CAMS)[145] uses near real-time observations to **estimate the location and intensity of active wildfires**, as well as the emissions of pollutants. These forecasts are then used in air quality apps that are geared towards helping people limit their exposure to pollution. They are also used to support local authorities to manage the impact of fires. The use of remote sensing to detect beetle outbreaks is the focus of many research projects. For example, the Bavarian State Institute of Forestry is currently working on two projects **to detect beetle outbreaks** with Earth observation tools[146].

Near real-time deforestation alerts are also being used to combat deforestation. For example, Global Forest Watch is facilitating a community monitoring programme in the Peruvian Amazon. It transfers early deforestation alerts to trained and incentivised members of Indigenous communities, who then patrol those forests. Slough et al. (2021) assessed the effectiveness of this programme, which was randomly assigned to 39 out of 76 communities. While the estimated results were somewhat imprecise, they calculate a reduction of 8.4 ha per community in the first year and 3.3 ha in the second year, with the greatest reductions in the communities with the highest levels of threat [307]. Such a programme could provide a mechanism to help turn deforestation alerts into action on the ground in time to deter deforestation. WWF Forest Foresight is another example, with evidence that an early warning system in the design phase of a project in Borneo/Sumatra supported reductions of 22% in illegal deforestation[147].

145 https://atmosphere.copernicus.eu/fire-monitoring
146 https://www.lwf.bayern.de/informationstechnologie/fernerkundung/286072/index.php
147 For more information, see: https://ewsdeforestation.atlassian.net/wiki/spaces/EWS/overview?homepageId=32961; accessed March 2022.

Detailed mapping of forests enables a better assessment of potential wood supply because it is possible to assess more parameters than just standing stock. Forest management types, trade-offs among ecosystem services, accessibility, and the type and quality of the wood have major implications for sustainability. It is now possible to perform a spatially explicit analytical assessment of such parameters based on forest maps with enough spatial resolution (e.g. 1 ha) integrated with other spatial data sets [308]. The Copernicus Sentinels mission (European Space Agency) and the Landsat programme (NASA) currently provide open-access, frequent and high-resolution satellite data for forest monitoring [309]. The combination of this data with cloud computing capacities enables the development of "temporally consistent and spatially detailed maps of forest cover, forest change and forest properties" [308] over large areas [310]. Better data can also complement data generated by inventories on the ground. To this end, dedicated efforts towards the harmonisation of forest statistics (e.g. at a European level) have strengthened the comparable knowledge base [308] and bode well for the future.

High-consuming countries, like Germany, need to evaluate and adjust their consumption patterns.

And yet, it still must be about consumption

Such tools focused on production and on supply capacities help to better understand the state of global forests. This will enable more robust and reliable estimates of sustainable supply capacities. However, **waiting for better data in order to act is no longer an option.** We can clearly see that trends are converging and consumption practices, in general, are going in the wrong direction. The planetary boundaries for biodiversity loss have been exceeded and we are in the "zone of uncertainty" for climate change. Overuse of our global forests must be prevented. High-consuming countries, like Germany, need to evaluate and adjust their consumption patterns. Pockets of innovation, as briefly described in this chapter, have not nearly reached the scales capable of transforming our economies. Tools are available to monitor, inform, evaluate and learn, but they are not transformative in and of themselves. Social engagement is needed. Overall, good practices focused on monitoring the forest resource and on making supply chains more ethical and sustainable are necessary and important, but they must be linked to wood consumption and our planetary boundaries.

Satellite images for forest and fire monitoring

6 Conclusions and policy messages

Can wood be used to build our houses, power our heat and electricity grids, clothe us, package our deliveries, and replace our plastics all at the same time?

No, wood cannot be used for everything.

No, wood cannot be used for everything.

Data show that wood cannot be used for everything. Data shows that at a global level, we have overshot the planetary boundary for forests. Germany is a country with a large forest resource relative to its population, but its high level of demand already makes Germany import-dependent. Planting trees can have a positive effect, but even more relevant is the consumption side. Policy must halt wasteful consumption and prioritise efficient wood consumption. If wood is sustainably harvested within the planetary boundaries and products are produced with fewer emissions and in a way that does not harm nature, than binding CO_2 in long-lived and durable products can support mitigating climate change. For this potential to be realised and upscaled, the direct burning of wood at (an industrial) scale is counter-productive and polluttive. Policy must find ways to promote wood use that take into account long-term supply capacities under sustainable conditions. **If current incentive structures for promoting wood as the "green solution" for all kinds of use persist, we will move away from our target to halt deforestation.** The global destruction of biodiversity and the climate will get worse, which has immense impacts for the well-being of human life.

Sao Paulo and the sharp borderline with the forest.

© iStock/Getty Images

The issues touched on in this report are complex, but the main findings are not. It is clear that **consumption must be cut** to reduce the pressure that we are putting on the world's forests. The expectations of multiple sectors and of the bioeconomy in general are based on a potentially false assumption about the environmental benefits of using wood. While wood can and should contribute to sustainable development, our results irrefutably show that scale matters. We see an urgent need for footprint monitoring to guide bioeconomy policies and support investment decisions today with the full picture.

There are no "unused" supply capacities

The concept of "unused" supply capacities is unfounded. **First, the concept of "use" must be expanded to include ecological services and the forest should and must not be assessed for its capacity to supply timber alone.** Intact forests are used by the wild animals of the world, for example. New Zealand has granted legal standing to a forest that recognises its value in and of itself. **Second, our what-if considerations illustrate how little room there is to manoeuvre with regard to increasing forest supply capacities.** We have already overshot planetary boundaries (we calculate that global consumption was 3% to 67% higher than our risk corridor in 2020) and the supply gap is rapidly growing. We recognise that alternative studies have come to different conclusions regarding the scale of supply. However, the utmost caution is needed here, as these studies 1) are based on assumptions that focus narrowly on wood supply and do not take sustainable forest management into account or 2) generate assumptions about forest productivity gains using theoretical Earth simulation models and optimistic assumptions that, in many cases, do not reflect experiences on the ground. Drought, fire, storms and pest outbreaks are devastating forests at record-breaking levels. Policy makers need robust, system-wide evidence to design high-level, integrated strategies.

