Potential and Limits of Forest Ecosystems on Climate and Biodiversity Protection and Implications for the Legislative Process

4

Abstract

Our analysis shows that the preservation of intact forest ecosystems is indispensable to protect climate and biodiversity in the long term, and the health and well-being of humanity. Despite this, the destruction of the last intact ecosystems (especially primary and old-growth forests) is increasing at rapid pace. This applies particularly to tropical forests but also to the last European primeval forests. The cause lies in humankind's gigantic hunger for resources, whether it be woody biomass or arable land to produce beef, feedstuffs such as soya, palm oil, rubber, etc. The transition to a post-fossil society and the partial replacement of fossil fuels with woody biomass is further pushing this development and therefore requires appropriate legal containment to finally achieve sustainable resource and forest management. Apart from that, demand-sight mitigation measures that steer consumption patterns (particularly but not only) in the western world, i.e. meat and biomass consumption, alongside frugality strategies are highly necessary.

At the same time, the book critically reviewed the potentials of afforestation and reforestation for climate mitigation, which is often presented as the new saviour to fulfil the commitments of the Paris Agreement and to reach climate neutrality in the future. It became clear that ultimately only biodiverse and thus resilient forests can function as a C sink in the long term (!). However, in the short term, the C storage capacity of newly planted forests is almost negligible and very small. In fact, due to necessary interventions in the soil, young forests are frequently a source of CO_2 and do not function as a sink. Potential trade-offs with regard to food security, biodiversity protection, e.g. of species-rich grasslands and wetlands, and the total amount of land available also come into play. In addition, existing forests worldwide are currently reducing their original sink

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capacity and release more CO_2 into the atmosphere. This is because of changing environmental conditions such as long dry seasons often coupled with unsustainable forest management. Overall, the expected future sink capacity of newly planted or existing forests is therefore often overestimated.

Nevertheless, monitoring and measuring GHG fluxes in forest ecosystems as accurately as possible is a necessary prerequisite for policy approaches (see Chap. 5). It became clear that this is very challenging. To date, it is hardly possible to achieve an accurate measurement of GHG fluxes in forest ecosystems and to monitor the development of forest ecosystems in a globally comprehensive and accurate manner. The problem of depicting is comparatively large in forest ecosystems as they are influenced by multiple factors. Efforts to reduce the problem of depicting as best as possible are therefore necessary. However, the problem will always remain to a certain extent which in turn has to be considered when developing policy instruments.

In this chapter, the importance of forests in the climate – and biodiversity – discourse is discussed on the basis of natural scientific data, which is essential for the development of effective policy instruments. Therefore, the forests' potential to function as a nature-based solution to mitigate the climate and biodiversity crises is investigated. Firstly, it is outlined why forest ecosystems are essential for the stability of the global climate and biological diversity in general, and which factors are driving their degradation and destruction. Secondly, their emission saving potential is pointed out in more detail taking into consideration afforestation and reforestation.

4.1 The Importance of and Risks for Existing Forest Ecosystems

This section explains firstly why forest ecosystems are important for the planet and humanity and how they can be categorised. Thereupon, it identifies risks, respectively drivers of forest loss and forest degradation.

4.1.1 Importance of the World's Forest Ecosystems

Today, forests cover approximately 31% of the world's terrestrial surface, whereby 49% are evaluated as relatively intact and 9% are fragmented, showing little or no connectivity (FAO and UNEP 2020, xvi). Forests provide manifold services to nature, humankind and the economy. First of all, they function as an essential basis of life on earth, providing numerous ecosystem services. Water and soil protection are important to name in this respect, next to the purification of air. They purify the air, prevent soil erosion, regulate water flows and serve as huge water storages, which they are also able to purify (Eikermann 2015; Brockerhoff et al. 2017). They can be distinguished from forest-free areas by higher humidity, lower temperature fluctuation and wind protection (Brockerhoff et al. 2017). Concerning the economy, forests deliver wood as a raw material, e.g., as fuelwood and for innumerable manufacturing processes (industrial wood, but also non-wood products such as bioplastics) and therefore play a major role in the transition to a post-fossil society. At the same time, their social functions: recreation and ecotourism, next to spiritual, cultural and heritage values, continue to play a significant role (Eikermann 2015, 15 et seq., 2018, 416). As they store about 45% of all terrestrial carbon (Bonan 2008; Zhao et al. 2019), forests are potential carbon sinks that help to mitigate the climate crisis. In addition, forests accommodate 80% of global biodiversity (IPBES 2019; European Commission 2019) and play a key role in protecting biological diversity. In the context of their importance for biodiversity, intact forest ecosystems are essential to prevent health risks such as pandemics whose major global driver is land-use change (IPBES 2020, 6; UNEP and ILRI 2020, 16 et seq.).

