Carbon sequestration through forest management and wood use

This fact sheet is a product of the ACRP project "Strategies for the optimal bioenergy use in Austria from societies point-of-view – Scenarios up to 2050" (BIOSTRAT). The fact sheet intends to show how Austrian forests can contribute to carbon sequestration and at the same time provide incentives for forest management and an optimised use of wood as a resource.

BEST Bioenergy and Sustainable Technologies
BFW Austrian Research Centre for Forests
TU WIEN
klima+ energie fonds

Main statements

- Austrian forests are an important part of the carbon cycle and can counteract climate change sequestering carbon dioxide from the air in biomass and in the soil (CO_2 sequestration). The increase in carbon stocks in forest biomass and in wood products improves Austria's greenhouse gas balance.
- Forests are managed with many objectives in mind. Forests supply the bioeconomy, protect against natural hazards, purify air and water and are an essential element of the landscape. This multifunctionality goes hand in hand with the storage of carbon in the biomass and in the soil.
- Long-living wood products replace non-biological products and can be used for energy at the end of their life cycle (= cascading wood utilisation). The energetic use of sustainably produced forest biomass (residual forest wood, sawmill by-products, firewood, etc.) is an indispensable component of the Austrian energy transition in the medium term.
- Forest damage caused by storms, fires, drought and bark beetles, is increasing with climate change. As a result, carbon stored in forests is released back into the atmosphere.
- Climate change requires rapid adaptation of forest management in order to minimise carbon losses and maintain, or ideally improve, CO_2 sequestration. Possible measures include the choice of resilient tree species, optimised harvesting strategies, and an increase in forest area.
- At the current rate of climate change, the future of our forests is uncertain and their function as a carbon sink is difficult to maintain.

Forests - climate victims and a beacon of hope at the same time

Forests play an important role in the political and social debate on climate change. The guiding principle of Austrian forestry is multifunctionality. Forests simultaneously fulfil different functions such as the provision of wood and natural habitats for animals and plants, protection against natural hazards, recreational space for people and at the same time they contribute to climate change mitigation by sequestering atmospheric CO_2 (Forest Act, Federal Law Gazette 440, 1975). Different actors and interest groups, such as forest owners, nature conservationists, climate activists, the timber and sawmill industry, etc., place different priorities on the individual ecosystem services provided by forests. There are a variety of supporting and opposing arguments for each of their positions but conflicts of objectives between the various stakeholders and sectors are inevitable. A central question is whether forest management should be intensified or extensified in order to achieve climate mitigation in the best possible way.

Political embedding

The **European Forest Strategy** (EC, 2021) adheres to the classic goals of sustainable, knowledge-based forest management and forest protection. It emphasises that forests provide renewable raw materials for the bioeconomy and can therefore be a mainstay of the regional economy. The **Biodiversity Strategy** (EC, 2020) calls for the decommissioning of old-growth forests as refuges for animals and plants and the **Renewable Energy Directive** (RED I-III) (EC, 2018; EU, 2023, 2009) calls for the increased use of renewable energy sources, in particular through the use of wood by-products, to reduce the consumption of fossil fuels. The new version of the **LULUCF Regulation** (EU 841, 2018) provides for this, that forests sequester more CO_2 from the atmosphere and store it in biomass and soil. In this way, forests should compensate for the unavoidable greenhouse gas emissions from agriculture and from industry and transport. The regulation implies that the CO_2 sink capacity of forests can be prolonged and expanded. Austria is obliged to achieve a provisional overall target of 5 650 kt CO_2 equivalents as a sink in the LULUCF sector. The value is made up of the average for the years 2016-2018 and a 15% surcharge. The final overall target will not be set until after the 2032 LULUCF report.

CO_2 sequestration and CO_2 emissions

During the process of photosynthesis forest plants sequester atmospheric CO_2. Part of the bound carbon is respired by the plants and released back into the atmosphere, while another part is fixed in their biomass (needles, leaves, branches, trunk, roots). Dead biomass is decomposed by micro-organisms and most of the carbon is released back into the atmosphere as CO_2. The nutrients present in the dead biomass become available for renewed plant growth. Similar to decaying wood, harvested wood that leaves the forest is considered a CO_2 emission in the UNFCCC greenhouse gas balance. Figure 2 shows the CO_2 balance of the Austrian forest as reported in the greenhouse gas inventory. In recent years, for the first time, the sink capacity was not achieved and forests temporarily became a CO_2 source. The fluctuations in source and sink strength result from various factors, such as changes in harvest intensity or the occurrence of major disturbance events, but global warming also plays a direct role. For example, in very warm and precipitation-rich years, more organic carbon is decomposed in the soil and released as CO_2.

