Hubert Hasenauer

The importance of forestry to the carbon balance

Coal, natural gas and oil are the world's main sources of energy. But burning these fossil fuels releases carbon that was bound for millions of years in the earth's crust. And this is increasing the quantities of the greenhouse gas carbon dioxide (CO_2) in the atmosphere. It has been shown that in the past, the earth has experienced periods with lower and considerably higher amounts of CO_2 in the atmosphere than today. Lower CO_2 concentrations led to, among other things, ice ages in the past.

Temperatures change as a result of the relationship between plant growth and the CO_2 contained in the atmosphere. Higher levels of CO_2 in the atmosphere cause global warming, which in turn increases plant growth. More plants and faster-growing plants mean that photosynthesis increases so that more atmospheric CO_2 is bound in the biosphere. This in turn reduces the level of CO_2 in the atmosphere and consequently causes it to cool – thus resulting in less favourable growth conditions.

Throughout the history of the earth, the end of the warmer phases has been associated with large quantities of plants dying back so that their biomass was then locked into sediments. Over millions of years, this biomass turned into oil, natural gas and coal. Since the beginning of industrialisation, these fossil energy carriers have been increasingly utilised as fuels. But this has resulted in large quantities of fossil CO_2 being released from the earth's crust (lithosphere) into the atmosphere.

In contrast to previous phases in the history of the earth, the current climate change is being caused by humans. This means that the effects are no longer due to long-term cyclical processes resulting from how plants interact with the environment. Today's CO_2 increases are being caused by the release of carbon previously bound in fossil materials. Other gases that also have an impact on the greenhouse effect, e.g. methane, are also being released in conjunction with the higher CO_2 emissions. Even if these gases do have a greater effect by unit (e.g. methane), carbon dioxide remains the most significant greenhouse gas due to the high levels being released into the atmosphere. Greenhouse gases are causing global warming because they prevent radiation from the earth's surface from escaping into space by reflecting it back – just like a greenhouse does. How much radiation is reflected depends on the levels of CO_2 contained in the atmosphere. It must be noted here that – without natural greenhouse gases – the earth's average temperature would only reach minus 18°C and would not range around the 15°C level as it does today.

Closed carbon cycle

Photosynthesis, which constitutes the foundation for plant growth, utilises solar energy to convert CO_2 into carbon and oxygen and then store it as carbon chains (rows of carbon molecules) in biomass (wood, leaves, humus).

The carbon is released again when wood is burnt. Stored carbon is also released when wood decays, for instance, in forests. However, the energy it contains can then no longer be utilised by humans. Both cases constitute closed carbon cycles.

It would be possible to store large quantities of carbon in plant mass and the ground (see Tab. 1) if we were able to reforest large areas and then sustainably manage these new forests. It is not possible to return carbon that has been released into the atmosphere from the combustion of fossil fuels back into the earth's crust (or it would be technically very difficult to do so) and this carbon will therefore remain above ground for thousands of years.

Fig. 1 shows how much carbon is being released into the atmosphere as a result of fossil fuel consumption. More than 90 % of global CO_2 emissions in 2010 were caused by the use of fossil fuels. Changes in land usage, e.g. forest clearing and the conversion of meadows and pastures into farmland, were responsible for around 10 % of the emissions. It is estimated that the anthropogenic CO_2 in the atmosphere increases by an estimated 3.2 billion tonnes a year. The world's forests bind around 0.9 billion tonnes of CO_2 a year. The concentration of CO_2 in the atmosphere would be around 30 % higher than it is today without biomass growth. Forests that are not managed and which, like primary forests, die back after they have reached their physiological age, release the carbon that was bound in them

Tab. 1: Carbon storage in European forests (in tonnes C)

Carbon stored in European forests	
Trees and soil	12,052 million
Of which trees	7,927 million
Annual carbon increases in European forests	
In trees	101 million
In soil	28 million
Carbon stored in a beech forest (800 fm/ha)	
Merchantable wood	640
Brush-wood and leaves	191
Carbon stored in a common spruce forest (800 fm/ha)	
Merchantable wood	528
Brush-wood and leaves	205