As nature-based solutions, forest ecosystems provide different values to biodiversity and climate protection depending on their state or type of re-growth (monocultural or species-rich, site-adapted, natural forests). This is why a further definition and possible classification of forest ecosystems appears valuable. According to the Food and Agriculture Organisation (FAO), forests are defined as an area of at least 0.5 hectares covered with trees that are higher than 5 meters or are able to reach this height in situ, and a canopy cover of more than 10% (FAO 2018, 4). The absence of other predominant land use such as agriculture or settlements is crucial. Fruit or oil palm plantations, olive chards or most agroforestry systems are thus not considered as forests according to the FAO definition. However, according to this definition nothing is said concerning the state and the provided ecosystem functions (FAO 2018, 4). Therefore, it is useful to classify forests further, e.g., into primary, secondary or old-growth forests. Primary forests have never been logged but might be used by indigenous communities that contribute to their diversity and protection (CBD 2006). They are characterised by their capacity to naturally regenerate, native tree species and functioning ecological processes without significant human influence. They account for 34% of the world's forests (FAO and UNEP 2020, xvi). Secondary forests have recovered either artificially or naturally after being logged (CBD 2006). Definitions of old-growth forests are ambiguous (Wirth et al. 2009). Here we follow the definition of the CBD according to which old-growth forests are old stands within either primary or secondary forests where old trees have accumulated in a way to form a different ecosystem than any younger class parts of the forest. Intact old-growth forests are – as primary forests – mainly characterised by their developed structures, which act as a distinct forest ecosystem. Plant, animal and microorganism communities and their abiotic environment form a functional unit (CBD 2006). This is why in particular primary and old growth forests are so-called biodiversity hotspots and deliver irreplaceable habitats for plants, animals and fungi (Watson et al. 2018; Di Marco et al. 2019; Hawes 2018; European Commission

2020, 5). Biodiversity hotspots contain at least 1500 endemic species found nowhere else on earth and have lost at least 70% of their primary native vegetation (CEPF 2021). In general, when the recruitment, growth and mortality of trees is balanced, their ecosystem is highly resilient and able to regenerate itself (European Commission 2020; McDowell et al. 2020). Thus, particularly intact forest ecosystems, provide additionally high resilience against natural disasters and minimise the risk of rapidly spreading pandemics (Wilkinson et al. 2018; Gómez-González et al. 2020; European Commission 2020, 2; UNEP and ILRI 2020). They therefore carry a significant value to all human life.

However, forest degradation and deforestation are progressing, particularly at the expense of primary forests as will be shown in the following Sect. 4.1.2. This can be observed in Latin America (e.g., Brazil, Nicaragua, see INPE Data 2020; Tyukavina et al. 2018; Tobar-López et al. 2019), Asia (e.g., Indonesia, see Tyukavina et al. 2018) and Sub-Saharan Africa (e.g., Congo, see Tyukavina et al. 2018) concerning the last remaining tropical rainforests. But also in Europe, the last primary forests are threatened, e.g., in Rumania and Poland (Niţă 2015; European Commission 2017, 38, 2020; Sabatini et al. 2018).

4.1.2 Drivers of Forest Loss and Forest Degradation

Understanding the drivers of forest degradation and deforestation that risk their potential to mitigate climate change and biodiversity loss is a prerequisite for successful forest governance. The European Commission defines deforestation as "the permanent destruction of forests and woodlands and conversion to non-forest uses" and forest degradation as "the loss of the forests' capacity to provide their essential goods and services" (European Commission 2021). In general, drivers of forest loss can be of natural or anthropogenic origin.

