Chapter 6
Carbon Sequestration and Storage in European Forests

Antti Kilpeläinen and Heli Peltola

Abstract European forests have been acting as a significant carbon sink for the last few decades. However, there are significant distinctions among the forest carbon sinks in different parts of Europe due to differences in the area and structure of the forests, and the harvesting intensity of these. In many European countries, the forest area has increased through natural forest expansion and the afforestation of low-productivity agricultural lands. Changing environmental conditions and improved forest management practices have also increased the carbon sequestration and storage in forests in different regions. The future development of carbon sequestration and storage in European forests will be affected both by the intensity of forest management and harvesting (related to future wood demand) and the severity of climate change and the associated increase in natural forest disturbances. Climate change may also affect the carbon dynamics of forests in different ways, depending on geographical region. Therefore, many uncertainties exist in the future development of carbon sequestration and storage in European forests, and their contribution to climate change mitigation. The demand for multiple ecosystem services, and differences in national and international strategies and policies (e.g. the European Green Deal, climate and biodiversity policies), may also affect the future development of carbon sinks in European forests.

Keywords Carbon balance · Carbon sink · Carbon source · Carbon stock · Climate change · Forest ecosystem · Forest management · Growth · Net ecosystem CO_2 exchange · Mitigation

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A. Kilpeläinen (✉) · H. Peltola
University of Eastern Finland, Joensuu, Finland
e-mail: antti.kilpelainen@uef.fi

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6.1 Current Carbon Storage and Sink

Forests can contribute significantly to the global carbon cycle and climate change mitigation by sequestering carbon from the atmosphere and storing it in forests (forest biomass and soil) and in wood-based products (with long life-cycles), and also through the use of forest biomass to substitute for fossil-fuel-intensive materials, products and fossil energy (Nabuurs et al. 2017; Leskinen et al. 2018). This is also the case in Europe, where the majority of forests are managed. Forest management has largely influenced the present tree species composition (Spiecker 2003) and wood production potential (Rytter et al. 2016; Verkerk et al. 2019) of forests, and will continue to do so for the coming decades (e.g. Koehl et al. 2010; Lindner et al. 2014).

In Europe, the forest area and carbon storage have both increased since the 1950s for several reasons. The forest area has increased by about 30% between 1950 and 2000, and by 9% since 1990 up to the present (Forest Europe 2020). This has occurred through natural forest expansion and the afforestation of low-productivity agricultural lands (e.g. Gold et al. 2006; Forest Europe 2015; Vilén et al. 2016). The ratio of annual harvested timber to the total annual increment of forests is below 80% across Europe, remaining relatively stable for most countries for the last few decades (European Environmental Agency [EEA] 2017). Additionally, improved forest management practices and changing environmental conditions (e.g. nitrogen deposition, climate warming and the elevation of atmospheric CO_2 concentrations) have increased the carbon sequestration and storage in European forests (e.g. Pretzsch et al. 2014; Etzold et al. 2020). However, the growing (carbon) stock of European forests has clearly increased more rapidly over the last few decades than the forest area (e.g. 17.5 million ha between 1990 and 2015), as the average volume per hectare has been increasing.

However, there are significant distinctions among the forest carbon sinks in different parts of Europe due to large differences in the forest area and structure (age and tree species composition). These are related to differences in the prevailing climatic and site conditions, the intensity of past and current forest management activities, and the level of socioeconomic development (EEA 2016). In Northern Europe, where the share of forest area is higher than in other parts of Europe, the forest landscapes are dominated by mainly coniferous, (very often) single-species and even-aged forests. In Central and Southern Europe, broadleaved deciduous and mixed evergreen forests are more common (Forest Europe 2020). Overall, the forests are more productive and have higher volumes of growing stock in Central Europe than in other parts of Europe. Forest productivity is, nowadays, limited by the length of the growing season and the relatively low summer temperatures in Northern Europe, whereas in Southern Europe, it is limited by water availability, with many forests also being located on sites with low potential for wood production.

