Climate Smart Forestry in Europe

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Summary

The Paris Agreement and the latest IPCC Assessment Report (2018) emphasize urgent and efficient actions for climate change mitigation. This means that we must rapidly reduce global greenhouse gas emissions and, therefore, also the use of fossil-based raw materials, energy and products.

Climate Smart Forestry (CSF) is one approach for achieving these goals in forests and the forest sector. CSF is more than just storing carbon in forest ecosystems. It builds upon three main objectives: first, reducing the net emissions of greenhouse gases into the atmosphere; second, adapting and building forest resilience to climate change; and third, sustainably increasing forest productivity and economic welfare based on forestry. CSF can help to mitigate the EU's CO_2 emissions up to 20% by 2050 (Nabuurs et al. 2017).

Implementing sustainable and resource-efficient methods of wood processing and consumption, while at the same time promoting the forest carbon sink and improving forest growth must become universal goals for the global Land Use, Land Use Change and Forestry – LULUCF– sector.

Forest management should be regionally optimized within the EU and worldwide. For example, in some regions conservation and sink enhancement may be the priorities, while in other regions sustainable harvesting is preferred.

If industrial wood production in the EU slows down, the demand will be satisfied with forest products made outside the EU, where production methods may be ecologically less sustainable, less resource-efficient and less carbon-neutral. Instead, we must promote innovations and improve the resource-efficiency of making and distributing wood-based products in the EU. This will make an important contribution to climate change mitigation.

Climate policy is a top priority, yet it alone cannot dictate how we use forests. As emphasized by the latest IPCC (2018) assessment, climate policy targets must build on synergies with the 17 Sustainable Development Goals of the UN. The better the climate mitigation measures in the forest support also the other needs we have for them, the wider will be the support for these mitigation measures.

Introduction

Time span of climate change mitigation

Urgent action is needed to mitigate and halt the change of the global climate system (IPCC 2018). The main obstacle in climate change mitigation is the excessive use of fossil-based energy and the dependency of the economy on fossil-based materials, such as plastics and synthetic textiles. Fossil fuels provide four-fifths of the global energy demand, and the global consumption of fossil fuels has continued to increase significantly (Figure 1). The global growth of fossil-based emissions must first be halted before emissions can be reduced.

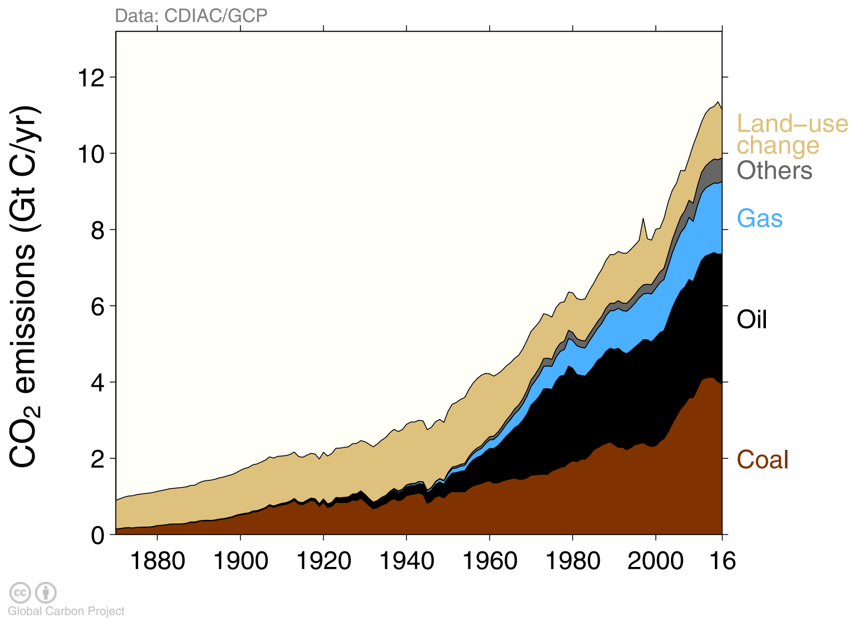

Figure 1. Sources of carbon dioxide emissions. The combustion of coal and oil generates the majority of carbon dioxide emissions. Land use change is the only source of emissions showing a downward trend (mainly reduction in net deforestation). The emissions of carbon dioxide from land-use change are primarily related to the conversion of forest to non-forest such as agricultural land and settlement. Source: Global Carbon Project, 2017.