Today, the pressure on forests occurs due to diverse needs, which poses different risks to forests: While growing populations and poverty threaten forest conservation, the consumption patterns of more affluent populations drive deforestation (FAO and UNEP 2020, 82). Consumption patterns leading to deforestation and forest degradation (embodied deforestation) are linked to an increasing demand for agricultural and forest products that in turn is driven by global market pressures, dietary preferences and loss and waste along agricultural value chains (IPCC 2019b). In total, about 75–80% of today's global deforestation is caused by the expansion of agricultural land, followed by the extraction of timber, the expansion of infrastructure as well as mining activities and wildfires each accounting for about 7–10% (Kissinger et al. 2012; Curtis et al. 2018; ECOFYS et al. 2018a; European Commission 2019). The expansion of agricultural land is mostly linked to large-scale land acquisition and land-grabbing to establish agro-industrial plantations, commercial ranching and timber extraction or mining activities (Chen et al. 2019; Davis et al. 2020). In this context, also land speculation plays a strong local role (WWF 2021a, 7). Drivers of deforestation are therefore old and new; however, they are not static but their influence, and those of actors, changes over time as well as across regions which mainly depends on political and market shifts (WWF 2021a, 10, 28). The major role of livestock farming and fossil fuels in this respect have already been mentioned in the introduction of the present volume. A huge part of embodied deforestation is based on a demand and associated consumption patterns distant from the area of impact and outweighs local causes of deforestation, such as subsistence agriculture or small-scale timber extraction, e.g., for fire and fuelwood (Kissinger et al. 2012; European Commission 2019; Skutsch and Turnhout 2020). This becomes even more significant considering that the average rate of global net forest loss is declining Because in some countries forest loss was reduced and in others there were forest gains, the average rate of net forest loss declined by 40% between 1990–2000 and 2010–2020 (FAO 2020a). However, forest decline differs locally: While the forest area in Europe is increasing (Forest Europe 2020, 31), two thirds of global forest cover loss occurred in the tropics and sub-tropics from 2000 to 2018 (WWF 2021a, 20). An accelerating decrease concerns primary tropical forest with a loss of 12% from 2019 to 2020, whereas the loss in Brazil, that is linked to forest fires and clear-cutting, was particularly high with 25% (Weisse and Goldman 2021). In Latin America, most land-use changes at the expense of forests are connected to soybean and beef, next to palm oil cultivation (Henders et al. 2015; Vijay et al. 2016), while palm oil production is the major driver of deforestation in South-East Asia (Vijay et al. 2016). In total, mostly export related soy, beef, palm oil, coffee and cocoa cultivation are responsible for almost 80% of tropical deforestation (European Commission 2013; detailed overview: ECOFYS et al. 2018a, 177). This is why export-oriented agricultural policies can be identified as the main drivers of deforestation (Hautala 2018, 33). Apart from that, the production of bioethanol based on starchy (corn, maize) or sugar-containing plants (sugar beet, sugar cane) increases land-use pressures worldwide (Lapola et al. 2010; Hennig 2017; Smith et al. 2014, 872), along with investments in large-scale production of paper, rubber or shrimp from mangrove areas as well as mining projects (European Commission 2013, 2019; ECOFYS et al. 2018b). Unsecured land rights of small-scale farmers and/or indigenous peoples combined with insufficient or dismantled environmental policies in countries rich in tropical forests further encourage deforestation. However, it remains true that tropical deforestation is significantly supported by China and the EU (Rajão et al. 2020; European Commission 2013) as the major importers of goods such as beef, soy or minerals (Ferrante and Fearnside 2019; Kehoe et al. 2019; Rajão et al. 2020; Scheidel et al. 2020). A recent study by the WWF illustrates the impact of European consumption patterns on tropical deforestation; in 2017, 16% of deforestation associated with international trade can be linked to the EU, with Germany ranking first (WWF 2021b, 12 et seq.). The most consumed commodities from 2005 to 2017 were soy (31%), palm oil (24%), beef (10%), wood products (8%), coffee (5%), cocoa (6%) (WWF 2021b, 21).