Source: Boku

Source: Global Carbon Project (2011), Le Quere et al. (2009), Nature G, Canadell et al. (2007), PNAS

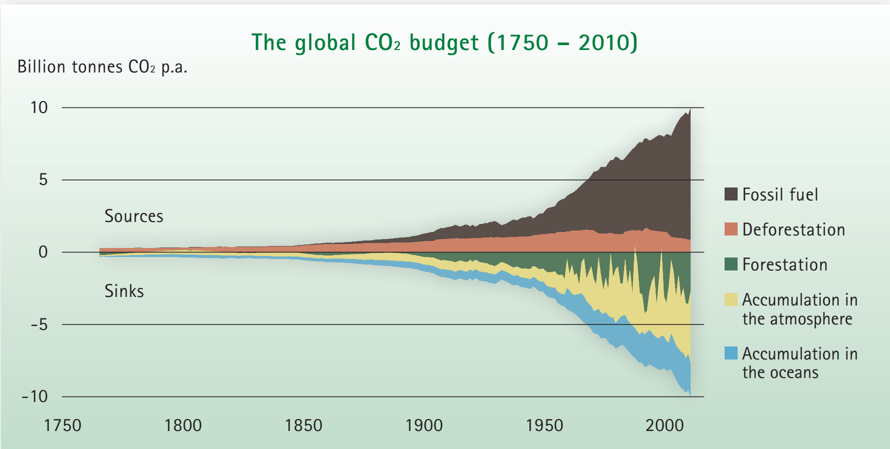


Fig. 1: Global CO_2 emissions – 90 % of which are caused by the use of fossil raw materials – accumulate particularly in the atmosphere and the oceans.

back into the atmosphere. This proportion of CO_2 in the atmosphere is caused by the decay of organic substances whereby in larger forested areas this so-called plant biomass cycle is balanced and is thus CO_2-neutral. Changes over large areas – caused, for example, by fire or storm damage – constitute the exception.

Forests in climate politics and the Kyoto Protocol

A range of initiatives were developed in response to the anticipated climate change. These initiatives were primarily aimed at reducing the use of fossil fuels and consequently the amount of CO_2 released into the atmosphere. The probably internationally most important agreement is the Kyoto Protocol. Other strategies include the EU's 20-20-20 targets and the member states' corresponding national action plans for renewable energy.

The application of Article 3.4 of the Kyoto Protocol that permits forests and their ability to store carbon to be included in national greenhouse-gas balances is voluntary at a national level. Regulations within the framework of Article 3.4 governing how carbon emissions are taken into account state that every use of wood should be regarded as being equivalent to carbon being released from forests. That's why Austria has refused to apply this article. The core problem here is that countries with large reserves of wood, e.g. Austria and Sweden, would as a result of this regulation inevitably be deemed to be producing more emissions over 1990 levels should they start to utilise their growth potential.

The effect of using other resources than fossil raw materials and energy carriers and of storing carbon in wood products as described below would not be included in the balance. Natural release through decay is also not deemed to be an emission – and this would place the above-mentioned countries at a serious disadvantage where the utilisation of wood is concerned.

The development of carbon contained in different forests

Over recent years, the Forestry Institute at the Vienna University of Natural Resources and Applied Life Sciences has carried out extensive investigations into surface and ground biomass as well as humus in the primary forests of Rothwald in Austria and Babia Hora in Slovakia in the hope of being able to understand material cycles (carbon, water, nutrients) in forests that are not managed (primary forests) and to compare the resulting figures with those from managed forests. Fig. 2 shows the various phases that primary forests go through and that may be defined as follows:

Fig. 2: Phases of forest development in primary forests and its effect on the carbon cycle