Policies and measures within the Land Use, Land Use Change and Forestry sector (LULUCF) have long been perceived as a partial solution to the climate problem (Dyson 1977, Kyoto Protocol 1997, IPCC 2014, Paris Agreement 2016). Forests and the forest sector can contribute to achieving climate policy targets in many different ways. However, especially since the Paris Climate Agreement (2016) and the new IPCC (2018) assessment, the urge to act very quickly has been emphasized. This has led to arguments that the best and quickest way for the LULUCF sector to contribute to climate change mitigation would be to conserve forests only to accumulate carbon in forest biomass and soils, and to reduce wood harvests (e.g. Holtsmark, 2012). However, this report argues that this would not be the optimal solution. Rather, we argue in favour of Climate Smart Forestry (CSF) (Nabuurs et al. 2015 & 2017; Yousefpour et al. 2018). This approach is the best, fastest and most sustainable way for climate change mitigation in the EU forest sector, both in the short- and long-term.

CSF consists of three interconnected parts: 1) Promoting the carbon sink in forest ecosystems (forest biomass and soil), and carbon storage in forest ecosystems and wood-based products (i.e. long-term products), 2) Overcoming the use of fossil-based resources by replacing fossil-based materials, energy and products (e.g. plastic packaging, etc) by using renewable and sustainable products, and 3) Strengthening the growth of forests and improving the resource efficiency in producing and consuming wood material. All these three components are needed.

Downsizing forest management and wood harvests, and thus, reducing the production of wood raw material and products counteracts the ultimate climate policy target – **reducing the consumption of fossil-based resources**. In addition, given such downsizing, forest disturbances are likely to increase under climate change, thus jeopardizing forest carbon stocks even in the short-term (Seidl et al. 2017). If policies sought to reduce wood-based industries within the EU, this would trigger increasing imports of these products from other regions, with significant CO_2 emissions also in the short-term (Kallio et al. 2018). Stopping or heavily downsizing sustainable management and industrial production in the EU would also make it more difficult to reach a number of the UN Sustainable Development Goals (SDGs), such as sustainable consumption and production, affordable and sustainable energy, and employment, and restrict the current forest usage rights. The more that measures for climate mitigation in forests also support the SDGs and other societal demands, the broader and stronger the public and political support will be for them.

In this report, we make an effort to address the following questions:

- What is the role of forests, forestry and forest-based industry – direct and indirect – in moving towards a fossil-free society?
- When, where and how much wood can be harvested from forests?
- When, where and how much can we save forest biomass (carbon) in forests?
- How can we further improve the standards and efficiency of making and consuming wood-based products?

Finally, we discuss the balance between supporting, provisioning, regulating and cultural services from forest ecosystems.

Climate change mitigation using forests in the European Union

Forest resources in Europe expand

In general, the forested area, forest growth and resources of EU member countries have increased in recent decades. This relates to the process called "forest transition" (Mather 1992, Kauppi et al. 2006, Barbier et al. 2010).

In fact, Europe was the first continent where forests ceased to shrink and started to expand (Fig. 2). Although forests and wood biomass in forests are expanding in the EU, deforestation still predominates at the global level. Between 2010 and 2015, there was an annual loss of 7.6 million ha and an annual gain of 4.3 million ha per year in forest area, resulting in a net annual loss in global forest area of 3.3 million ha (FAO 2015). This annual net loss is bigger than the forest area of the Czech Republic (2.7 million ha).