Moreover, human-induced climate change is driving further loss and degradation of forests which is another compelling argument to combat climate change itself. Tree mortality is estimated to have doubled over the past four decades (Jofre et al. 2011; Craig et al. 2015; McDowell et al. 2020). Throughout Europe, increasing tree mortality leads to younger forests which negatively affects forest biodiversity and carbon storage potential (Senf et al. 2021). Driven by higher temperatures and long droughts, forest fires have reached a globally thus far unprecedented extent (Ryan et al. 2013; Michael and Tilman 2017; INPE Data 2020). In the future, tree mortality might further increase due to extreme weather events, such as extensive droughts and storms that further exacerbate wildfires or pest infestation (Ryan et al. 2013; Park Williams et al. 2013; Bugmann et al. 2019). Thus, natural causes of deforestation like wildfires or wind throw by storms and biotic attacks (insects, pathogen outbreaks) are exacerbated by human-induced climate change (Bond and Keeley 2005; Ryan et al. 2013; Park Williams et al. 2013; ECOFYS et al. 2018a, b; Bugmann et al. 2019; McDowell et al. 2020). However, the use of forests as a carbon sink is disputed, particularly when included in accounting rules, as will be shown in Sect. 4.2.2, sink capacity is linked to several uncertain factors. Indeed, with deteriorating forest conditions due to the advancing climate crisis, it is not certain if and how successful forest regeneration and forest preservation as such will be (on the emerging vulnerability of European forests due to climate change see Forzieri et al. 2021; see also Sect. 4.2.1). For forest biodiversity, “loss of habitats and species due to deforestation and forest degradation” (FAO and UNEP 2020, 82) is by far the greatest threat.

4.1.3 Interim Conclusion and Derivable Policy Implications

Today, not least due to the transition to a post-fossil society, forests worldwide are under unprecedented pressure of use and are exposed to changing climatic conditions, threatening the existence of the last primary forests in particular. Thus, in the future, policy instruments will need to be designed to interact in a way to halt the globally accelerating decline of forests and either strictly protect remaining primary, old growth and species-rich natural forests, following the principle of segregation, or ensure a sustainable and multifunctional forest use in clear favour of biodiverse forest ecosystems. Therefore, forest cover worldwide needs to be mapped and monitored more sufficiently (Luyssaert et al. 2008; Sabatini et al. 2020).

Considering the problem of embodied deforestation, it is important to highlight that the demand-side is neither locally nor globally fixed but is determined by consumption patterns which can (and have to be) changed by effective policy instruments. Thus, a strong focus needs to be set on demand-sight climate mitigation measures to minimise land-use pressures in favour of intact forests, tackling the livestock farming and the biomass sectors in particular (Smith et al. 2014; Hennig 2017; Ekardt 2019; Weishaupt et al. 2020). However, the implementation of policy instruments addressing the demand-sight and thus the drivers of forest loss are also– as we will show in the governance analysis in Chap. 5 in more detail – thus far widely missing so that direct and indirect land-use changes accelerate (ECOFYS et al. 2018a; European Commission 2013, 2019).

Concerning the use of biomass, not only the construction, textile or chemical sectors, but also the substitution of fossil-fuel based plastics might lead to a higher demand for timber in the future (Stubenrauch 2019; Verkerk et al. 2020). It is therefore prudent to foster the reuse of resources, enhanced recycling and the cascade utilisation of wood. Forest governance has to be integrated into a concept of circular economy, including efficiency, consistency and frugality strategies (Ted and Houten 1994; Claudia and Stern 2017; Ekardt 2019; Stubenrauch 2019; Köhl et al. 2020). The latter is even relevant when deadwood or agricultural waste is used for energy purposes. Coarse woody debris releases carbon more slowly and is more compliant with the natural carbon cycle than if energetically used (Smith et al. 2014, 871; Pfeifer et al. 2015) and agricultural wastes are important organic fertilisers that can contribute to the substitution of mineral fertilisers in the future (Smith et al. 2014; Stubenrauch 2019, 871; Garske 2020).

To guarantee the protection and the reconciliation of both climate and biodiversity, crucial is that conflicting goals are to be avoided and synergies be used. This is also essential for facilitating health provisions by forests, as reforestation and afforestation in form of plantations can, next to forest clearance, be responsible for outbreaks of infectious diseases (Morand and Lajaunie 2021). We have already seen so far that reducing land-use pressure caused by fossil fuels and animal husbandry could be a key element for this. Furthermore, reducing the usage of land-based biomass might therefore bear immense potential to reduce CO_2 emissions and decrease land use pressures at the same time (Smith et al. 2014, 872).