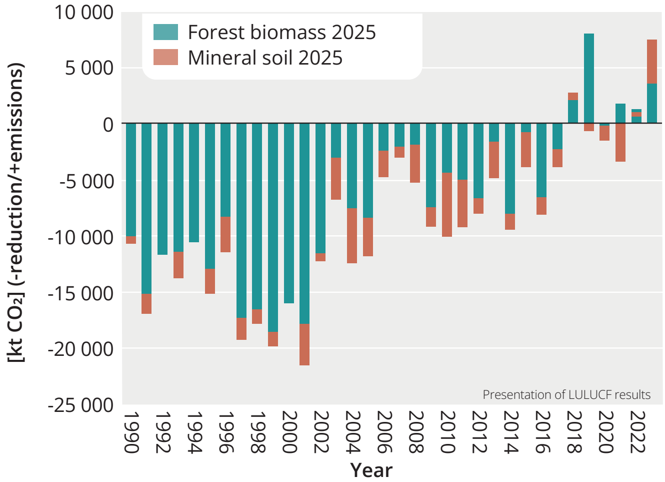

Figure 2: CO_2 sink effect (negative values) and source effect (positive values) of biomass and mineral soil of Austrian forests (forest land remaining forest land) from 1990 to 2023 (source: Federal Environment Agency, 2025)

In a rapidly changing climate, there is a risk that the carbon pool in forest biomass and soils will decrease rather than increase as a result of reduced tree growth and increasing disturbances (storms, snow, insects, drought, forest fires) (Kraxner et al., 2024). The annual amount of damaged wood is fluctuating. Abiotic damage, such as windthrow or snow breakage, occurs periodically and is favoured by extreme weather events (Figure 3). Forests have a certain resilience to external stress factors; once this is exceeded, the consequences of extreme events can no longer be mitigated by forest management. In some years, the wood harvests resulting from disturbance events amounted to more than 50% of the total wood utilisation in Austria (Figure 3).

The increased incidence of disturbance-related damage poses economic and logistical challenges for harvest operators and leads to increased management costs and low planning certainty for forest management.

Forest damage offers an opportunity to plant and promote climate-fit tree species and thus grow more resilient forests for the future. One problem is the selective browsing of these tree species (e.g. fir, sycamore maple, oak) when game populations are high. A consensus between hunters and forest managers is essential for limiting damage caused by excessive game populations, but it is difficult to achieve (Schodterer and Kainz, 2022).

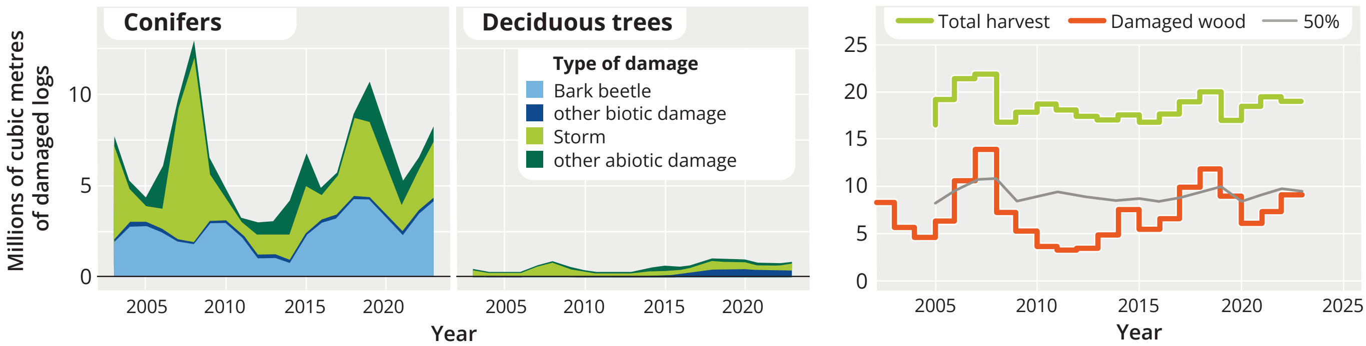

Figure 3: Damage in Austrian forests based on timber harvest report. On the left the amount of damage for coniferous and deciduous species, on the right the volume of damaged wood (orange) compared to the total harvest (green) and 50% of the total harvest (grey) (source: BML, 2023)

Impact of forest management and wood use

Three main forest functions in relation to greenhouse gas emissions are summarised in Table 2.