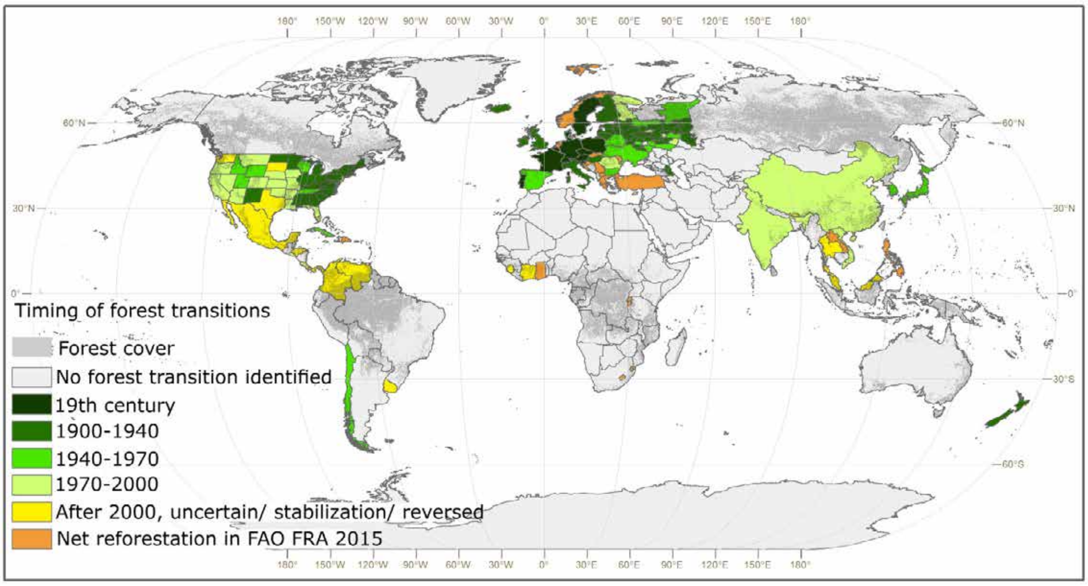

Figure 2. Coloured areas indicate expanding rather than a shrinking area of forests within the given country or region. The colour code indicates the timing of the forest transition, i.e. the turn-around from shrinking to expanding forests (reproduced from Kauppi et al. 2018).

Sweden, Finland and Spain are the three countries with the largest area of forested land in the EU. Together they account for about 43% of the total EU forest area (EU total = 160 million ha; SWE+FIN+ES = 69 million ha[1]). Since the mid 20th century, the forest area in these countries has grown by 4 to 40 percent (Table 1). At the same time, the forest growth in these countries has increased even more rapidly, between 34 to 87 percent (Table 1). In Europe, these countries are no exceptions. For example, from 1963 to 1991 in Austria the annual forest increment improved from 22.9 million m^3 to 27.3 million m^3, and in the Netherlands from 0.9 million m^3 in 1963 to 2.2 million m^3 in 1994. In the EU28, the forest area has increased from 1990 to 2015 by about 9% (Forest Europe 2015).

Climate Smart Forestry can further promote these positive trends. Given the success in the EU, the experience and case examples provide pilot tests regarding how to revert trends of deforestation and forest degradation in the tropics and elsewhere. The growth and the growing stock of forests could still be increased by further improving forest management under the gradually changing climate, which would promote harvests without decreasing the current volume of growing stock (Heinonen et al. 2018 a & b). At the same time, the precision and resource-efficiency of wood processing industries and recycling should also be promoted to further contribute to climate change mitigation targets.

1 Note that the forest area here uses the definition of forest area by FAO, which differs slightly from the national definitions of Finland, Spain and Sweden, used in Table 1.

Table 1. Growth of Forest Resources in Finland, Spain and Sweden from 1970s to today.

	1970s	2010–2017	Change, %
Finland			
Forest area, *Mha*	18.7	20.3	8.6
Annual increment, *Mm³/yr*	57.2	107.0	87.1
Volume of growing stock, *Bm³/yr*	1.49	2.5	67.8
Spain			
Forest area, *Mha*	11.8	16.5	39.8
Annual increment, *Mm³/yr*	31.3	46.1	47.3
Volume of growing stock, *Bm³/yr*	0.77	1.03	33.8
Sweden			
Forest area, *Mha*	27.2	28.3	4.0
Annual increment, *Mm³/yr*	80	120.00	50.0
Volume of growing stock, *Bm³/yr*	2.3	3.2	39.1

Data sources: National Forest Inventories and National Statistical yearbooks

Global demand drives harvests

The demand for wood-based products is concentrated in highly populated regions, especially in urban areas. Industrial roundwood is sustainably sourced mainly from relatively few forested regions in the world (parts of Europe, South-East USA, Western Canada, plantations in Brazil and China). Forests are located far away from the population centres. A network of trade, transport, manufacturing and logistics connects the consumer to the source of wood in forest ecosystems.

Consumers dictate the demand for all products. In other words, the global consumption of products drives global harvests. Geographical shifts in the location of industrial plants and wood harvests have environmental consequences. An unwanted scenario is that wood harvests are restricted in the EU, and other world regions fill the gap using less advanced technologies. Regardless of the world region, Climate Smart Forestry can promote the modernization of silviculture, improvements in the production methods of wood processing industries, and further development of consumption applications of wood-based products.

A Swiss study demonstrated how global consumption of roundwood affects biodiversity (Chaudhary et al. 2016). Logically, if roundwood is procured from biodiversity hot-spot areas, or primary forests, the impact of logging on the composition of species will be large and vice versa. Thus, in roundwood logging it is important to avoid hotspot biodiversity areas. This holds true at regional, national, European and global levels.