4.2 A Critical Review of Natural Scientific Data on Forests in the Climate Discourse and Implications for the Legislative Process

The carbon storage potential of forests is increasingly stressed within the climate mitigation debate. Thus, the following two sections seek to answer two main questions with major significance regarding the development of policy instruments: Firstly, which contribution to climate (and biodiversity) protection can be expected to be provided by the forest sector and particularly afforestation projects in the future, and secondly, can this contribution be reliably measured against a specific baseline?

4.2.1 Emission Saving Potential of Forests, Interlinkages with Biodiversity Protection and Depictability

Forest ecosystems contribute to approximately 50% of terrestrial net primary production and store approximately 45% of total terrestrial carbon and are therefore a crucial element in the global carbon cycle (Bonan 2008; Zhao et al. 2019). Forest biomass becomes a carbon sink as soon as the biological CO_2 uptake is higher than the total release of GHGs (e.g., through respiration, forest fire, profound disturbances; see Griffiths and Jarvis 2004). The net carbon balance of forest ecosystems is regularly positive and even old growth forests are not per se carbon neutral (Odum

1969; Lal 2005) and are able to further sequester carbon (Carey et al. 2001; Luyssaert et al. 2008; Jiang et al. 2020).

The carbon sequestration rate of forests depends on the type, age and density of trees, soil properties as well as latitude and connected climatic influences (e.g., temperature, precipitation, CO_2 concentration, nitrogen (N) deposition, and ozone (O_3) exposure) (Jandl et al. 2007; Luyssaert et al. 2008; Grüneberg et al. 2014; de Vries et al. 2017; Büntgen et al. 2019). With increasing latitude, the potential of forests to store carbon generally decreases due to a reduced net productivity (Erb et al. 2018). Tropical forests, that at the same time function as biodiversity hotspots, this have the largest potential to store carbon.

The total carbon storage in forest ecosystems consists of carbon sequestered in the forest biomass (including stem biomass, coarse woody debris, roots) and in the soil organic matter (SOM) (Lal 2005; Luyssaert et al. 2008; Grüneberg et al. 2014). Soils store most of the total carbon in forest ecosystems (Jandl et al. 2007; Luyssaert et al. 2008; Zhao et al. 2019; Terrer 2021). The amount of carbon sequestered in forest soils depends on their specific characteristics, which in turn are influenced by the upstanding trees and their productivity. Luyssaert et al. (2008) estimate for old-growth forests older than 200 years that they sequester 2.4 ± 0.8 tons of carbon per hectare and year (t C ha^{-1} $year^{-1}$) on average, thereof 0.4 ± 0.1 t C ha^{-1} $year^{-1}$ in the stem biomass, 0.7 ± 0.2 t C ha^{-1} $year^{-1}$ in the coarse woody debris (deadwood) and 1.3 ± 0.8 t C ha^{-1} $year^{-1}$ in the roots and the SOM. Coarse woody debris is often underestimated as a carbon reservoir and releases carbon more slowly and is more compliant with the natural carbon cycle than, for example, energetically used woody biomass does (Smith et al. 2014, 871; Pfeifer et al. 2015).

Degradation processes or unsustainable forest management might further harm the carbon stock of forest ecosystems. This is why the sink capacity of forests is regularly overestimated. According to Tubiello et al. (2021), the net contribution of worldwide forests for the period 2011–2020 was calculated to be less than −0.2 Gt CO_2 $year^{-1}$, when net forest conversion emissions (3.1 Gt CO_2 $year^{-1}$) were offset with net removals from forest land (−3.3 Gt CO_2 $year^{-1}$) (Tubiello et al. 2021). For the Amazon rainforest it was proven that forest degradation contributed three times more to the loss of aboveground biomass than deforestation (Qin et al. 2021). Apart from that, the exposure of the soil during silvicultural processes (logging or planting) can lead to a higher decomposition of SOM and thus to considerable carbon losses from belowground biomass (Jandl et al. 2007; Luyssaert et al. 2008). Moreover, the capacity of forest ecosystems to store carbon might be reduced under climate change conditions that do not enhance forest growth over the long term due to the expected accelerated life-cycles of forests and additionally lead to comparable high losses of carbon pools in the below ground biomass (Park Williams et al. 2013; Gatti et al. 2014; Büntgen et al. 2019; Yu et al. 2019; Nottingham et al. 2020; Varney et al. 2020):