Table 2: Triple impact of forests on greenhouse gas emissions

Forest function	Outlook/assessment with regard to climate change mitigation measures
Carbon bound in biomass and soil	Focus on preserving forest carbon stocks through adapted forest management. An increase in biomass stocks is temporarily possible through forestry measures. Major influence of ecosystem disturbances (storms, pests), which can only partially be controlled.
Carbon bound in wood products	Significant mitigation effect can be expanded in the medium term through increased timber construction and further development of high-quality products such as glulam beams, etc. Focus on the durability of wood products.
Energy source / substitution effect	Wood enables CO_2 savings in the short and medium term by substituting fossil fuels. The substitution effect will decrease in the long term due to the expansion of other renewable energy sources and technical developments in the materials sector.

In a study on carbon flows in Austrian forests and the downstream value chain (Care4Paris), the effects of different forest management strategies on the carbon balance were analysed. The following future scenarios were compared:

- Reference scenario **R4.5**: Forest management and timber supply as before, under a regionalised climate scenario RCP4.5 (slightly above the +2°C target).
- Reference scenario **R8.5**: Forest management and timber supply as before, under a regionalised climate scenario RCP8.5 (well above the +2°C target).
- Calamity scenario **KAL**: Forest management and timber use as before, with a further increase in disturbance events under RCP8.5.
- Rotation time reduction scenario **UZV**: RCP8.5, reduction of the end-use age as a climate change adaptation measure.
- Tree species change scenario **BAW**: RCP8.5, change from conifers to native hardwood species as a climate change adaptation measure
- Stockpiling scenario **VAU**: RCP8.5, wood harvest will be gradually reduced by 2100.

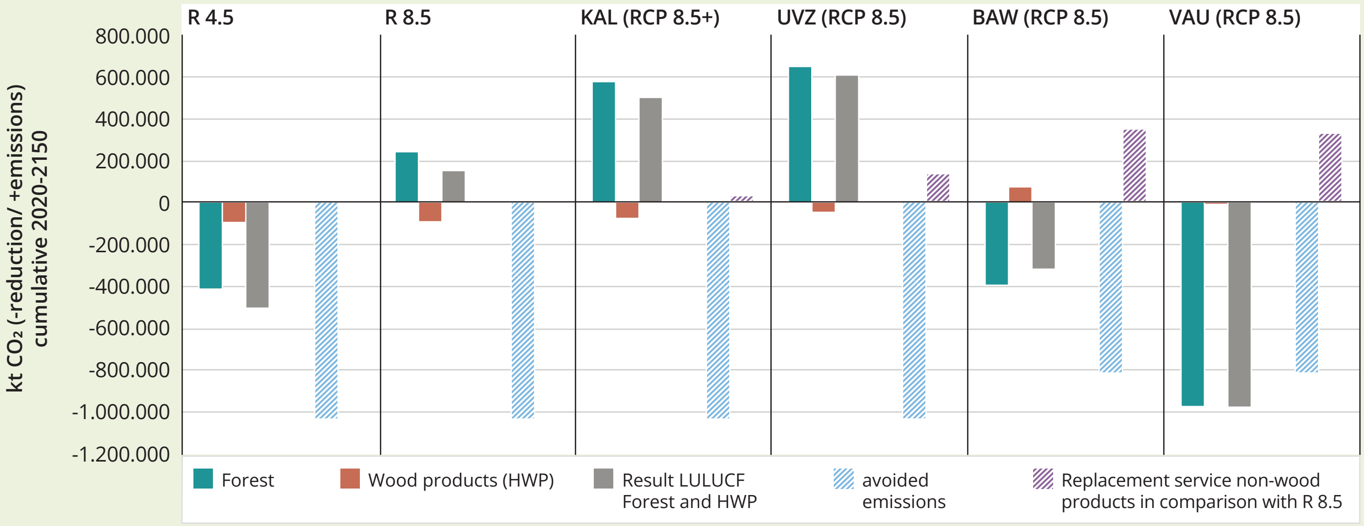

Figure 4: The cumulative source and sink effect of Austrian forests and wood products in the years 2020-2150. Results of the Care4Paris study from Weiss et al. (2020). Negative values mean CO_2 uptake, positive values mean CO_2 emissions. Avoided emissions occur when wood replaces other materials or fossil fuels. Substitute services are products that are manufactured from other materials because wood is not available. The detailed results of the Care4Paris study can be found in Box 5.1. in Kraxner et al. (2024), in detail in Weiss et al. (2020) and in a popular format in Lackner (2020).