Deforestation and forest degradation still prevail in many areas of the world. It makes sense to avoid industrial wood harvests in areas where forest resources shrink. In these areas, the prime objective must be forest regeneration, replanting and capacity building, for which the EU has expertise.

Promoting the best available, sustainable, resource-efficient and climate-neutral (low-carbon) technologies in forest management and forest industries is important everywhere in the world. This will also add to the other ecosystem services obtained per unit of wood harvested and per area of forest land harvested. The wise location of future wood harvests is an important element of Climate Smart Forestry.

For the EU, research has analysed all interconnected parts of Climate Smart Forestry (Nabuurs et al. 2015, 2017). The carbon sink of forests has been larger than that of wood-based products (Fig. 3). Wood fibres and packaging materials provide alternative materials for making consumer products such as plastic cups and synthetic oil-based textiles. Moreover, wood construction has helped to reduce the use of fossil-intensive materials such as concrete and steel.

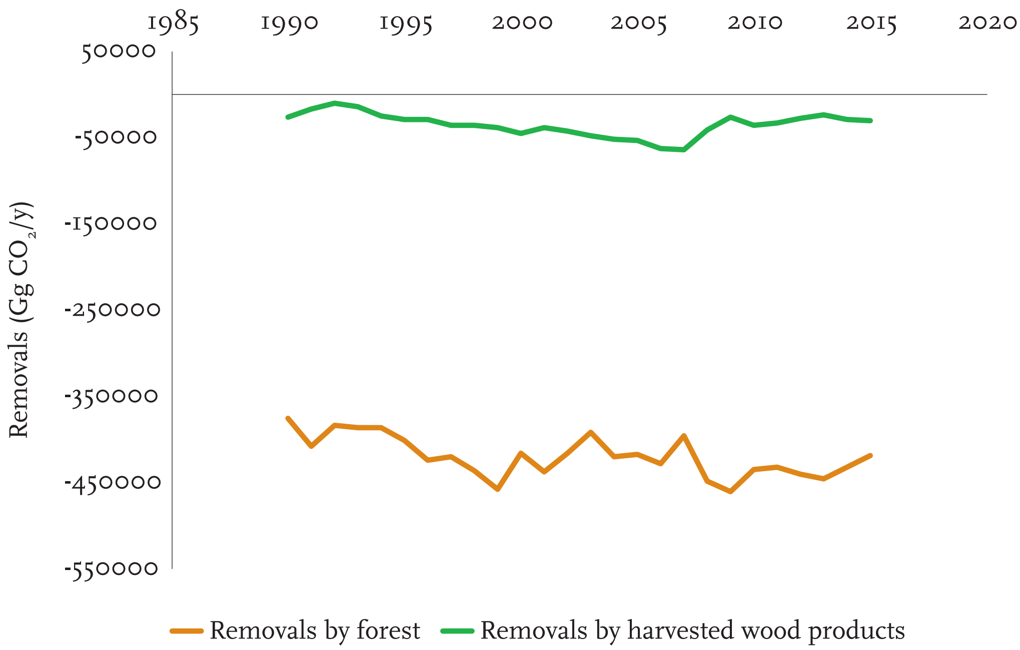

Figure 3. Recent development of atmospheric carbon removals (carbon sequestration; or sink) in forests and wood-based products in the EU (Data source: EEA 2018).

Climate Smart Forestry pilots in the Netherlands

The Dutch Government is negotiating a Climate Accord. In the run-up to this Accord, measures need to be tested and started in all sectors. In 2018, 2 million euros has been allocated to forestry pilots in Climate Smart Forestry. The ambition is to achieve an additional 1.5 million tons CO_2 per year capture by 2030 in forest management including the wood chain.

The pilots are a first important step towards the realization, testing, monitoring and filling of a climate management toolbox with pilot experiences. This creates a basis for larger scale measures in subsequent years. The pilots focus, e.g. on forest regeneration with new tree species, small afforestations, agroforestry, set-aside of forest reserves, novel combinations of new forests with water storage, building using wood, biomass from hedges and small forests, etc.