> **"By 2030, eliminate unsustainable consumption patterns, ensuring people everywhere understand and appreciate the value of biodiversity, and thus make responsible choices commensurate with 2050 biodiversity vision."**
>
> Proposed target 15 of the post-2020 global biodiversity framework (CBD 2020)[148]

148 More information on the CBD Proposals and Agreements online: https://www.cbd.int/conferences/post2020

Connecting consumption to planetary boundaries – scaling down versus scaling up

The aim is to prevent the problem shifting associated with consumption. **It is about balance.** This means finding a balance between the level of use (enough to supply humanity with, at least, a decent standard of living) and natural systems (keeping Earth operating systems below their tipping points). We thus applied a **downscaling approach to planetary boundaries for monitoring purposes.** However, downscaling is not the only approach [256]–[258]. It represents a way of thinking embedded in the economic principles of supply and demand. **Other approaches related to regenerative business models and broader definitions of value (beyond monetary value) may lead to deeper changes not only in business, but also in the natural world** [299]. For example, if a financially driven investment is made to buy a forest, the decisions made on the ground concerning how that forest is managed will be guided by the need to make a profit. This could lead to an exploitative model of generating capital.

We need a balance between supplying enough wood for a decent standard of living and keeping Earth operating systems below their tipping points for their destruction.

"Scaling up" is an alternative method more aligned to regenerative business models and applicable to investors [257]. It is characterised by the question of how local activities impact global processes. On the forestry side, regenerative business models are characterised by incentives to improve landscape resilience by planting and managing forests sustainably in ways that not only optimise for timber growth, but also for biodiversity, community and long-term gains in both. This requires determining where foreign investment in plantation expansion comes from and what the underlying purpose of that investment is (e.g. returns for shareholders, carbon offsets, foreign development). If appropriate, this may need to be addressed through regulation. On the "consumption side", regenerative business models are also those that aim to serve the community by providing a necessary function, but in a way that favours long-term value over short-term profits. Such concepts should be explored simultaneously to build the knowledge and mindset needed for doing business and developing policies in a sustainable world economy. **While downscaling seems more appropriate for monitoring, upscaling could help to promote the kinds of change needed.**

Better data is needed

Throughout this report, gaps regarding data were identified. This pertains to uncertainty, missing statistics and transparency. **Policy makers, investors, companies and consumers need better data.** It is difficult to comprehensively assess sustainability using the data currently available. Our attempts to do so, in particular in Chapter 4, underscore the need for more research, starting with comprehensive, harmonised and reliable data on the state, productivity and sustainable potential of world forests for wood production. In 2021 the EU's Joint Research Centre also found considerable inconsistencies in data on the use of wood. According to its estimates, the amount of wood that would be needed to manufacture wood products and produce energy exceeded the total amount reported by sources by more than 20%. "We conclude that it is of utmost importance to improve the availability and quality of data with respect to the forest-based sector, and the energy use of wood in particular" [95]. With regard to future potential, **models are critical to develop scenarios and provide a basis for a dialogue on how to become truly sustainable as a society that respects planetary boundaries.** However, "there is a lack of systematic and up-to-date outlook studies providing a sound basis for conclusions on world roundwood consumption in the decades to come" [38]. More interdisciplinary and cross-cutting research is needed to assess future consumption in light of future production capacities that consider sustainable management of the forest resource for multiple purposes.

“Forestry crimes, including illegal logging and deforestation for agricultural expansion, have probably become the single greatest threat to life on the planet.”

FIVE KEY MESSAGES FOR POLICY MAKERS

Perception and acceptance of the problem

According to this study, there is already not enough wood to sustainably meet demands. In addition, established and new industries are planning to intensify the use of wood. Without political guidance, this will most likely lead to accelerated deforestation and degradation of forests. We have developed five key messages for policy makers.

1. Prioritise how wood is used

A political and social discussion on the most sensible use of wood is necessary. Do not leave it to markets to decide how wood is consumed. Eliminate perverse and potentially conflicting incentives generated by policies to use wood inefficiently (e.g. subsidies). Take an active role to define priorities on what, where and how timber should be used most efficiently. Consideration should also be given to the following, for example.

Prioritise long-term use

a) Promote wood use that takes long-term sustainable supply capacities into account and prioritise long-term use, durable products and design for reuse.

b) Invest in building up the infrastructure, knowledge and mindset for reuse, high-quality recycling and the further use of waste wood. A circular economy and cascades are good options for efficient timber use.

c) The industrial burning of wood for energy is the worst use of our limited wood supply, particularly in light of the climate crisis. The use of wood for energy should be at the end of a utilisation cascade. Remove incentives to burn wood and support finding clean alternatives to inefficient and polluting wood burning for smallholders.

d) Make excessive and wasteful behaviours more difficult. For example, free newspapers and printed advertising material distributed to households that do not want them or disposable coffee cups are not sustainable. We need to reduce packaging substantially.

e) Invest in innovative solutions that adapt the way resources are used in the community and in society. Foster a balanced bioeconomy through societal transformation in mobility, housing, food and culture. Lead the way on social norms – be an example of changed behaviours in public procurement.

2. Stop environmental and forest crime

“Forestry crime is a growing problem with its links to organised crime and corruption. In financial terms, **environmental crime is the third largest crime sector in the world**” [311].

“Forestry crimes, including illegal logging and deforestation for **agricultural expansion,** have probably become **the single greatest threat to life** on the planet” [23].

“Forestry crimes may involve the **greatest mismatch of government and intergovernmental resources** spent on combating them **relative to the crime profits** that they generate” [23].

These statements make it clear that there is a need for an internationally coordinated effort to combat forest crime with a strong concerted effort on a national basis. Ignoring these crimes will fuel deforestation, forest degradation, climate heating and species loss. It will also impede or destroy political efforts like afforestation or protection of forests. Increased demand combined with a shrinking forest area may increase incentives to engage in illegal activities, whereas reducing consumption will support efforts to make forestry crime less attractive.