- Firstly, photosynthetic activity of mature trees is not expected to be further enhanced due to higher atmospheric CO_2 concentrations (Carey et al. 2001; Jandl et al. 2007; Luyssaert et al. 2008; de Vries et al. 2017; Jiang et al. 2020) and even the stimulated growth of younger forests goes along with enhanced respiratory fluxes. Thus, large amounts of the additionally sequestered carbon are released through enhanced respiration (Jandl et al. 2007; Veldman et al. 2019; Jiang et al. 2020). Apart from that, a transition to a period dominated by vapor pressure deficits that significantly restrict tree growth, health and thus their longevity, is expected (McDowell et al. 2020). There are various indications that a higher stem productivity of trees in their early growth period leads to an earlier biomass turnover rate and thus a shorter carbon residence time (Bigler and Veblen 2009; Büntgen et al. 2019; Yu et al. 2019; McDowell et al. 2020).

- Secondly, extensive droughts already cause significant carbon losses in tropical forests which in regular (more wet) years function as carbon sinks, but due to missing precipitation seasonally turn into carbon sources (on the example of the Amazon Gatti et al. 2014). Generally, already small changes in precipitation can show significant effects on the carbon fluxes between forest ecosystems and the atmosphere (Naudts et al. 2016; Zhao et al. 2019).
- Thirdly, also in general, it is expected that soils release more carbon to the atmosphere due to a higher microbial activity. This has been proven for temperate latitudes as well as for the tropics, where carbon losses will be particularly high and (Nottingham et al. 2020; Varney et al. 2020) and are expected to increase by up to 55% due to further changing climate conditions (Nottingham et al. 2020).

It becomes clear that the sensitivity of forest ecosystems mainly influenced by any kind of soil disturbances, climate change and hereby induced weather phenomena, next to the expectable earlier tree mortality, means there are significant uncertainties in predicting the development of the carbon stock potential of forest ecosystems over time. All these factors would need to be considered in earth system model (ESM) projections, which is, however, hardly feasible due to the high intrinsic uncertainties (Luyssaert et al. 2008; Bigler and Veblen 2009; Steffen et al. 2018; Bugmann et al. 2019; Büntgen et al. 2019; Yu et al. 2019; Wieding et al. 2020). This is why, e.g., the shortened life span of trees is hardly considered in the modelling so far and also self-reinforcing processes regarding the loss of SOM are difficult to model accurately (Büntgen et al. 2019; Varney et al. 2020). This demonstrates how difficult it is to accurately depict increased or decreased sink capacities of forest ecosystems and therefore has far-reaching consequences for policy instruments based on them (see the REDD+ approach, Sect. 5.1.6 or the EU's LULUCF regulation, Sect. 5.2).

4.2.2 Afforestation and Reforestation – A Cheap and Feasible Solution to Combat the Climate Crisis? On False Hopes and the Problem of Depicting

Afforestation and reforestation are both associated with planting and/or deliberately seeding trees on land (FAO 2018, 6). However, in contrast to reforestation, afforestation implies land-use changes (FAO 2018, 7) as it includes planting forests on lands that did contain tree cover before (IPCC 2000). Afforestation should therefore be assessed differently from the reforestation of areas that are still classified as forest, e.g., due to a canopy density higher than 10% (FAO 2018, 6) meaning that forests are planted on land that had already contained forests before (IPCC 2000). The FAO, however, connects both with planting and/or deliberate seeding activities, only excluding natural forest regeneration processes (FAO 2018, 6). Terms such as "global tree restoration potential" (Bastin et al. 2019) therefore usually include both afforestation and reforestation as they equally refer to the planting and/or deliberate seeding of trees (Bastin et al. 2019; see, e.g., also Doelman et al. 2020). The boundaries between afforestation and reforestation become partially blurred in practice. Generally, planting trees as a climate change mitigation measure is regularly considered to be economically feasible already with CO_2 prices below USD 50/t CO_2 (see in detail Doelman et al. 2020). In the EU it is envisagedto plant at least 3 billion additional trees according to the EU's biodiversity strategy (critically Selva et al. 2020). The Bonn Challenge is aiming to globally restore 150 million hectares of deforested and degraded land by 2020 and 350 million hectares by 2030 based on the concept of forest-landscape restoration (IUCN 2020). Thus far, however, the challenge suffers from insufficient participation and requires better forest accounting on a national level (Bastin et al. 2019).