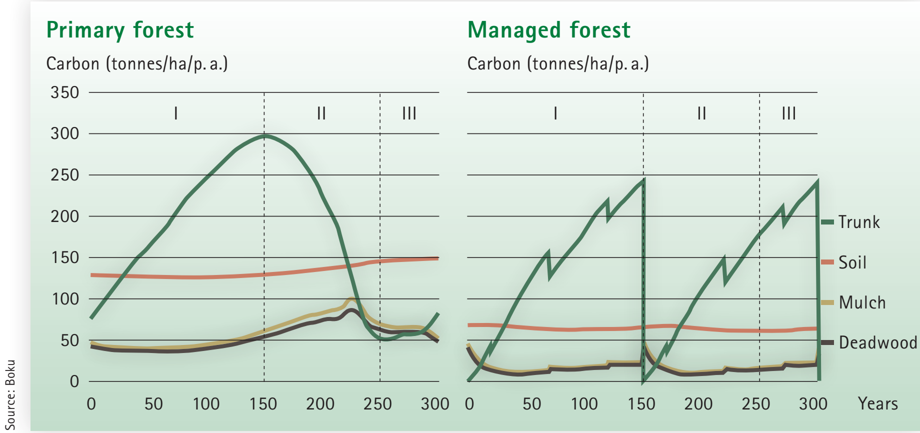


Fig. 3: Carbon content in trunks, mulch, soil and deadwood in a primary forest (left) and a managed forest (right); left image: I. Growth phase, II. Decay phase, III. Initial or transitional phase in a primary forest; right image: Two rotation cycles with three customary management interventions in a managed forest

I. Optimum phase – the trees grow and their wood volume increases. Forests constitute a carbon sink during this phase.
II. Decay phase – the trees reach their highest physiological age. Only very little growth still occurs. Trees reach their natural age of mortality and start to die back. During this phase, the forest becomes a source of carbon because the natural decomposition processes release CO_2 into the atmosphere.
III. Rejuvenation phase – the forest starts to become younger and the cycle commences again. During this phase, forests are CO_2-neutral.

The forests' ecological systems were mapped using a bio-geochemical-mechanistic model to allow the relationships to be analysed. Fig. 3 shows the carbon progression in a primary beech forest (left image) compared with a managed beech forest (right image). The CO_2 developments in the primary beech forest are neutral because the stored carbon is released back into the atmosphere when the wood decays. The image on the right (managed forest) shows that two production cycles are possible during the same period of time. The accumulated carbon is utilised when the wood is harvested.

The time over which these processes occur depends on the types of trees as well as local and climate conditions. The warmer it is, the faster the trees grow – but this also means that the processes of decay that release carbon stored in organic materials will also occur more rapidly. In contrast, managed forests (right image) are always in a state of growth. The stored carbon is initially not released into the atmosphere. The stem wood does not decay as the crop is removed for „cascading" utilisation before the process of decay commences. The customary forest management interventions – in Fig. 3, a reduction in the number of trunks and two thinning processes – remove wood, which in turn reduces the carbon stored in the forest. The reduction of „trunk carbon" is apparent through the breaks in the carbon curve. These management interventions limit continued growth to fewer trees which in turn increases the stability and quality of the individual trunks and

© Liptay

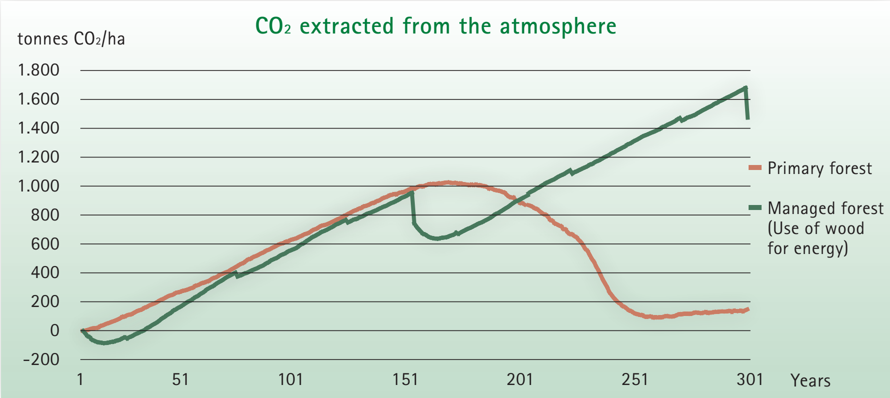
Fig. 4: Wooden structures (such as this one at the Centre Pompidou in Metz, France) store CO_2 over many years.

helps them achieve the desired diameter in the final phase of growth more quickly. The wood gained from the two thinning procedures is also put to cascading use and does not decay in the forest. The managed forest therefore – except for immediately after the process of tidying up and the brief phase following thinning or end utilisation – always constitutes a carbon sink. The short phases during which the forest releases carbon into the atmosphere are due to decaying branch material and forest residues (branches, needles/leaves and roots).