3. Prioritise healthy forests

a) Put the resilience of forests and the enabling of ecosystem services first. Promote robust, multi-functional forests above and below ground (soil, water and species diversity) and respect protected and primary forests.

b) Invest in developing biodiversity and improving climate change adaptation strategies for forest managers.

c) Invest in and promote financial incentives for forest owners that do not rely only on selling timber but also focus on measurable biodiversity and climate impacts.

d) Promote forest species diversity, including native tree species such as birch and poplar. Prepare industry in Germany toward shifts in species composition from softwoods to hardwoods, i.e. from coniferous to deciduous wood.

The connection of forest and water are crucial for the sustainable landscape services, Güeppi Sekime National Park, Loreto, Peru.

4. Monitor consumption and set benchmarks

a) Implement footprint monitoring in official statistics. Such accounting methods are being developed in research projects and must be taken up by national agencies. This is needed before governments further invest in and incentivise the widespread use of wood.

b) Set benchmarks to put the scale of consumption into perspective. The conventional perspective on the production side needs to be complemented by the consumption perspective to promote sustainable development.

c) Engage in a societal dialogue on targets within the planetary boundaries. This requires defining norms and values related to risk.

d) Determine together, on the basis of science and a societal dialogue, how much forest use for wood production is sustainable over the short and long term and in light of interrelated goals (biodiversity, climate, well-being).

e) Continue to develop and grow complementary measures focused on ethical and ecological supply chains by promoting transparency, corporate reporting and widespread global commitment to deforestation-free supply chains.

5. Invest in research

a) Develop models to assess future forest product markets and their raw material streams (e.g. recycled flows, plantation timber).

b) Develop a consistent, harmonised and reliable global data set on the condition of forests (including standing stock, deadwood, growth, native tree species, area, forest biodiversity, and tree species and health).

c) Evaluate how much land area is required for low-intensity management and mixed-species planted forests, including their potential to meet demand while taking multiple sustainability constraints into consideration

d) Assess good practices to discover why and how people reduce their environmental footprints, and how such behaviours can be incentivised and mainstreamed.

This report is a first step to connect the consumption of wood products with what happens in the forest. Our findings should be a warning flag and a call to action for policy makers to address wood consumption. It is the start of a discourse about how wood should be best used in a balanced bioeconomy.

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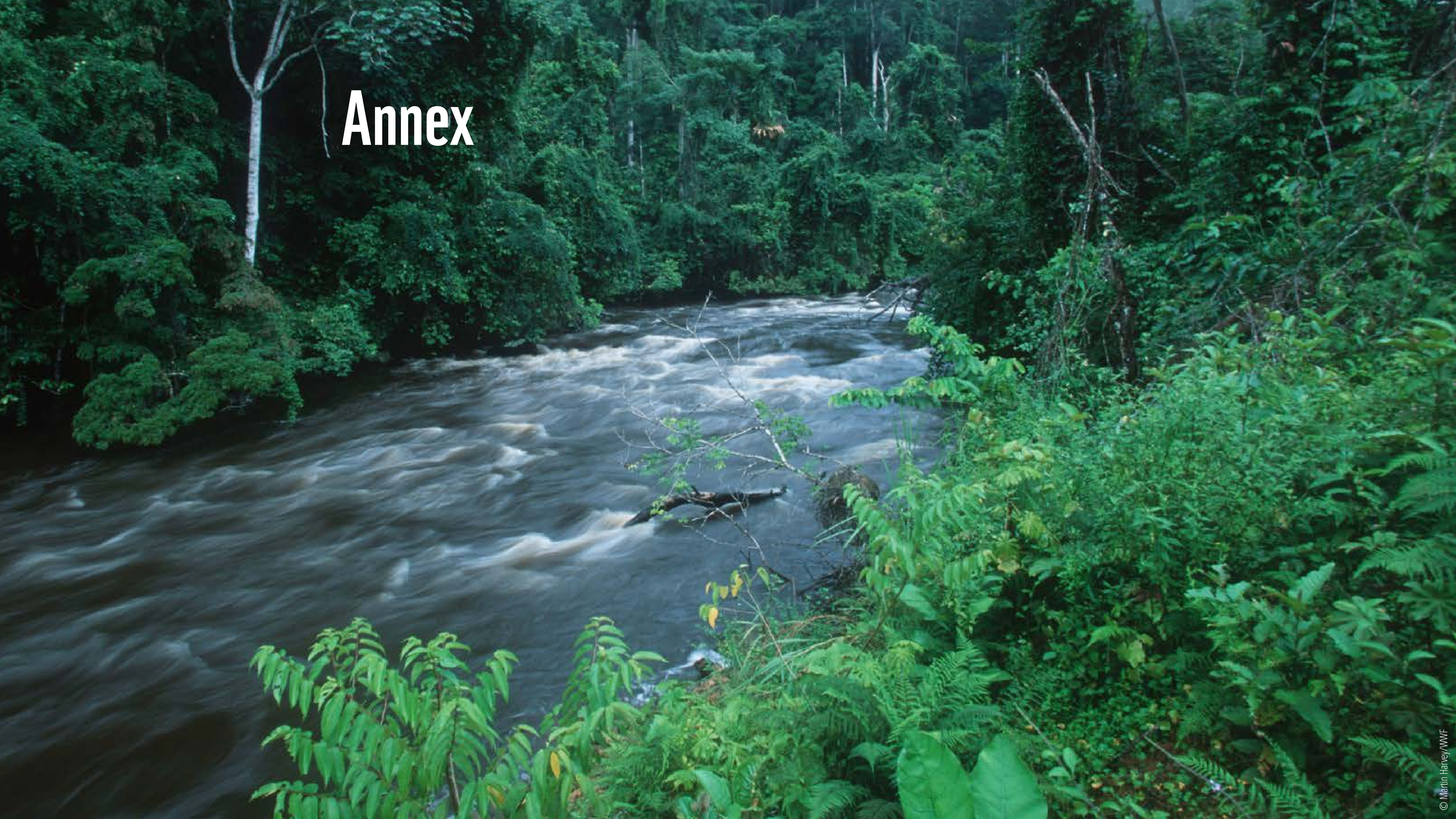
Annex