The prevailing environmental conditions, current forest structure, management traditions and different socioeconomic factors have also affected the intensity of forest management. Management intensity varies from fully protective for biodiversity conservation, to uneven- and even-aged rotation forestry, which affects forest carbon sequestration and storage. Forest ownership structures, and targets set for forest management and its possible constraints, have also, together, affected the intensity of forest management and harvesting, affecting the development of carbon sinks and storage and the wood production potential of European forests (Rytter et al. 2016; Verkerk et al. 2019). Currently, ca. 50% of forests in the EU are privately owned, with about 16 million private forest owners (Nabuurs et al. 2015). In forest management, different ecosystem services may also be emphasised to a greater degree, depending on set targets and constraints in different regions (Hengeveld et al. 2012; EEA 2016; Forest Europe 2020).

The growing (carbon) stock of European forests is currently double what it was in the 1990s (Forest Europe 2020). The carbon-stock increases in forests and wood products, and the average annual sequestration of carbon in the forest biomass, was 155 million t in 2020 (Forest Europe 2020). Currently, EU forests sequester ca. 10% of Europe's greenhouse gas (GHG) emissions (Forest Europe 2020). When considering the carbon storage in wood products (an additional ca. 12 Tg C year^{-1}) and the substitution effects of the forest sector, ca. 3% of the total GHG emissions in the EU28 are avoided (Nabuurs et al. 2015). Furthermore, woody biomass provides ca. 6% of the energy consumed in the EU (Eurostat 2020). On the other hand, the first signs of saturation in the European forest carbon sink were recognised in the 2010s (Nabuurs et al. 2013). Despite this, the European forest carbon sink is still projected to last for decades. However, there may be a need to adapt forest management and utilisation strategies to promote the sequestration of carbon in forest sinks under the changing climatic conditions. Whether the carbon sink contained in European forests (and the broader forest sector) will remain at the same level as today, or increase/decrease in the future, will strongly depend on changes in the forest area and structure, the intensity of management and harvesting, and the severity of climate change and the associated increase in natural disturbances in different parts of Europe.

6.2 Dynamics of Carbon Sequestration and Storage in a Forest Ecosystem

6.2.1 Basic Concepts of Carbon Dynamics in a Forest Ecosystem

The carbon dynamics in a forest ecosystem comprise the carbon uptake by trees (and ground vegetation) in the above- and belowground forest biomass, and carbon release through the autotrophic (metabolism of organic matter by plants) and heterotrophic (metabolism of organic matter by bacteria, fungi and animals) respiration. The forest ecosystem is a carbon sink if it absorbs more carbon from the atmosphere than it emits, resulting in an increase in the carbon storage of the forest (forest biomass and soil). The carbon dynamics of a forest ecosystem are controlled

Table 6.1 Commonly used basic concepts of the sources, sinks and storage of carbon in a forest ecosystem

Carbon sequestration	Capture of CO_2 from the atmosphere and its transformation into biomass through photosynthesis
Carbon storage	Amount of carbon (stock) in the forest biomass and soil that has been removed from the atmosphere and stored in a forest ecosystem through carbon sequestration
Carbon sink	A forest ecosystem is a carbon sink if it absorbs more carbon from the atmosphere than it emits, resulting in an increase in carbon storage in the forest ecosystem. The net ecosystem exchange is negative (NEE = NPP – RH, <0)
Carbon source	A forest ecosystem is a carbon source if it emits more carbon into the atmosphere than it absorbs, resulting in the consequent reduction of carbon storage in the forest ecosystem. The net ecosystem exchange is positive (NEE = NPP – RH, >0)
Carbon balance	The carbon balance (NEE) of a forest ecosystem refers to the sum of carbon absorbed by and emitted from the forest ecosystem. If the carbon absorption is equal to the carbon emission, the carbon balance is zero

NEE net ecosystem CO_2 exchange, *NPP* net primary production, *RH* heterotrophic soil respiration

by environmental (climate, site) conditions, and the structure (age, stocking, tree species composition, etc.) and functioning of the forest ecosystem.