Photo: Gert-Jan Nabuurs

Regeneration with a richer species variety is one measure. Here Tilia cordata is planted to improve the soil properties through its litter which reduces soil acidification

See also https://www.vbne.nl/thema/klimaatakkoord/english

Increasing forest disturbances

Concern about forest disturbances increases with the changing climate (Reyer et al. 2017, Seidl et al. 2017). "*Warmer and drier conditions particularly facilitate fire, drought and insect disturbances, while warmer and wetter conditions increase disturbances from wind (and snow) and pathogens. …Future changes in disturbances are likely to be most pronounced in coniferous forests and the boreal biome.*" (Seidl et al. 2017). Different disturbances are often also linked to each other. For example, wind- and snow-induced damage may increase insect damage, like that of bark beetles in Norway spruce, without efficient salvage loggings. It is estimated that 15–20 million m^3 of damaged beetle wood will be harvested in Czech Republic forests in 2018 (EUWID 2018). This would amount to the average annual wood harvest of 17 million m^3 per year in recent years. Another major disturbance example is the Gudrun storm in Sweden in 2005, which caused an abrupt windfall of about 75 million m^3. As a result, such major disturbances result in decreased carbon sequestration of forests and severely distort the roundwood market (Mitchell, 2013; see also Fig. 4).

Forest fires increasingly trigger disturbances, and release CO_2 and other greenhouse gases, such as methane into the atmosphere. According to Liu et al. (2014) "*Wildfire emissions can have remarkable impacts on radiative forcing. Smoke particles reduce overall solar radiation absorbed by the earth-atmosphere at local and/or regional scales during individual fire events or burning seasons. Fire emissions of CO_2, on the other hand, are one of the important atmospheric CO_2 sources and contribute substantially to the global greenhouse effect.*" In Greece, Portugal and Spain difficult forest fires have occurred in recent years, also resulting in the loss of human lives. In Portugal, in some years the CO_2 emisisons from forest fires alone have amounted to around 10% of the country's annual emissions (Rosa et al. 2008). Drought increases the risk of forest fires especially in Southern Europe. However, unexpected large forest fires were also experienced in 2014 and 2018 in Sweden, indicating the increasing vulnerability of northern forests to climate change and the associated increase in disturbances.

In countries such as Spain the forest area and the growing stock have clearly increased in recent decades (Table 1). The management of fuel in a sizable portion of a landscape is the only way to reduce the risk of large catastrophic fires, when dealing with extreme weather conditions (drought, strong winds) that are far beyond suppression capabilities (Fernandes et al. 2016 a & b). Reducing forest density and surface by establishing optimized mosaic landscapes (González-Olabarria & Pukkala 2011) appears essential for controlling the risk of large forest fires, thus becoming an element of Climate Smart Forestry. The maintenance of these landscapes must be based on marketable/competitive products and value chains, aligned with circular bioeconomy approaches (Hetemäki et al. 2017). Truffle plantations, cork forests or the use of softwoods for producing cross-laminated timber may be good examples for achieving this. The sound implementation of Climate Smart Forestry may also improve the provision of services such as biodiversity, amenity or water provision (Ameztegui et al. 2017). Indeed, Climate Smart Forestry, if properly implemented, can enhance both the product-related service as well as the non-wood services and biodiversity.

Unexpected disturbances occur in all forests. In British Columbia, about 1.2 and 1.3 million hectares of forest burned in 2017 and 2018, respectively (Kurz, 2018). This is about 15 times more than the average annual area burned in 1990–2015. The initial – albeit unofficial – estimate is that the direct fire-caused emissions in 2017 were about 150 (plus/minus 30) million tons of CO_2. This is two to three times the emissions from fossil fuel burning from all other sectors in British Columbia.

Forest disturbances trigger not only immediate emissions of CO_2 and black carbon but also have secondary effects on greenhouse gas emssions. Trees killed by fires or insects will decompose over the following decades, releasing incremental CO_2 into the atmosphere. In addition, trees killed by fires do not remove CO_2 from the atmosphere as living trees do. The combined impact of disturbances on the greenhouse gas emissions is hence larger than just the effect of direct emissions.

It has been suggested that increasing damage by various abiotic and biotic disturbances may at least partially counteract the expected positive effects of climate change on forest productivity in Europe (Reyer et al. 2017). Moreover, it should be noted that forest growth slows down naturally as forests get older and such forests are particularly vulnerable to different abiotic and biotics disturbances.[2]

2 *Abiotic* disturbances are caused by non-living chemical and physical elements in the environment, such as storms, heavy snow-load and drought. *Biotic* disturbances are related for example to insects, pathogens and wildlife herbivory.

Photo: bertknot /Flickr

Photo: Thomas Adolfsén / SkogenBild

Figure 4. Forest fires are causing devastating damage in the Mediterranean region of Europe, while wind storms are the predominant forest disturbance occuring naturally in Central and Northern Europe. For example, more than 75 mill. m^3 of trees were blown down in Sweden by storm Gudrun in 2005. In the second photo, you see one million cubic meters of these stacked on an abandoned airfield in Southern Sweden.