Abbreviations and units

List of abbreviations

AAC	Annual allowable cut
AZE	Alliance for Zero Extinction
BMEL	German Federal Ministry of Food and Agriculture
CBD	Convention on Biological Diversity
CCF	Hundreds of cubic feet
CLT	Cross-laminated timber
EEA	European Environment Agency
ee-MRIO	Environmentally extended multi-regional input-output
EU	European Union
EUTR	European Timber Regulation
FAO	Food and Agriculture Organization of the United Nations
FAWS	Forest available for wood supply
FLR	Forest landscape restoration
FRA	Forest Resources Assessment
FSC	Forest Stewardship Council®
GDP	Gross domestic product
GHG	Greenhouse gas
GINFORS	Global Interindustry FORescasting System
GIS	Geographic Information System
GFPM	Global Forest Products Model
GRAS	Global Risk Assessment Services
IBPES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
ICCA	Indigenous and community conserved area
ITTO	International Tropical Timber Organization
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
KBA	Key biodiversity area
LULUCF	Land Use, Land Use Change and Forestry
MAI	Mean annual increment
MMCF	Man-made cellulosic fibres
NAI	Net annual increment
NYDF	New York Declaration on Forests
o.b.	Over bark
OECM	Other effective area-based conservation measures
R&D	Research and development
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SDG	Sustainable Development Goal
SPOTT	Sustainability Policy Transparency Toolkit
SSP	Shared socio-economic pathway
ToF	Trees outside forests
u.b.	Under bark
UN	United Nations
UNECE	UN Economic Commission for Europe
UNEP	UN Environment Programme
UNEP-WCMC	UNEP World Conservation Monitoring Centre
UNFCCC	UN Framework Convention on Climate Change
USA	United States of America
USD	US dollar
WHO	World Health Organization
WWF	World Wide Fund for Nature

List of units

CO_2	Carbon dioxide
CO_2eq	Carbon dioxide equivalents
Gha	Billion hectares
Gm^3	Billion cubic metres
Gt	Billion tonnes
ha	Hectare
kha	Thousand hectares
m^3	Cubic metre
Mha	Million hectares
$m^3/ha*y$	Cubic metres per hectare per year
Mm^3	Million cubic metres
Mt	Million tonnes
Mtoe	Million tonnes of oil equivalent
Pg C	Petagrams of carbon
PJ	Petajoule

Consumption footprints – extended methods

Given the limited supply of global resources, sustainable development is only possible by decoupling value creation and resource use. Furthermore, it must be ensured that the planetary limits of resource availability are not exceeded. This requires detailed monitoring of the consumption of abiotic and biotic resources at the country level. In this study, the environmentally extended multi-regional input-output analysis (ee-MRIO) method was chosen to calculate German round-wood equivalent consumption and its origins. The following sections explain in more detail how the method works, and which research questions can be answered.

Environmentally extended multi-regional input-output analysis (ee-MRIO analysis)

What is an ee-MRIO analysis?

Input-output analysis models have been used for many years to quantify the exchange between all production and consumption sectors in a national economy. Leontief received the Nobel Prize for his approach in 1973. In the 1980s the concept was extended to include the exchange between the economy and the environment. For this purpose, monetary input-output models were coupled with material flow accounts (Leontief et al., 1982). When the environmentally extended input-output tables of several countries or regions are combined, ee-MRIO tables can be established.

The basis of a MRIO analysis is a large matrix where economic sectors in different countries are viewed in relation to one another (Annex table 1). In our case, this matrix contains data for 200 products and combines 49 countries and regions with about 96 million data entries. The matrix delivers information about how much of the monetary value added from every sector in every country is consumed in any sector in any country covered. To transfer the monetary "consumption" into physical units, a second "satellite matrix" containing the physical production of all primary materials for all countries covered is used. Combined with a third "final demand" matrix, the final consumption of products and materials can be traced back to their origin.

The structure of an MRIO database is shown in Annex table 1. The connection between regions and sectors allows monetary and resource flows to be tracked along the value chain.

Annex table 1: Structure scheme of an MRIO database

		SECTORS			FINAL DEMAND		
		Region 1	Region 2	...	Region 1	Region 2	...
SECTORS	Region 1	Input	Imported input	Imported input	Final demand	Imported final demand	Imported final demand
	Region 2	Imported input	Input	Imported input	Imported final demand	Final demand	Imported final demand
	...	Imported input	Imported input	Input	Imported final demand	Imported final demand	Final demand
	Value added	Value added	Value added	Value added			

How did you calculate the timber footprint of final consumption?
The data was based on earlier work conducted by the Institute of Economic Structures Research (GWS)[149] (MRIO calculations) and the University of Kassel, Center for Environmental Systems Research[150] (forest expertise) as part of the SYMOBIO project[151] (Systemic Monitoring and Modelling of the Bioeconomy).

In this report, the newest version (EXIOBASE 3.8.1) of the environmentally extended input-output matrix EXIOBASE 3 (EXIOBASE Consortium, 2021) covering the period from 1995 to 2022 is used as a base for the footprint calculation (Stadler et al., 2018; Tukker et al., 2016). The database covers 44 individual countries and 5 Rest of World (RoW) regions; 200 different products and 160 industries are included.

The procedure for calculating the footprints is as follows[152].

For all (n) sectors, the total output (X_i) of a sector (i) is the sum of intermediate inputs supplied (X_{ij}) and final demand (Y_i) for the sector's goods:

$$X_1 = X_{11} + X_{12} + \dots + X_{1n} + Y_1$$
$$X_n = X_{n1} + X_{n2} + \dots + X_{nn} + Y_n$$

Input coefficients describe the inputs required for production (or the cost structure) for each production area. The inputs are expressed in relation to the corresponding production values.

$$a_{ij} = \frac{X_{ij}}{X_j}$$

Substituting the X_{ij} in the above system of equations, we get a system of n inhomogeneous linear equations.

$$X_1 = a_{11}X_1 + a_{12}X_2 + \dots + a_{1n}X_n + Y_1$$
$$X_n = aX_1 + a_{n2}X_2 + \dots + a_{nn}X_n + Y_n$$

In matrix notation, the system of equations is as follows

$$x = Ax + y$$

A is the square nonnegative matrix of the input coefficients, x is the n-element column vector of the outputs, and y is the n-element column vector of the total final demand. Isolating the output vector x gives

$$(I-A)x = y$$
$$x = (I-A)^{-1}y$$

The matrix $(I-A)^{-1}$ is called the Leontief inverse. Given that the final demand (y) and the coefficient matrix (A) is known, the sectoral outputs (x) can be calculated as the total economic output of a respective sector in a respective nation as a function of the final demand y of the consuming nation. The footprint calculation is based on the standard Leontief input-output model (Miller and Blair, 2009). A detailed description of this method was published by the GWS[153].