The carbon sequestration and stock of forest biomass may vary greatly in a forest ecosystem over time, these are controlled by the initial stand characteristics, the type and intensity of management (e.g. forest regeneration material, thinning and fertilisation) (Routa et al. 2019) and the length of the rotation period (Lundmark et al. 2018) or other time period being considered. The carbon stock in soil is generally relatively stable, although it is affected by carbon inputs from litter fall and carbon outputs from the decay of litter and humus, the latter representing earlier litter input of unrecognisable origin (Kellomäki et al. 2008). The decomposition of old humus and litter contributes significantly to soil carbon emissions at the beginning of the rotation period, but in the later stages of stand development, the decay of new litter contributes more (e.g. Kilpeläinen et al. 2011). Generally, for most of the duration of stand development, the stands act as carbon sinks (Table 6.1).

6.2.2 *Management Effects on the Carbon Dynamics of a Forest Ecosystem*

Management intensity affects the carbon sequestration and stocks in forest ecosystems through changing the structure and functioning of an ecosystem. A managed forest ecosystem sequesters carbon as trees grow, but loses carbon in harvesting. By comparison, in unmanaged forest ecosystems (e.g. old-growth forests), the carbon dynamics are affected by the age structure, the mortality of mature trees, natural regeneration and the ingrowth of seedlings in canopy gaps (Luyssaert et al. 2008). The annual growth rate of trees can be higher in managed than in unmanaged (intact) forest ecosystems, but the carbon sink is lower due to harvesting (Kellomäki 2017; Moomaw et al. 2020). Older forest stands can store more carbon, but the rate at which they remove additional carbon from the atmosphere is substantially lower, and can even become negative as the mortality increases and exceeds the regrowth (Gundersen et al. 2021). On the other hand, devastating abiotic (e.g. wind storms and forest fires) and biotic (e.g. insect outbreaks) disturbances may cause a sudden decrease in carbon sequestration and storage in forest ecosystems.

The use of appropriate, site-specific regeneration methods and materials (e.g. improved regeneration materials with better growth rates and survival), the proper timing and intensity of pre-commercial and commercial thinnings, and forest fertilisation on sites with limited nutrient availability, have been proposed as ways of increasing carbon sequestration (and timber production) over one rotation in boreal forests (e.g. Nilsen 2001; Saarsalmi and Mälkönen 2001; Bergh et al. 2014; Haapanen et al. 2015; Hynynen et al. 2015). According to Olsson et al. (2005), in addition to forest productivity, nitrogen fertilisation may also increase the sink and storage of carbon in upland (mineral) soils in Norway spruce stands due to the simultaneous increase in litter production and decrease in the decomposition of soil organic matter and heterotrophic respiration in the soil. However, there have been contradictory findings on the effects of nitrogen fertilisation on the decomposition of soil organic matter and soil respiration (e.g. Magill et al. 2004; Frey et al. 2014; Högberg et al. 2017). The maintenance of higher stocking in thinnings, together with longer rotations, may also increase the annual mean carbon sequestration and carbon stock in forest ecosystems over a rotation period (Liski et al. 2001; Routa et al. 2019). Overall, carbon sequestration and storage may be increased in forests in different ways by modifying current forest management practices. However, the same measures may affect forests differently, as outlined in Table 6.2. Also,

Table 6.2 Possible measures to increase carbon sequestration and storage in forests over a stand rotation

Measures at stand level	Carbon sequestration	Carbon storage
Use of improved, more productive and climate-adapted forest regeneration material	+	+
Proper region−/site-specific cultivation of different tree species	+	+
Use of mixed-species stands	+/−	−
Maintenance of higher stocking in thinning	+	+
Use of fertilisation	+	+/−
Use of longer rotation	−	+
Use of shorter rotation in storm-, drought-, fire-, insect- or fungus-prone forests	+/−	−
Decreased drainage (low-productivity peatlands)	+/−	+/−
No management	+/−	+