Substitution and storage effects through forest management

The relationship between sustainably managed forests and CO_2 levels in the atmosphere may be described as follows: carbon which would be released into the atmosphere during the primary forests' phase of decay (see Fig. 3) is put to use in the form of cascading utilisation. This means that wood and the carbon it contains is stored for the time being in structures, furniture and so on with the energy then being recovered at the end of the value-adding chain. The carbon stored in the wood is actually released into the atmosphere at the end of the product life but – and this is the important difference to the natural release of carbon in primary forests – only after this carbon has served as construction material or heating material and so on. Product lives vary greatly. The product life of paper for hygiene applications, for instance, is just a few weeks while timber used in construction could last for hundreds of years.

Wood may also be used as a substitute for construction and other materials that require large amounts of energy to produce (plastic, concrete and steel) as well as for fossil fuels (natural gas, oil and coal). For example, glued laminated timber may be used as a substitute for steel (see Fig. 4) and pellets as a substitute for heating oil. Such substitution would result in less fossil carbon being released from the earth's crust.



Source: Boku

Fig. 5: Total carbon storage in a managed forest and in a primary forest – assumptions: two rotation cycles in a managed forest are the equivalent of one primary forest cycle, utilisation of the wood extracted from the managed forest for energy (beech for firewood with 20 % water content), substitution effects through the use of wood instead of heating oil included, substitution effects through the use of wood as a material and intermediate carbon-storage effects in wood products are not depicted.

The „solar energy" stored during the process of photosynthesis becomes available when wood is burnt. Just one tonne of carbon extracted as wood from a forest may reduce CO_2 emissions by 2.7 tonnes through energy recovery (assuming air-dried beechwood as firewood to substitute heating oil). Fig 5. takes account of substitution effects through energy recovery compared with primary forests. The forests presented as the example in Fig. 2 have been used as the basis. Balancing the effects of carbon storage, release and substitution over a period of 300 years (primary forest life cycle = two turnover phases in a comparable managed forest) reveals how important the use of wood as a renewable raw material from sustainable forestry is (see Tab. 2): due to the fact that the harvested timber may be used as a substitute for fossil energy carriers, the effect of the managed forest as a CO_2 sink is many times that of the primary forest (in this example around ten times, the equivalent of 1,603 tonnes of CO_2). In practice, however, the values are much higher because the substitution effects resulting from material use have not been taken into account. Fig. 5 and Tab. 2 assume that the extracted wood is immediately used for energy and that the release of CO_2 is not delayed as a result of intermediate carbon storage in products made from wood. Carbon dioxide is stored and released to a roughly equivalent extent in both primary and managed forests. Due to the fact that managed forests are always kept in the best

Tab. 2: Comparison of the CO_2 effects of a primary forest and a managed forest on the atmosphere over a period of 300 years

	CO_2 emission (in tonnes)	CO_2 storage (in tonnes)	CO_2 substitution (in tonnes)	CO_2 sink levels (in tonnes)
Primary forest	889	–1,035	0	**–146**
Managed forest	2,653	–2,650	–1,607	**–1,603**

Source: Boku

© Archive ÖBMV

Fig. 6: Forests that are no longer managed may suffer serious beetle infestation and wide-ranging dieback which in turn releases large amounts of CO_2.

condition as a result of their being managed, they store far more CO_2 than primary forests do (2,650 tonnes). This carbon dioxide is then removed from the forest and stored through the use of products made from timber. When these products reach the end of their lives, the CO_2 that they contain is released back into the atmosphere when they are burnt or start to decay but only after the substitution effects have been realised. This means that this type of use is CO_2-neutral.