Adaptation of EXIOBASE 3.8.1 for this study
Several parts of the database were adapted. The quantities of roundwood production in countries and regions (named "domestic extraction used" in EXIOBASE) are given in the unit kilotons in the original database. These values are converted into m³ based on currently reported roundwood production by FAO.

The statistical data was cleaned, as the data can contain minor errors, such as slipped decimal separators or data outliers for individual years. Furthermore, deviations in the volume and direction of trade (mirror flows) between EXIOBASE and FAOSTAT were cleaned. The MRIO database itself was also checked for irregularities. One result of comparing the official FAO trade statistics with the calculated results was that EXIOBASE overestimates the role of German direct imports from regions in the rest of the world. For further information, see the SYMOBIO project reports[154].

149 https://www.gws-os.com/de/
150 https://www.uni-kassel.de/forschung/cesr/forschungsgruppen/surf
151 www.symobio.de
152 https://symobio.de/wp-content/uploads/2018/10/gws-paper17-7.pdf
153 https://symobio.de/wp-content/uploads/2018/10/gws-paper17-7
154 www.symobio.de

MRIO alternatives

Is the MRIO you are using the only available database for this purpose?
The method of environmentally extended multi-regional input-output analysis (ee-MRIO analysis) has been increasingly used in scientific studies over the last decade. Various databases have been built: WIOD (Timmer et al. 2015), GTAP (Peters et al., 2011), Eora (Lenzen et al., 2012) and EXIOBASE (Stadler et al. 2018) are some of the examples; others are currently under development[155]. In all of these databases, a country's final consumption of a resource or a product can be traced back to the origin of primary extraction.

Research examples of MRIO-based footprint calculations

Has this method already been used and published by other research teams?
Yes, the method is used in numerous publications and for different target questions. In terms of wood consumption assessments, three key examples were published in 2021. Lenzen et al. (2021) calculated the global abiotic and biotic material footprint from 1970 to 2019 based on the Eora database. The biotic fraction of the material footprint includes the use of wood, but it is not explicitly reported. Dorninger et al. (2021) used an intersection of the global human appropriation of net primary production (HANPP) with the MRIO EXIOBASE 3 to show the effect of industrialisation on global land use. Bringezu et al. (2021) also used the MRIO EXIOBASE 3.4 to show the collected environmental impacts of the German bioeconomy in the context of the indicators "agricultural biomass footprint", "forestry biomass footprint", "land footprint", "water footprint" and "climate footprint".

Can the timber footprint of consumption also be calculated with different methods?
Yes, an ee-MRIO analysis as it is used for this study is one possible way to assess the resource footprints of products and nations. The method differs, for example, from that of (O'Brien and Bringezu, 2018, 2017a, 2017b), where a forest product chain-based life cycle approach was combined with a country-based accounting of roundwood production. Building on this method, the EU's Joint Research Centre published a report on land footprints in 2022 (Laurentiis et al., 2022). In this report, the forest land footprint is calculated by adding an additional step to the method used by O'Brien and Bringezu, (2018, 2017a, 2017b). The consumed "primary raw wood equivalents" are converted via net annual increment values into the forest area needed to cover this consumption.

Annex table 2: Global multi-regional input-output databases. Comparison of different MRIO databases

				ENVIRONMENTAL EXTENSIONS				
DATABASE	REGIONAL DETAIL	SECTOR DETAIL	PERIOD COVERED	LAND USE-RELATED	CARBON EMISSIONS-RELATED	WATER USE-RELATED	POLLUTION EMISSION-RELATED	AVAILABILITY
EORA	187 countries	Variable (26 – 511 sectors)	1990 – 2012		Yes	Yes	Yes	Free for use at degree-granting academic institutions
Exiobase 3	44 countries, 5 regions	163 sectors, 200 products	1995 – 2022	Yes	Yes	Yes	Yes	Free under licence
GRAM	54 countries, 1 region	48 sectors	1995, 2000, 2005		Yes			Not available
GTAP	122 countries, 18 regions	57 sectors	2004, 2007, 2011	Yes	Yes			Proprietary
WIOD	40 countries, 1 region	35 sectors	1995 – 2011	Yes	Yes	Yes	Yes	Free

Source: Adapted from Marques et al.(2017)

155 For example, researchers in Vienna are developing a model to calculate timber footprints based on physical flows (personal communication with Rosadio, 2 December 2021). See also the symobio.de website on bioeconomy monitoring in Germany.

Deviations from the results of other studies

Why do the thematically related studies not always come to the same results?

On the one hand, the results of such calculations are influenced by the target questions and the method used; on the other hand, they are strongly influenced by the input data. An identical version date is a prerequisite for comparability, especially when statistical information from national and international databases is used, since these databases are updated and corrected at irregular intervals. The same is true for GIS-based analyses.

Another reason for different results is the inclusion/exclusion of different processing stages of the material across the life cycle. For example, the Thünen Institute's wood flow diagram[156] takes secondary flows into account. This shows that the traded quantities total is significantly larger than when the analysis only covers primary resources, as is the case in the footprint calculation in this report, which focuses on the extraction of timber from forests. Both method types are thus critical for policy makers to be able to make evidence-based decisions – they answer different research questions and can provide complementary data sets.

Tracing of individual products

Are you able to trace individual wood products (e.g. a chair) along the whole value chain?

Not with the current resolution. We are able to differentiate 200 different product classes for 49 countries and regions[157]. One example is the product class "Furniture and other manufactured goods n.e.c." (not elsewhere classified). Here, however, no distinction is made between specific individual items. The global resolution of the database comes at the expense of the level of detail, so that it still remains manageable. Theoretically, it would be possible to track individual products along the value chain using this method. However, this would require the corresponding data to be available in full resolution for every country in the world, which is currently not the case.