+ increase, − decrease, +/− direction of effect uncertain

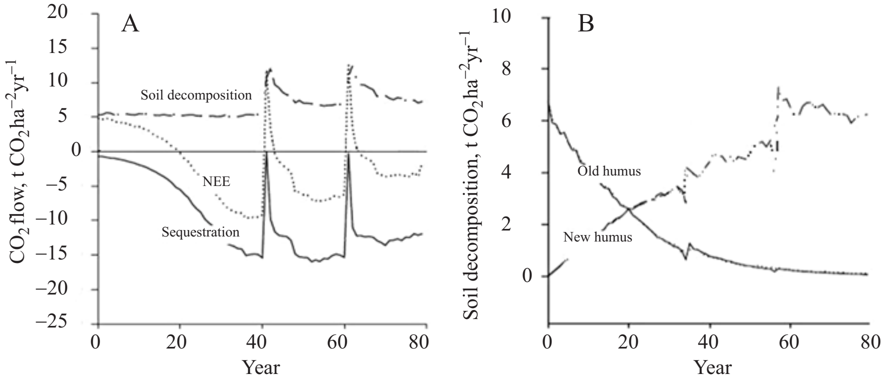

Fig. 6.1 Development of annual carbon flows of NEE (carbon sequestration + soil decomposition) (**a**) and soil decomposition of new and old humus (**b**) in a boreal Norway spruce stand after a clearcut over an 80-year rotation period with two thinnings at ages 40 and 60 years in southern Finland. Redrawn from Kilpeläinen et al. (2011). Positive values denote carbon flowing to the atmosphere, negative values denote carbon flowing to the ecosystem

management effects on the economic profitability of forest production should be considered in practical forestry.

Figure 6.1 provides an example of the development of the net ecosystem CO_2 exchange (NEE) of a boreal, even- aged Norway spruce stand on a medium-fertility upland site over an 80-year rotation period, based on gap-type forest-ecosystem model SIMA (Kellomäki et al. 2008) simulations (Kilpeläinen et al. 2011). Seedling stands (2000 seedlings ha^{-1}) act as a carbon source over the first 20 years after a clearcut because the carbon sequestration is lower in young seedling stands than the carbon emissions from decaying humus and litter in the soil. As carbon sequestration increases, a stand becomes a carbon sink. The mean annual carbon uptake over 80 years is 11.4 t CO_2 ha^{-2} $year^{-1}$, with the carbon emissions being 7.3 t CO_2 ha^{-2} $year^{-1}$. The thinnings at ages 40 and 60 years produce peaks in the carbon emissions due to harvesting and the decay of logging residuals.

In Fig. 6.2, a simulated example of the development of NEE (Fig. 6.2a) and carbon stocks (Fig. 6.2b) in a forest ecosystem is demonstrated under business-as-usual (baseline) thinning, 20% higher and lower tree stocking compared to the baseline, and an unmanaged (unthinned) boreal Norway spruce stand (Alam et al. 2017) over two rotation periods (i.e. 160 years). Over the whole 160-year period, the stands sequestered more carbon than they released (Fig. 6.2a). The NEE was the highest under higher stocking and the lowest under lower stocking. The increased carbon sequestration led to a 17% larger mean carbon stock (in the trees and soil) than in the baseline thinning, while decreased stocking led to a 21% lower carbon stock than in the baseline thinning. The mean carbon stock over the simulation period was the largest under the unmanaged regime (445 and 197 t CO_2 ha^{-1}in the trees and soil, respectively), while the mean carbon stock in the trees in the baseline thinning was 191 t CO_2 ha^{-1}, and in the soil, 111 t CO_2 ha^{-1} (Fig. 6.2b).