The potential for carbon storage in forests can be significantly increased in the medium term if harvest is reduced (Figure 4 „VAU" green bar). However, the trees that are not harvested reduce the corresponding carbon sink in long- and short-lived wood products, reduce avoided emissions and lead to additional CO_2 emissions through the production of wood substitute products (Figure 4 „VAU" red, blue and purple bars).

The increased carbon storage in forest biomass ("VAU") is limited in time, as trees do not live and grow forever. The achievable short to medium-term CO_2 storage in forest biomass can contribute to meeting political targets for offsetting greenhouse gas emissions from other sectors. However, there are considerable risks to consider. Older forest stands tend to be more susceptible to disturbance. Larger trees offer more surface area to attack and thus are more likely to fall victim to windthrow. Susceptibility to drought stress and bark beetle infestation also increases with tree age. It is therefore necessary to consider on a case-by-case basis whether it is appropriate to reduce or abandon harvesting, taking into account the current and expected future regional disturbance regime.

It should also be borne in mind that if less forest is harvested in Austria, more trees are felled elsewhere in Europe or abroad as a compensatory mechanism to serve the market. This phenomenon is known in technical jargon as „carbon leakage" and is highly problematic because national measures (e.g. harvest reductions) do not lead to any improvement in climate mitigation across regions.

Forward-looking, site- and climate-adapted tree species selection and forest management measures are powerful levers for preserving forests and the carbon sink in the forest. The establishment of mixed stands makes forests less susceptible to biotic damage. The mixture of tree species with different regeneration strategies increases resilience. In addition, a proportion of tree species with pioneer characteristics can accelerate natural regeneration after a disturbance. Non-native tree species can contribute to the preservation of ecosystem services if the tolerance limits of native tree species are exceeded in certain locations, for example in low-lying areas, due to climate change (Baumgarten et al., 2024; Wessely et al., 2024). Using seeds that originated in warmer, drier regions and are therefore already genetically adapted to our future climate, is a promising option for climate change adaptation of managed forests and is subsumed under the term „assisted migration" (Chakraborty et al., 2024).

In the tree species change scenario, it therefore is possible to maintain or even increase the carbon stock in the forest (Fig. 4, „BAW"). However, wood utilisation decreases as the hardwood produced is not in demand on the market to the same extent as the wood from coniferous tree species. This reduces the modelled carbon sink in the wood products and increases the demand for substitute services (Figure 4, „BAW").

The efforts to create climate-adapted forests are manifold. The experiences are summarised on a website (www.klimafitterwald.at). In addition, there are numerous regional observations by forest experts that are incorporated into the decision-making process.

The use of tree biomass for energy provision is a controversial topic. In Austria, biomass for energy purposes is predominantly a by-product of wood processing. During the production of sawn timber, considerable quantities of by-products are generated, which are channelled into other product streams and ultimately into energy generation (Strimitzer et al., 2023).

In addition to sawmill by-products, firewood obtained directly from the forest also plays a significant role in energy provision. The production of firewood and other forest biomass is particularly relevant in rural areas with decentralised energy supply. Private small forest owners sometimes cover their own local energy requirements for heat generation.

CO_2 produced during the combustion of biomass is released directly into the atmosphere and excessive biomass extraction leads to nutrient losses and damage to the forest floor. However, if biomass comes from sustainable forestry (less biomass than re-grows is harvested only at suitable locations), its use is nearly CO_2-neutral and can contribute to climate protection by substituting fossil fuels. The capture and storage of CO_2 from biomass energy utilisation (BECCS: Bioenergy with Carbon Capture and Storage) is being considered as a method of CO_2 sequestration in the future (Kraxner et al., 2024). The share of energy generated from biomass in Austria is currently higher than energy production from wind, water and solar radiation together, and thus represents a central component of Austria's energy supply. Figure 6 shows the still enormous dependence on fossil fuels in Austria. There does not currently appear to be any scope for a targeted reduction in the provision of forest biomass for energy utilization for the purpose of increased CO_2 sequestration in standing forest biomass or dead wood necromass. Before that, fossil energy resources would have to be replaced by other renewable energy sources or the energy demand would have to be significantly reduced.