Carbon storage through sustainable forest management

The effects of releasing and extracting carbon overlap when larger forested areas are considered as opposed to individual forests. In forestry, this is called a balanced age group ratio, which means that the different phases of the forest's development are distributed over a larger forested area thus enabling the sustained and continuous utilisation of wood. If no more wood is taken from the forest than the amount of wood that is growing (sustainable forestry), the amount of total carbon contained in the forest will remain constant or will increase. This is the case both in primary forests as well as in sustainably managed forests. Sustainable forest management reduces the natural release of CO_2 (through decay).

Changing sustainably managed forests into primary-like forests does not necessarily cause the stored carbon to increase. The forest will develop in accordance with the natural progression. This may happen radically and over a large area as has happened in the Bavarian National Park. After the forest was taken out of use, the bark-beetle population exploded resulting in the destruction of large areas of forest (see Fig. 6). The trees are rotting away, releasing all the carbon they had stored into the atmosphere. Also, the decision not to use the wood will result in the consumption of more fossil fuels, which again increases the negative impact on the atmosphere.

Coniferous forest benefits

A survey by the Northwest German Forestry Research Institute took a new approach to examining how carbon is stored in forests and timber products. It did not only look at the living and dead biomass in the ground and trees themselves but also surveyed how the timber was being used.

It turned out that the forest floor (humus cover and mineral ground up to a depth of 90 cm) in hardwood forests contains just as much carbon as the living biomass. The ground in coniferous forests is able to store twice as much carbon as the biomass itself. The survey assumed three different forestry scenarios. One pursued an income-oriented approach, the second a nature-proximate approach and the third a nature-conservation approach over a simulated period of 30 years. As expected, greater utilisation also resulted in the lowest carbon content; the conservation-oriented approach produced the highest concentration of carbon which was naturally due to the larger number of trees.

Deadwood decays independently of how stocks are managed after around 35 years and therefore does not contribute to any reduction in carbon contained in the atmosphere. That meant that an entirely different picture emerged when the utilisation of wood was taken into account. Timber products contribute greatly to the carbon balance. The use of the timber materials increases storage in general and such materials may also be used as a substitute for construction and raw materials which consume large amounts of energy in production and are consequently CO_2-intensive. They therefore help cut down the use of fossil energy carriers.

When the potential to store carbon in the product pool is taken into account (long, medium and short life spans and wood for energy), the income-oriented approach delivers the highest carbon accumulation over the 30-year period. The lowest carbon accumulation was achieved with the conservation-oriented approach. In accordance with the breakdown of uses in wood products, in all three scenarios the pool of products made from hardwood increased the most in the energy wood product class, that of coniferous wood most in products with long life spans (e.g. construction timber).

The authors of the survey recommended that nature-proximate forestry methods that pursue the basic principle of sustainable, multifunctional forestry should be continued. This will keep carbon stored in forests at sustainably high levels. The storage of carbon in timber products, which is similarly high to the income-oriented scenario, delivers high sink levels.

Management risks

The risks that accompany increased biomass utilisation may of course not be ignored. This particularly concerns the removal of nutrients, which especially becomes a concern when the branches, bark, needles and leaves are also removed with the wood from the forest's ecological system for energy recovery. The removal of nutrients may cause degradation of the location which in turn may stunt growth and thus endanger sustainability. From the point of view of climate protection, the following requirements for forest management should be taken into account:

- No clearing of forested areas without reforestation.
- Sustainably managed forests make a far greater contribution to climate protection than forests that are not managed, as the cascading utilisation of wood constitutes a substitute for products and fuels made from fossil materials (natural gas, oil, coal).
- CO_2 emissions from forests into the atmosphere are not reduced when forests are no longer managed and left to themselves.
- Reforestation of degraded areas that are not required for agriculture and the sustainable management of these reforested areas will deliver significant positive effects in regard to the reduction of CO_2 in the atmosphere, as massive amounts of carbon are bound during the forest's growth phase and large quantities of fossil fuels and raw materials may be substituted with materials taken from sustainably managed areas.

Univ.-Prof. Dr. Hubert Hasenauer
Forestry Institute, Department of Forest and Soil Sciences,
Vienna University of Natural Resources and Applied Life Sciences,
hubert.hasenauer@boku.ac.at