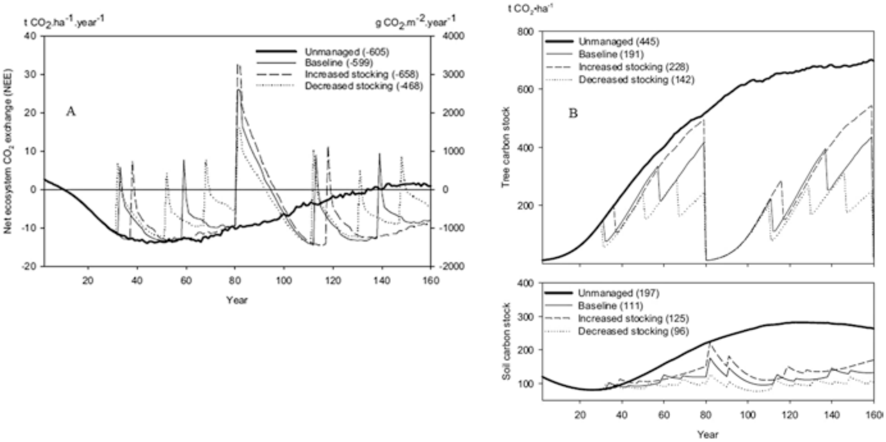

Fig. 6.2 (**a**) NEE under different management regimes in a Norway spruce stand under boreal conditions over a 160-year period under different management regimes. (**b**) Development of ecosystem carbon stocks (expressed as CO_2) in trees (top) and soil (bottom) under different management regimes. Values in parentheses in the legends indicate mean NEE (**a**) and mean carbon stock (**b**) over the simulation period. Each reduction in the tree carbon stock corresponds to the harvesting of timber from the ecosystem and its mobilisation to the technosphere as harvested wood products. After Alam et al. (2017)

Figure 6.3 shows an example of how alternative forest management regimes (use of better-growing seedlings, nitrogen fertilisation, higher stocking in thinning) might increase the simulated NEE of a forest ecosystem under even-aged management in a boreal upland Norway spruce stand with (BT, basic thinning) and without (BT-NO BIO, no bioenergy harvesting) harvesting logging residues from a clearcut. The highest increases, compared to BT-NO BIO, were observed with the use of improved seedlings in regeneration (i.e. 20% better growth than seedlings of forest-seed origin) and nitrogen fertilisation (2–4 times during a rotation period at the same time as thinning, depending on the management regime), along with the maintenance of (30%) higher stocking in thinnings over a rotation compared to the baseline management. The increases in NEE in these regimes, compared to BT-NO BIO, varied between 22 and 200%. Maintaining a higher growing stock over the rotation also increased the carbon benefits when compared to BT.

6.3 Impacts of Management and Harvesting Intensity on Carbon Storage in Forests

Forest resources comprise mosaics of single stands with varying climatic and site conditions and forest structures (age, tree species composition and stocking), which together affect the future of carbon sinks and storage in forests, and the forest harvesting potential, in different regions (Hudiburg et al. 2009; Kilpeläinen et al. 2017;