Conversion factors for individual wood products

What conversion factors are you using to convert individual timber products to weight or roundwood equivalents?

In the MRIO, product flows are expressed in monetary terms. The final demand must therefore be converted into physical units (m^3). For this purpose, the m^3/€ coefficient is used. This is obtained by dividing the total roundwood production of a country by the total value added of the primary forestry sector in that country. Note: This is what makes it different to other methods, which rely on tracing purely physical flows (Laurentiis et al., 2022; O'Brien and Bringezu, 2018, 2017b, 2017a) where specific conversion factors are needed to convert individual products (e.g. a chair, a table) into roundwood equivalents.

Multiple counting of wood volume through downstream processing steps

How do you avoid counting roundwood equivalents multiple times when residual materials from one sector are used in another?

The MRIO method used here avoids multiple counting from the onset. The database contains information on the total value added and the total material input (only primary material is taken into account) for the primary sector "forestry" in each country. Based on this information, the coefficient m^3 of wood production per € of value added can be derived. Starting from forestry, wood passes through the various processing stages of the value chain. Following the same logic, the final economic value of each product is the sum of all values added along the value chain. Since the database must be balanced, total input (total value added by all primary forestry sectors) equals total output (total final demand for wood-related products and services). Finally, the total final demand in monetary units (e.g. for a product or for all products in a country) can be converted into physical units via the calculated coefficient (€/m^3). This represents the total resources extracted from nature that were needed for an economic interaction.

156 https://www.thuenen.de/de/wf/zahlen-fakten/holzbilanzen/gesamtholzbilanz/
157 Detailed information about the structure, products and industries of the EXIOBASE database can be found in the supplementary information in Stadler et al., 2018.

Secondary material flows

What about secondary material flows and recycling material?
Only primary material (wood) is accounted for in the analysis. Secondary flows are not included in the input-output matrix due to the way these models are built (see the description in the previous section on how they are based on an economic distribution of only primary flows at the onset). This applies to recycled wood (e.g. from old furniture) and to all secondary material flows mixed in the paper and packaging sector. In order to be able to record secondary flows using this method, additional independent sectors would have to be incorporated into the database as extensions, as was done by Wiebe et al. (2019), based on the hybrid accounting method of Merciai and Schmidt (2018).

Known problem of trade statistics

How do you cope with the usual statistical problem that large commodity points (e.g. large ports like Amsterdam) distort trade statistics?
This problem occurs when large quantities of goods, such as coffee, appear in the exports of a country that is not a producer of these goods because of the existence of large transhipment centres (e.g. Rotterdam in the Netherlands). This can give the impression that the country is a major producer of the goods in question. The fact that these goods are re-exports from other countries is masked. With the MRIO method, any product along the value chain can be traced back to the country of origin where the primary material was extracted. Genuine exports and re-exports can therefore be identified and reported separately.

Gaps and research needs

What limitations does the MRIO method have?
The results of classical MRIO analysis are strongly impacted by price changes. This is due to the fact that the material flows are tracked in monetary units along the value chain and only in the last step is the final consumption translated back into physical units. Giljum et al. (2019) compared the results of a material footprint analysis between the three MRIO databases: Eora, EXIOBASE and ICIO. They found that especially the primary raw material extraction and basic processing sectors explain 60% of the total deviation of results. This is due to the fact that the global MRIO databases show different monetary values for the deliveries of these sectors both within the domestic economy and in trade with other countries. This leads to significant differences in the material footprint results due to the large amount of materials included in the respective supply chains.

Although there are examples of the calculation of "forest footprints" as presented, there is still a great need for research in this field. Budzinski et al. (2017) have shown the possibility of a structural decomposition of the German wood-based economic sectors based on an earlier version of EXIOBASE 2. This method serves the purpose of expanding the degree of detail of the analysis to include more wood-based products and thus to better reflect more specific market changes. However, the degree of detail is not available for every country on a global basis. Furthermore, with each additional sector in the database, its size increases dramatically, and with it the computational effort. Adding only five more products increases the number of elements in the main matrix by five million entries.

Conclusions and next steps

The overall research field is expanding rapidly. Lenzen et al. (2021) published a paper to show the potential utility of MRIO-based material footprints in general and the new data capacities for trying to move these indicators from Tier II to Tier I in the UN SDG indicator framework. With regard to forestry and wood flows specifically, our results depict the usefulness and applicability of such monitoring tools. Such indicators should be taken up and strengthened by official statistical institutions as part of their methodological toolboxes for monitoring sustainable wood consumption.

Sustainable wood supply – extended methods

Multiple steps were taken to determine the risk corridor for sustainable wood supply capacities in terms of quantities. These include the following steps.

1. Determine how much forest is available for wood supply
2. Estimate the net growth of available forests, and the share which can be "sustainably" harvested
3. Compare results to literature and alternative methods (plausibility check)
4. Compare the results to consumption, adjusted to be comparable

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This section contains some more in-depth considerations on the methods described in the previous sections of the report. In general, it must be emphasised that this report presents the type of approach (benchmarks) we think is necessary to support strengthened monitoring. This should be interpreted as a starting point for further research, not a method that is set in stone.

Forest available for wood supply (FAWS)

Forest available for wood supply (FAWS) is calculated by combining multiple data sources to make the best possible estimate. This was done at a country level. The multiple data sources are based on different methods, and thus provide sometimes quite different estimates. We relied on satellite images (GIS analysis), FAO Global Forest Resources Assessments over the years (gathering different indicators over time and relying on country-based reporting) and country-specific estimates (which may rely on more detailed forest inventories). Each of these data sources has weaknesses and strengths and the challenge is that they do not always align. For that reason, we used expert judgement to make estimates based on the data.