Climate Smart Forestry seeks to address forest disturbances and make EU forests more resilient, and therefore provide a more reliable and predictable contribution to climate change mitigation. The possible measures under CSF include the use of more climate change-adapted (climate variability, heat and drought extremes) tree species (genotypes) and their mixtures (Jactel et al. 2017), and also more frequent and intensive thinnings and shorter rotation length, if necessary (Jactel et al. 2009).

We will need to assess the increasing abiotic and biotic risks to forests in forest management and harvesting in order to adapt properly to climate change. Different risk management strategies will be needed depending on the region and timespan. Therefore, the simple answer "to harvest and to save" is not good enough. Climate Smart Forestry can provide regionally specific and frequently updated answers to the questions: How much, when and where to harvest? How much, when and where to save? A universal answer "never harvest" is simply wrong.

Economic efficiency in climate change mitigation

Harvesting versus not-harvesting clearly has an economic dimension. Accumulating carbon in living biomass in forests and thus retrieving it from the atmosphere is seen as one effective measure to mitigate climate change. However, when we leave timber in the forest we produce a so-called 'opportunity cost', as we have an economic alternative: to sell the timber on the market. The opportunity cost is higher, the higher the market price that a forest owner can get for the timber, and the greater the demand for this timber.

One example of where a high demand for timber on a global level has led to high prices, is oak that is produced in Western and Central Europe (France, Germany) and which is used for oak barrels or high value furniture. The revenue that forest owners get from the timber can be used to safeguard the forests or – in the case of Norway spruce – to pay for costly forest conversion activities. In some cases, it may be that a tree species is not adapted to changing climatic conditions and has to be replaced by other tree species, or harvest takes place too early compared to the economically optimum rotation length to create space for other tree species, for example.

Climate Smart Forestry in this case suggests selling (in a sustainable manner) timber in order to finance the conversion of disturbance-vulnerable forests to a more resilient new forest type (Yousefpour et al. 2018). A key objective of CSF is to adapt forests and forest management to the gradual changing of climate.

Time frame of sustainable forestry

Human beings are forced to use natural resources. Wood-based products have been essential to the wellbeing of people for thousands of years (Fig. 5). When we consume natural resources, we need to assess whether or not the resource becomes overharvested, and whether to use renewable or non-renewable resources.

Photo: Henrik Herajärvi / Natural Resources Institute Finland

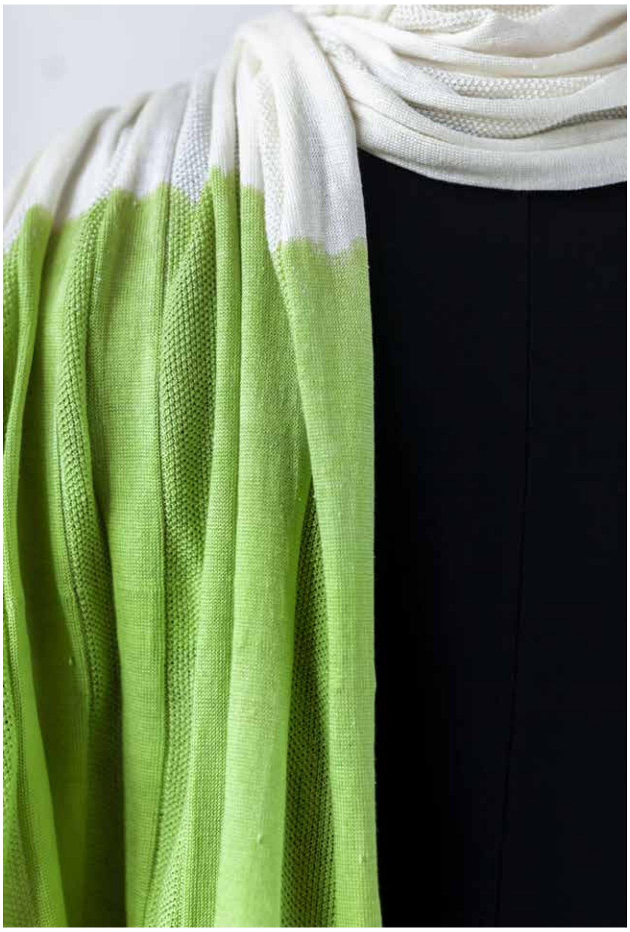

Photo: Eeva Suorlahti

Figure 5. Forest-based products, such as furniture, are used in many ways in our daily life. Another example showing increasing markets is wood fibre textiles, which can substitute for synthetic oil-based textiles and cotton. The scarf in the photo is made from wood using Stora Enso ioncell technology.