The future development of the use of biomass for energy provision can be optimised. In the ongoing ACRP project BioStrat, scenarios are being developed for the optimal utilisation of the declared biomass quantities up to 2050, based on a life cycle and techno-economic assessment. This includes forestry and agricultural biomass that is available for energy production. In future, the availability of firewood may decrease if the material use of wood can be optimised. This development depends on technological innovations in wood processing. In this context, the transition from coniferous forests to deciduous and mixed forests also represents an economic challenge for the wood processing industry. New developments in wood technology are aimed at finding solutions here (Boiger et al., 2024).

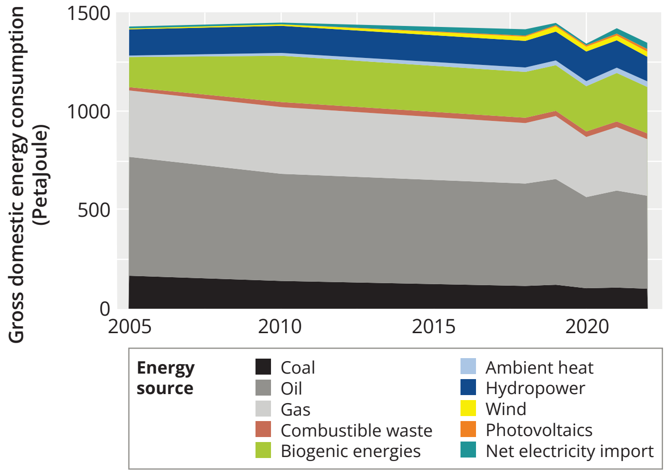

Figure 5: Gross domestic consumption in Austria by energy source in petajoules 2005 - 2023 (source: BMK, 2024)

Outlook

Austrian forests are expected to sequester CO_2 from the atmosphere and thus fulfilling the country's commitment to reduce greenhouse gas emissions. At the same time, the bioeconomy is to be supplied with wood assortments and biomass for energy production. Whether this will succeed altogether remains to be seen. Rapid climate change is increasingly leading to calamities that counteract the CO_2 sink capacity of forests. In addition to actively adapting forests to climate change („climate-fit forests"), there are options for increasing biomass carbon stocks and thus CO_2 sequestration in Austria's forests, at least temporarily. These include growth-optimised management and/or harvest reductions in order to sequester CO_2 in additional forest biomass. This needed to go hand in hand with a shift in the value chain towards fewer, more durable and higher quality wood products. On the other hand, high biomass stocks in the forest harbour the risk of high carbon losses in major disturbance (fire, bark beetle, storm, etc.). In all this discussion, it should not be overlooked that the effects of the rapidly occurring climate change are already placing a heavy burden on forest in Austria. An expansion of the carbon sink in Austrian forest can only succeed if greenhouse gas emissions are reduced in all sectors, so that global warming remains within a manageable corridor, and if forest management adapts to climate change as quickly as possible.

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Key numbers for Austrian forests

47.9% of Austria is forested. The forest area is just over 4 million hectares. The forest area and the wood harvest have been steadily increasing for decades (Table 1). With relatively constant growth (+3%), wood utilisation from the forests has increased (+40%). Nevertheless, less wood is still harvested in Austria than is regrown each year (Table 1). A considerable part of the harvested wood is damaged wood, which is increasingly occurring due to climate change. The proportion of deciduous and mixed forests has increased in recent years, while the proportion of pure spruce forests is decreasing (Table 1).

Figure 1 shows the average age structure of Austria's forests. The commercial forest is younger than the protection forest. Around 40% of the Austrian forest area has protective functions. The fact that protection forests are very strongly represented in the oldest age class, but only very weakly represented in the youngest age class, is a cause for concern. On the one hand, protection forests in hard-to-reach locations are used less for cost reasons, and on the other hand, high game densities often prevent natural regeneration (Schodterer and Kainz, 2022). Both of these factors lead to an overhang of old stands, i.e. an overageing of the protective forests.

In commercial forests, the proportion of stands over 100 years old is low (Figure 1). The rotation period (the age at which a forest is harvested) is 80 to 100 years under common forest management, which explains the high proportion of age classes 21-60 years in commercial forests. An extension of the rotation period through delayed harvest is being discussed as a possible measure to at least temporarily increase CO_2 sequestration in our forests.