In the GIS analysis, spatially explicit maps for 2015 obtained from two sources are analysed to combine their information. First, the land cover maps produced by the European Space Agency – Climate Change Initiative (ESA, 2017) show the extent of forest area. Second is "the global forest management layer" produced by Lesiv et al, (2021). The first map provides information on how much forest area a country has, while the second map provides a breakdown by use class (1. primary forest, 2. secondary forest, 3. planted forests, 4. short-rotation coppice, 5. oil palm plantations, 6. agroforestry). To determine FAWS, only use classes 2–4 and 6 are considered in this study. Classes 2, 3 and 6 constitute the "production forest" area. It should be noted that only the portion of class 6 "agroforestry" that falls under the FAO forest definition is used (e.g. no area in Germany is assigned to class 6). Agroforestry systems in which the trees are not used for timber supply should not be considered as part of "forest available for wood supply". However, in some contexts, agroforestry is used to supply timber (e.g. there are estimates from India to this end, see below). Using the current data , it was not possible to distinguish when and how agroforestry contributed to timber supply and when it did not. Omitting this use class would have led to wider differences in the total global forest area reported by FAO and the total global forest area determined by the GIS analysis (these do not align perfectly).

We therefore decided to assign these areas to FAWS. Finally, in GIS, the areas of class 4 "short-rotation coppice" are exclusively attributed to "plantation forests" in our evaluation.

In the future, another approach to estimate FAWS, or potentially even sustainable quantities, would be to do a bottom-up analysis of each country's forestry concessions or nationally determined quotas and/or regulations. For example, the Global Forest Watch[158] platform assesses logging concession data in countries. So far, this method has only been undertaken for nine countries, revealing that 26% of the total forest area in those countries is "available" for logging in a regulatory sense (concessions do not always imply active logging). Intact forests comprised 13% of the concession area. While national and sub-national forest agencies tend to have collected detailed data, this data is often not publicly available, nor is it globally consistent. Improving transparency and comprehensiveness could go a long way to strengthening the robustness of our benchmark.

The literature review and selection of FAWS for the "Big 5" are described in Annex table 3.

Annex table 3: Supplementary information – Adaption of the "Big 5" FAWS values

COUNTRY	NFI VALUE AAC (MM³)	NFI VALUE AREA (PRODUCTION FOREST) (MHA)	SOURCE	LESIV+CCI (PRODUCTION + PLANTATION) (MHA)	FRA 2020 % PRODUCTIVE + MULTIPLE USE (MHA) ON LESIV TOTAL FOREST AREA 2015	REASONING
China		94.59	National Forest Inventory, 2019. Forest Resources in China – The 9th National Forest Inventory, China Forest Resources Monitoring. Beijing, China.	**129**	147	NFI data < GIS result and closer to GIS than to FRA. Therefore GIS is chosen.
Canada	217.9	**217.9/1.81 (mid NAI)= 120.39**	Natural Resources Canada, 2020. Canada's forests: Adapting to change. The state of Canada's forests. Ottawa, Canada.	115	297	NFI AAC number is higher to GIS result. Therefore NFI number is chosen.
Russia		**300**	Leskinen, P., Lindner, M., Verkerk, P.J., Nabuurs, G., Wunder, S., 2020. Russian forests and climate change. European Forest Institute, Joensuu, Finland.	224	461	NFI result > GIS result. NFI is chosen.
Brazil		98	ITTO, 2005. Country Profile Brazil. Yokohama, Japan.	**104**	208	NFI < GIS result, closer to GIS than to FRA and old source. GIS is chosen.
USA			FAO, 2020. Global Forest Resources Assessment 2020	215	**221**	GIS and FRA result very similar. No NFI data. FRA number is chosen.

Notes: Bold values = used in the report

NFI = National Forest Inventory; AAC = annual allowable cut; FRA = Forest Resource Assessment; CCI = Climate Change Initiative; GIS = Geographic Information System.

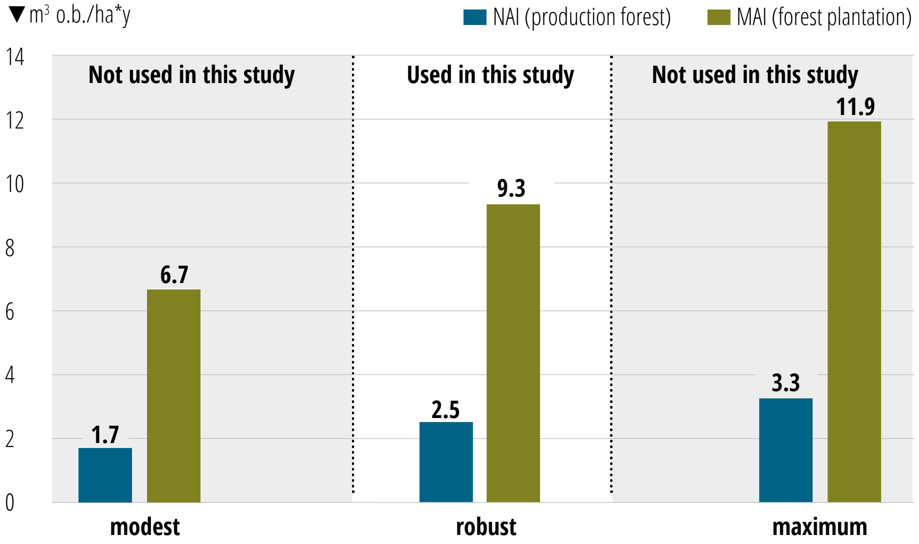
158 Online resource of the World Resources Institute; available at: https://research.wri.org/gfr/forest-designation-indicators/production-forests

Net annual increment

As described in Section 4.3.3 of this study, three different increment categories were derived: a modest, a robust and a maximum country-specific NAI and MAI. The results of the analysis are summarised as global averages (Annex figure 1). The data sources used provided single-year values or time series. In addition, data points for individual years may differ, depending on the source used. To define the three levels, the lowest value reported in any of the sources examined is used as the modest value. Similarly, the highest value is used as the maximum value. The robust category is the average of all increment data reported for a single country. For transparency reasons, only the robust values are considered in this study.

In particular, MAI values would require perfect climate and soil conditions for "maximum" increment, which is not the case for large forest areas. This would lead to a significant overestimation of increment. The modest NAI values are at the lower limit of the data reported in the sources used. Since the average increment rates of various individual periods over the last 20 years are considered, there is a risk here that the modest NAI underestimates increment.