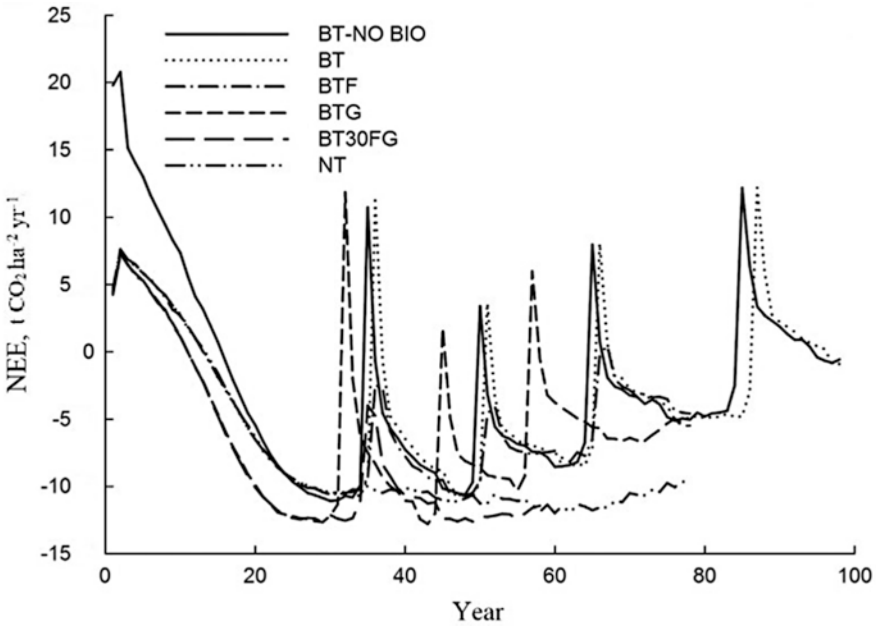

Fig. 6.3 Annual NEE (t CO_2 ha^{-1} year^{-1}) of a Norway spruce stand under alternative management regimes, with harvesting of logging residues, stumps and coarse roots (BT, BTF, BTG and BT30FG, NT) and baseline forest management (BT-NO BIO), with no harvesting of logging residues. *F* nitrogen fertilisation, *G* use of genotypes with 20% increased growth, *BT30* use of 30% higher stocking in thinnings, *NT* no thinning. (After Kilpeläinen et al. 2016)

Thom et al. 2018). At the regional level, the development of carbon sequestration and carbon storage in forests is strongly affected by the initial age structure of the forests, which also affects possible management measures over time (Baul et al. 2020). Therefore, differences in past forest management regimes in European countries will also reflect the future potential of increased carbon sequestration, wood production and carbon stocks in forests.

Heinonen et al. (2017) showed that, with around 73 million m^3 of annual timber harvesting, the carbon storage of Finnish forests (forest biomass and soil), excluding forest conservation areas, may remain quite stable over the 90-year simulation period, compared to a situation with the initial growing stock (Fig. 6.4). However, with a lower even-flow timber harvest, the 40–60 million m^3 levels may increase significantly. On the other hand, despite the harvesting level, the forest carbon stock starts to decrease after the first 40 years of the simulation period due to the changing forest age structure. This decline is also relatively greater at a lower harvesting intensity, which is associated with a larger share of unmanaged forests with decreasing growth and increasing mortality over time. Heinonen et al. (2017) did not consider either the effects of intensified forest management or climate change on the forest growth, or natural disturbances. By intensifying forest management, for example, by using improved regeneration materials and nitrogen fertilisation on

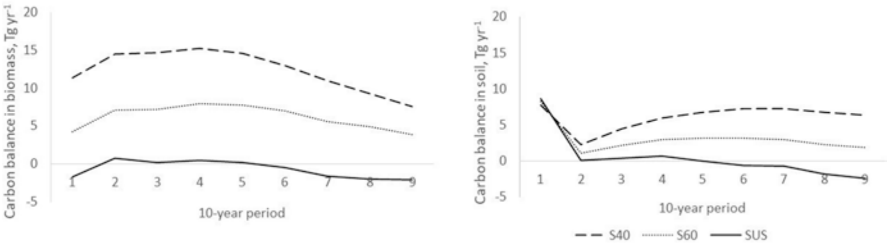

Fig. 6.4 Development of the carbon balance (i.e. the difference between sequestrated and released carbon) in the forest biomass and soil in three cutting scenarios in Finland, for nine 10-year periods under current climate. S40 and S60 denote cutting scenarios with 40 and 60 million m^3 $year^{-1}$ cutting drains, respectively. In the SUS (sustainable) cutting scenario, the cutting drain was the highest possible (73 million m^3 $year^{-1}$), which it was assumed would not lead to decreasing growing stock volume during the 90-year period without assuming improved forest management or climate change. Redrawn from Heinonen et al. (2017)

Table 6.3 Possible measures to increase carbon sequestration and storage in European forests and thus mitigate climate change

Measures at regional (national) level	Carbon sequestration	Carbon storage
Increase forest growth by different measures	+	+
Reduce harvesting level	+	+/–
Increase forest conservation area	+	+/–
Reduce disturbance risks in storm-, drought-, fire- or insect-prone forests by considering risk in adaptive management	+	+
Reduce deforestation and increase afforestation and reforestation	+	+

+ increase, – decrease, +/– direction of effects uncertain

upland forest sites, both the growing (carbon) stock and wood production could increase under boreal conditions with minor climate change (e.g. the RCP2.6 forcing scenario) in the coming decades (Heinonen et al. 2018a, b).