In some cases, carbon can be stored for a longer time in wood products than in forest ecosystems, for example in old farmhouses in mountainous areas of Southwest Germany or in the ceilings of large historical buildings like churches (Figure 6). These constructions are several hundred years old. Once sequestered, carbon in some cases can be effectively retrieved from the atmosphere in wood products.

Future generations will need their share and the use of resources needs to also be sustainable in the long term. This has been the rationale for sustainable forestry for a long time and should also be applied in the future.

Photo: T.Weidner / FVA Freiburg

Figure 6. Roof structure of the Münster in Freiburg, Germany. The beams are made of Silver fir (*Abies alba,* Mill.). The construction dates back to the period between 1252 and 1307. Given that the trees that have been used had an age of up to 200 years, the carbon in the building may have already been stored for almost 1000 years.

The concept of sustainable development has parallel albeit broader definitions. Here are two of them:

Gro Harlem Brundtland, "the mother" of the sustainable development concept: *"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."*

Ismail Serageldi, Egyptian intellectual and renowned international figure: "*Sustainable development means leaving as many opportunities for future generations as we have had, if not even more.*"

The origin of the sustainability concept lies in the forest science literature of Germany in the 18^{th} century. At that time, the woodlands of Germany were severely degraded, as they are today in many densely populated tropical areas. Based on early academic research and assessments, the consumption of woody biomass was limited so not to exceed the level of long-term annual forest increment. Forest managers, including tree planters, cultivated forests, thus gradually providing increasing opportunities for wood harvests. Forest scientists spread the idea of sustainability from Germany to the global community.

The requirement of sustainable timber production was introduced into the national legislation in many countries. “Deforestation” and “forest degradation” were banned in Europe by law. A forest owner was not permitted to over-harvest, because he had responsibilities for the wellbeing of future generations. Sustainable forestry was strongly promoted.

Harvesting too much too early is not a common problem in Europe any more. The annual forest increment clearly exceeds the annual wood harvests in Europe. A fully stocked forest develops on a clear cut area within a few decades virtually everywhere in Europe due to sustainable forest management. However, this may not be the case in many developing countries.

Many needs for forests

In European forest policy, the proper balance for different ecosystem services is still a major management challenge. In the 1970s, the role of forests in climate change mitigation was hardly discussed at all. At present, climate change mitigation is clearly a top priority in environmental policy related to forests.

Forests are important to humans in several ways. They offer ecosystem services and, more broadly, contributions of nature to humans. For example, beautiful forested landscapes and groundwater reserves, formed as rainwater penetrates though forest canopy and soil, are all valuable to people even though they are delivered free of charge. Biodiversity is highly valuable, with or without a price attached (Figure 7).

Photo: Petra Kohlstädt /Fotolia

Figure 7. The biodiversity of the world´s forests including Europe´s wildlife is important and irreplaceable, often perceived as an intrinsic and absolute value.

The concepts ´ecosystem service´ and ´nature´s contributions to humans´ have elevated our appreciation of the multiple values of nature. Forests are available for people to enjoy, simply as a landscape (Figure 8). With these new concepts, we start to see things and aspects which we would not have thought about without such a systematic mapping of values and perceptions. This approach will assist in the formulation and implementation of Climate Smart Forestry.