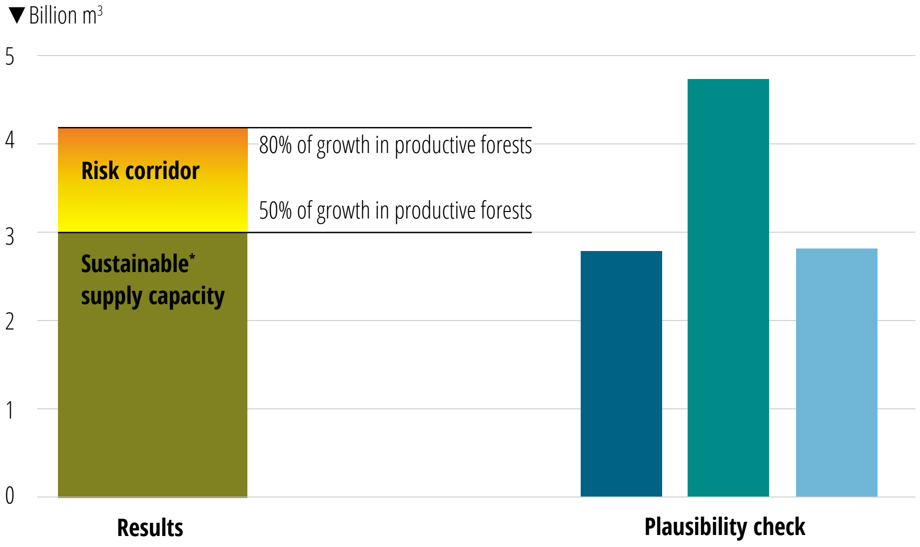
However, as described in Section 2.5, the severe impacts of climate change may reduce the average NAI towards the modest NAI in the future.



Annex figure 1: Overview of global NAI and MAI (in roundwood) values based on the described sources

Plausibility check of results

This study estimates a corridor between 50% (low risk) and 80% (high risk) of NAI on available productive forest area. Our risk corridor thus ranges between 3.0 and 4.2 Gm^3. These results were compared to illustrative calculations and literature sources as a plausibility check. Annex figure 2 depicts how the risk corridor would relate to global calculations following a different approach. For example, Canada and Russia have an allowable cut that is roughly equivalent to 0.5% and 0.85%, respectively, of their total growing stock (from all forests – not as the sustainability requirement but as a rough and theoretical indication of “harvestable” quantity compared to total quantity). Taking these percentages as a global indicator shows that 0.5% of global growing stock would equate to a value somewhat below our lower boundary (2.78 bilion m^3) and 0.85% of global growing stock would be somewhat above our upper boundary (4.73 Gm^3; see Figure 4.11). It should be noted that some researchers judge the Russian boundary to overstimate realistic supply capacities by two-fold (see Section 4.2). If 1% of the total productive area could be harvested annually, the volume of wood growing in that area would be equivalent to 2.81 Gm^3. These calculations are rough and should be interpreted as illustrative. Yet, they do indicate that **our results are in the order of magnitude generated by alternative calculations.**



Annex figure 2: Comparison of the sustainable* supply capacity and risk corridor to alternative and illustrative calculation approaches

Note: *Sustainability here refers to quantity considerations, which is only one consideration when aiming for holistic forest management.

The literature on global supply capacities that take ecological constraints into consideration is limited. In 2021 researchers estimated a planetary boundary for global timber supply of 7.1 Gm^3 (Zhang et al., 2021). However, they did not appear to consider any limitations to the share of growth which can be harvested under sustainability considerations, and it is unclear whether and how limits to forest area were taken into account. Nevertheless, they found that **harvests in 47 nations exceeded their national forestry boundaries (mostly in Africa and Asia)** and that these **overshoots were mainly driven by the high levels of demand in high-income countries.** Finally, a previous study from 2015 estimated a rough global sustainable supply capacity for 2020 that is similair to the results presented here: namely between 3.2 and 4.4 Gm^3 (O’Brien and Bringezu, 2017a).

Adjusting production for bark and harvest losses

To compare production and consumption to the sustainably available net annual increment of forests (NAI) the metrics must be the same. However, the official reported roundwood production figures are commonly reported under bark so that an adjustment is needed. We add 12% of roundwood volumes as bark, which is in line with FAO and ITTO recommendations (FAO et al., 2020). In addition, a portion of the total wood volume of a tree is always lost during harvest and remains in the forest. This share differs for different harvest procedures and tree species. We add 10% of the volume as harvest losses following Englert et al., (2018). The total adjustment of +22% added to the official production value in this study is close to the result of Pilli and Grassi (2021), who calculate an average share of +27% "irretrievable losses" for the EU28 countries.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Statistics on forest roundwood have to be adjusted for trees outside forests.

Adjusting for trees outside forests (ToF)

All trees which do not fullfill FAO criteria for forest ("[l]and spanning more than 0.5 hectares with trees higher than 5 metres and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use") are known as trees outside forests (ToF). These ToF play an important role for nature and humans, but are not yet well documented (Schnell et al., 2015). FAO is well aware of this problem and is working to improve its data and support national reporting (FAO, 2018). The gradual improvement in remote sensing techniques is also improving the data situation on ToF. Brandt et al. (2020) used satellite images to analyse ToF in the West African Sahara and Sahel and found an unexpectedly large number of over 1.8 billion ToF. Based on a study in Bangladesh, Thomas et al. (2021) found that ToF are an underestimated resource.

The official FAO statistics on industrial roundwood and woodfuel production do not distinguish whether the wood is harvested on forest land as defined or on ToF. To be comparable with the calculated sustainable harvest potential, the amount of roundwood harvested on ToF should be subtracted from the total value of roundwood production. A few sources provide general estimates on gathering practices. For example, Heruela (2003) estimates woodfuel from trees outside the forest in Asia as comprising 60% on average. On average, 40% of the charcoal in Nairobi, Mombasa, Nakuru and Kisumu is harvested on rangeland instead of forests. In India, more than 90% of the industrial roundwood production is provided from agroforestry and ToF. Following the approach of Smeets and Faaij (2007), ToF is assumed to contribute only to the harvested woodfuel volume and not to the industrial roundwood volume. Due to the lack of country-specific data, exploratory adjustment values are derived and applied (Section 4.3.3) for all of Africa (-50%), all of Asia (-60%), and India (-49%) (FAO, 2001, 1983; Heruela, 2003; Kammen and Lew, 2005).

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