In European forests, the carbon storage (and sink) could be increased by modifying current forest management practices and harvesting intensities. However, same measures may affect the carbon sequestration and storage in different ways, especially over different time periods (Table 6.3).

When seeking to enhance the carbon storage in forests, it is important to bear in mind that forest disturbances are likely to increase in the future, with changing climate (Seidl et al. 2014; Venäläinen et al. 2020). Given this, the risk of decreasing forest carbon storage might increase, and therefore appropriate adaptation measures would be required to minimise the harmful effects (see also Chap. 5). The severity of climate change will also affect the carbon dynamics of forests through its effects on forest regeneration, growth and mortality processes, as controlled by management. These effects may also be contradictory, depending on the region.

Forests also contribute to climate through the absorption or reflection of solar radiation, cooling as a result of evapotranspiration, and the production of cloud-forming aerosols (Kalliokoski et al. 2020). These will affect the role of forests in climate change mitigation. An increase in the aboveground forest biomass and carbon stock, and the proportion of coniferous tree species in the growing stock, may decrease the planet's surface albedo (i.e. the reflection of solar radiation). This may result in enhanced climate warming in opposition to a lower carbon stock and greater proportion of broadleaf tree species (e.g. Lukeš et al. 2013). On the other hand, in managed, even- and uneven-aged boreal Norway spruce stands with relatively low average stocking over a management cycle, for example, the opposing effects on radiative forcing of changes in the albedo and carbon stocks may largely cancel each other out, providing few remaining net climate remediation benefits (Kellomäki et al. 2021). Alternatively, the maintenance of higher ecosystem carbon stocks in managed forests, or with no management, clearly implies greater net cooling benefits. This is despite the lower albedo enhancing radiative absorption, and thus enhancing warming. However, increasing the use of the no-management option may require compensation for forest owners for lost harvest income (Kellomäki et al. 2021).

Under sustainable forest management, the impacts of that management on ecosystem services other than carbon sequestration and its storage in forests, such as the production of timber and non-wood products, the maintenance of biodiversity and recreational value, should also be considered. This is important because carbon storage in forests and the amount of deadwood (an indicator of biodiversity), for example, correlate positively with each other, but negatively with harvested timber volume and the economic profitability of forestry (Diaz et al. 2021). Lower management and harvesting intensities will also lead to forest structures in which there are more older trees, a larger share of broadleaves and a greater amount of deadwood compared to forests under higher management and harvesting intensities (Heinonen et al. 2017).

6.4 Uncertainties Associated with Future Carbon Storage and Sinks

The future development of the carbon storage and sinks in European forests will be affected by the intensity of forest management and harvesting (and thus wood demand), the severity of the climate change (Kindermann et al. 2013) and the associated increase in natural forest disturbances (Seidl et al. 2014) in the different regions. In addition, the demand for multiple ecosystem services and different national and international strategies and policies (e.g. European Green Deal, climate and biodiversity policies) will affect the intensity of forest management and harvesting in those different regions. Thus, due to the complexity of the issue, there are many uncertainties in the future development of carbon sequestration and storage in European forests, and their ability to contribute to climate change mitigation.

In the EU Reference Scenario (EC 2016), forest harvests are projected to increase by 9% between 2005 (516 million m^3) and 2030 (565 million m^3) due to a growing

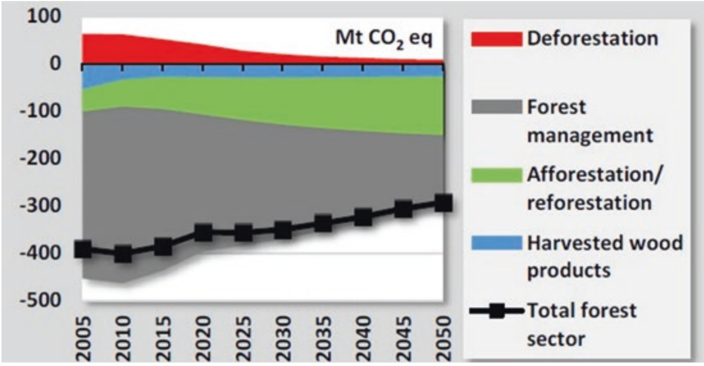

Fig. 6.5 Development of the EU-28's emissions/removals in the forest sector in Mt. CO_2eq. up to 2050 (EC 2016)