Table 1: Structural data of the Austrian forest (commercial forest and protection forest in yield) Source and further data: www.waldinventur.at, (interim evaluation, accessed on 25 March 2025)

	1992/96	2018/23	% Change
Total forest area [million ha]	3,92	4,02	2,4
Spruce forests [million ha]	1,87	1,65	-11,8
Laubwald [million ha]	0,75	0,99	31,5
Standing timber volume [million m^3]	988	1 211	22,6
Wood growth [m^3/year]	27 337 000	28 239 000	3,3
Harvest [m^3/year]	19 521 000	27 253 000	39,6

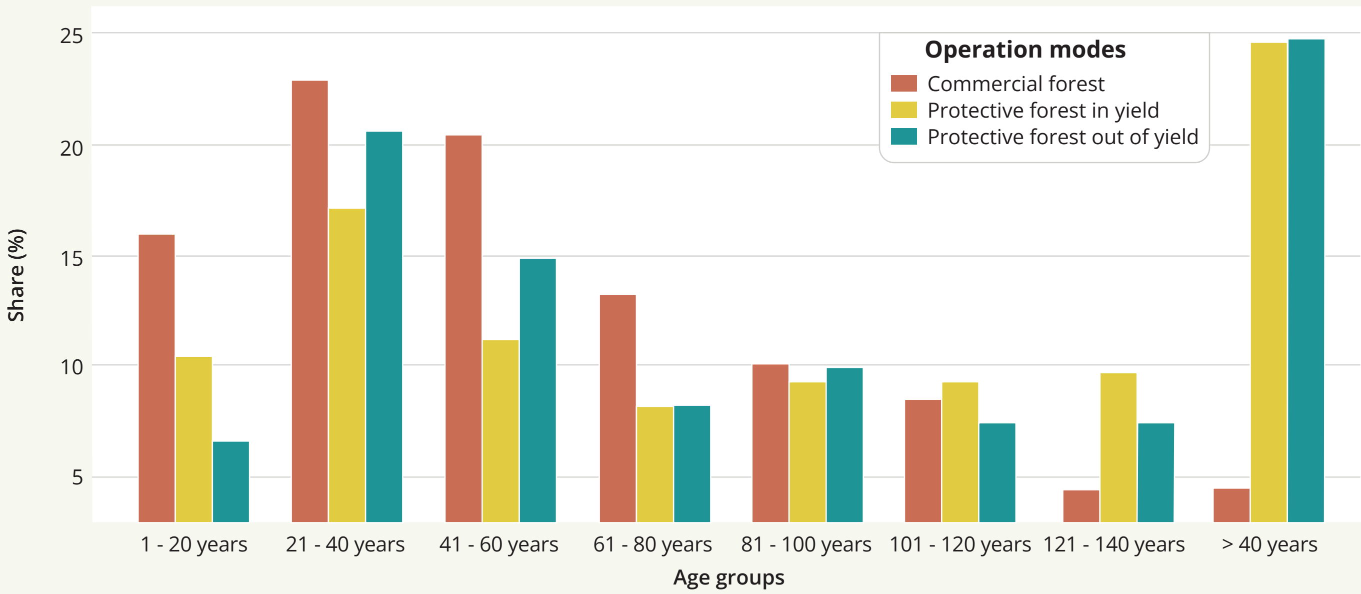

Figure 1: Area shares of the different types of operations in Austrian forests. Each type of operation adds up to 100%. (Source: www.waldinventur.at, accessed on 14/03/2025)

Forest carbon reservoir

In Austrian forests, around 320 million tonnes of carbon are stored in biomass and 515 million tonnes in the soil (Baumgarten et al., 2021; Weiss et al., 2000). According to the national greenhouse gas inventory, the „land management" sector is a sink for greenhouse gases. The CO_2 sink capacity of the Austrian forest is significantly influenced by its decades of underutilisation. In individual years, however, the forest can be damaged by large-scale disturbance events that warrant unplanned harvest on a large scale, or forests do not fulfil the expected CO_2 sink performance due to unfavourable climatic conditions (drought, heat) and represent a temporary source of greenhouse gases (Umweltbundesamt, 2024). Wood products are the second sink for greenhouse gases. Compared to forest biomass, the CO_2 sink capacity of wood products is around ten times lower.