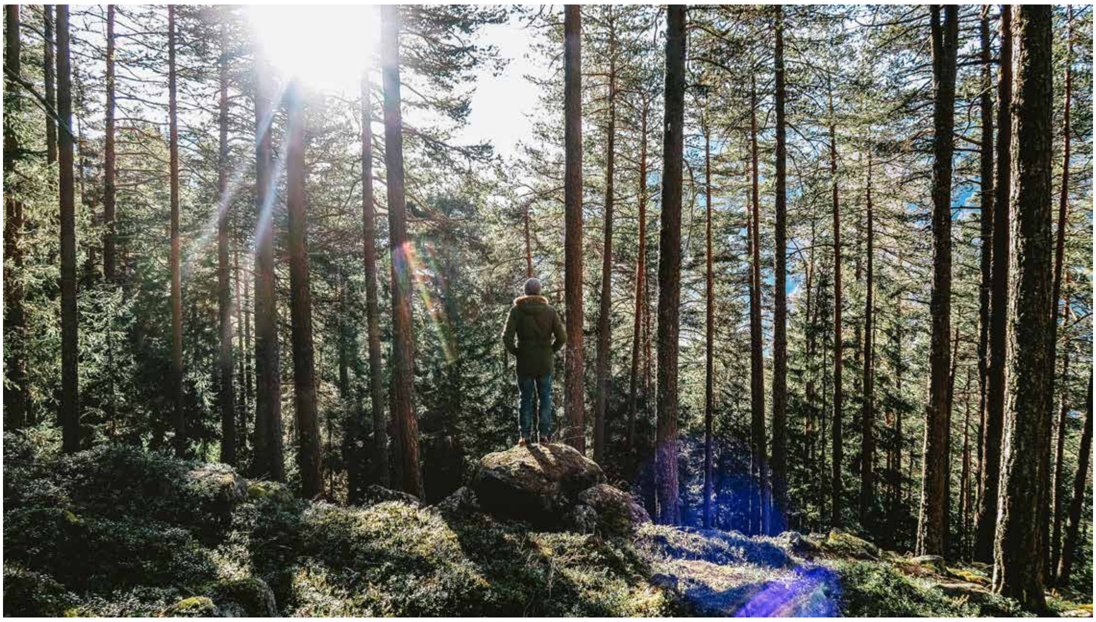

Photo: Paul Gilmore / Unsplash

Figure 8. Forested landscapes are valuable to people even though they are delivered free of charge.

It is important to continuously improve EU policies, promoting a balanced mix of forest ecosystem services. Forest-related polices must focus on a wide variety of ecosystem services and respond to changing situations and new opportunities.

The contribution of forests to climate change mitigation is one of the many services that forests provide. For example, forests should also support the achievement of the globally agreed UN Sustainable Development Goals. The Climate Smart Forestry approach accepts the fact that "nature is perceived and valued in starkly different and even conflicting ways". It is not wise to harness forests for only one purpose, even if it is as important as the mitigation of climate change. The goals of climate change mitigation are best achieved within a balanced combination of services from forest ecosystems.

Concluding remarks

To tackle climate change we must urgently reduce global greenhouse gas emissions and phase out fossil fuels and fossil-based materials and products. As regards forests, it has been increasingly argued that the biggest and fastest impact can be gained by conserving forests and storing carbon in them. This recommendation is too simple to be an all-inclusive answer to the problem of climate change mitigation. The statement by Henry Louis Mencken that "*For every complex problem, there is an answer that is clear, simple - and wrong*" seems to hold also for climate mitigation in forests. This cannot be done by one single means, but requires diverse and not always simple actions.

We think that saving all forests only for carbon storage would be a double-edged sword. Like humans, trees are mortal. Climate change threatens to increase the mortality rate of trees. Disturbances like fires, storms and bark beetle outbreaks have become stronger, more extensive and more damaging. We need old and less-managed forests for biodiversity conservation in some locations. But such old forests at very large scales are likely to suffer from disturbances, with adverse and unpredictable impacts on climate change.

Wood-based products can be found in virtually every European home and public building. If the EU downsized forest management and making products from wood, it could make it much harder and slower to reduce the consumption of fossil fuels and materials. Moreover, making these products in other regions would most likely lead to less sustainable processes and increase CO_2 emsisisons. Importing forest products from outside, rather than producing them in the EU would be counter productive to climate change mitigation, especially in the short term.

Climate change mitigation is clearly a top priority. Still, it is not the only service we obtain from forests. Forests should also contribute to the globally agreed 17 Sustainable Development Goals, such as the ending of poverty; sustainable production and consumption; providing affordable, reliable and sustainable energy; as well as stopping the loss of biodiversity. The better that climate mitigation measures in forests can simultaneously respond to these other human needs, the broader the support will be from citizens and politicians for climate change mitigation activities. We argue that Climate Smart Forestry, which adopts the ecosystem services approach and thereby acknowledges the supporting, provisioning, regulating and cultural services from forest ecosystems, is the best approach for promoting climate change mitigation.

We argue that Climate Smart Forestry approach is the fastest and most long-lasting way for forests to contribute to climate change mitigation. CSF stores carbon in forests and wood products, substitutes fossil-based raw materials, energy and products, promotes forest growth and makes forests more resilient for a changing climate. It can help to mitigate the EU's CO_2 emissions up to 20 percent by 2050 (Nabuurs et al. 2017).

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