demand for energy biomass and material use (Fig. 6.5). Consequently, forest growth is projected to decrease by 3%, and the carbon sink in forests by 32%, by 2030. This may be partially compensated for by increasing the carbon sink through afforestation and decreasing emissions from deforestation. In 2050, total forest growth is, however, clearly predicted to be higher than the wood harvests in this Reference Scenario (Fig. 6.5). Assuming a constant harvest scenario (e.g. Pilli et al. 2017), the carbon sinks in the forest pools of the EU-28 are estimated to decrease by 6% in 2030 compared to the average of the historical period 2000–2029. On the other hand, based on projections for forest resources under alternative management and policy assumptions, the increased carbon storage in the EU-28 forests could provide additional sequestration benefits of approximately up to 172 Mt CO_2 year^{-1} by 2050 (Nabuurs et al. 2017).

With the right set of incentives in place at the EU and Member States levels, the EU has the potential to achieve an additional mitigation impact of 441 Mt CO_2 year^{-1} by 2050 (Nabuurs et al. 2017). The measures to achieve this would include improving forest management, expanding the forested area (afforestation), substituting for fossil- based materials and energy by wood, and setting aside forest reserves for short-term carbon sequestration. In addition to mitigating GHG emissions, the suggested measures could also adapt and build forest resilience, sustainably increase forest productivity and incomes, and tackle multiple policy goals set for the future (see also Chap. 9).

6.5 Research Implications

Changes in the intensity of forest management and harvesting will affect the carbon sequestration potential of forests and the carbon storage in forests. Using different forest management measures could help to increase these. However, it should be noted that enhancing the carbon storage in forests through management may also increase the effects of natural forest disturbances, such as wind storms, fires, drought and pests. Therefore, it is crucial to consider how to increase forest resilience in the EU through forest management. Adapting thinning regimes, shortening rotation periods and using improved regeneration materials may help to decrease the vulnerability of forests to various natural disturbances, as well as providing the means for maintaining and enhancing forest carbon sinks. It should also be considered how and under what conditions various silvicultural methods, such as stand density control, fertilisation and mixed-species forests, could help to maintain and improve the adaptation capacity, resilience and mitigation potential of forests in parallel.

Besides forest carbon sequestration and storage, wood-based products can provide significant carbon storage. Wood products may also be used to substitute for fossil-fuel-intensive materials, products and energy (Nabuurs et al. 2017; Leskinen et al. 2018). However, regional conditions vary significantly across the EU. This partly explains the difficulties involved in quantifying the mitigation impacts of the EU-level forests and the forest-based sector. Moreover, the large diversity of abiotic and biotic circumstances and management practices also makes it challenging to generalise the results of individual studies to the EU level. On the other hand, variations in the growth potential and forest utilisation rates in the various value chains create a wide range of options for adaptation to, and mitigation of, climate change in the EU, depending on regional conditions. Beyond adaptation and mitigation, the simultaneous provisioning of multiple ecosystem services for society should also be ensured, in a sustainable way, while increasing forest resilience to natural disturbances. This requires thought to be given to the uncertainties associated with climate change and the risks in forest-management decision-making, which are still understudied topics, requiring further input.

6.6 Key Messages

- European forests have acted as carbon sinks for the last few decades due to increases in the forest area, improved forest management and changing environmental conditions.
- The future development of carbon sequestration and storage in European forests will be affected both by the intensity of forest management and harvesting (associated with future wood demand) and the severity of climate change and the related increase in natural disturbances.
- The great diversity of abiotic and biotic circumstances, management practices and forest utilisation levels in the different regions of the EU creates both a wide range of options, but also challenges, for the adaptation to, and mitigation of, climate change in different regions.

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