Modelling results regarding the potential to sequester carbon globally by the additional planting of trees until 2100 is, however, challenging and varies – due to contrary assumptions – considerably between 176 Gt CO_2 (Sathaye et al. 2006) and up to 800 Gt CO_2 (Humpenöder et al. 2014). Bastin et al. (2019) claim that globally the conversion of 1 billion hectares into forests with a canopy density higher than 10% could sequester approximately 205 Gt CO_2 under current climatic conditions (Bastin et al. 2019). Yet, they state that emission reductions might decline under changing climate conditions and that, in this regard, the model contains substantial uncertainties (Bastin et al. 2019). According to Veldman et al., the calculated climate effect is overestimated by at least the factor 5, as SOM gains are most probably lower, the albedo effect is inadequately considered and the afforestation is included in grasslands and savannas rich in biodiversity, where wildfires and omnivores naturally control the forest cover (Veldman et al. 2019). Therefore, afforestation can pose major threats to biodiversity-rich natural ecosystems (Bond and Keeley 2005; Veldman et al. 2019; Scurlock and Hall 1998; Selva et al. 2020) and can even increase the risk for spreading wildfires (de Rigo et al. 2017; Seidl et al. 2017). Concerning Europe, models of Strandberg and Kjellström reveal that afforestation of all unwooded areas in Europe could result in a cooling of 0.5–3 °C of seasonal mean temperatures, however, mostly with local and – again – hardly exactly predictable effects (Strandberg and Kjellström 2019) and without considering natural site conditions sufficiently.

In any case, modelling results and the potential contribution of afforestation and reforestation to climate change mitigation have to be reviewed critically due to the following:

- When estimating the climate effect, next to the challenging assessment of the potential carbon sequestration in forest biomass (see Sect. 4.2.1), surface albedo and evapotranspiration (the sum of evaporation and transpiration) have to be considered as interdependent biophysical climatic factors. Forested areas usually have a lower surface albedo compared to unforested areas and conceal the high albedo of snow. This causes a warming effect, which is particularly prevalent in lower latitudes, such as the boreal zone (Bonan 2008; Strandberg and Kjellström 2019; Kreidenweis et al. 2016; Hennig 2017; Fuss et al. 2021). In contrast, evapotranspiration of forest ecosystems interacts with clouds and influences precipitation, so that a cooling effect occurs (Bonan 2008; Strandberg and Kjellström 2019; Kreidenweis et al. 2016). The cooling effect due to enhanced evapotranspiration typically prevails but is particularly pronounced in the humid, tropical regions. The extent of these two contradicting effects is therefore determined by the amount of water in the ecosystems, positively influencing the evapotranspiration, and the latitude influencing the planar reflectivity together with the land-use changes, influencing the magnitude of the albedo effect (Henderson-Sellers and Meadows 1979). Therefore, afforestation and reforestation in tropical regions is estimated to be more effective than in more temperate regions with lower water availability but expectable greater changes in surface albedo (Strandberg and Kjellström 2019; Kreidenweis et al. 2016). In contrast, it is anticipated that afforestation in the boreal zone may even easily lead to adverse climate effects, meaning that it might contribute to global warming (Bathiany et al. 2010; Arora and Montenegro 2011; Gómez-González et al. 2020).
- Apart from that, there might be a limited or even an adverse climate effect of tree planting initiatives caused by reinforcing disturbances under changing climate conditions (Seidl et al. 2017; Bergkemper et al. 2016; Büntgen et al. 2019; Schwärzel et al. 2020; Hennig 2017; Fuss et al. 2021; Harris et al. 2021; Nabuurs et al. 2007). Firstly, increased tree growth requires sufficient water and nutrients such as nitrogen and phosphorus in order to take advantage of rising CO_2 content in the atmosphere, which however are limited (Norby et al. 2010; Terrer et al. 2019; McCarthy et al. 2010). Next to water shortage due to extended droughts this could be investigated concerning the plant available phosphorus that becomes further restricted under changing climate conditions, particularly but not exclusively in tropical environments (Touhami et al. 2020; Hou et al. 2018; Ellsworth et al. 2017). Thus, expectable enhancements in forest productivity might be considerably constrained by a shortage of essential nutrients such as phosphorus and might not occur in the expected manner. Secondly, with the increasing rising risk of droughts and as a result of the accelerated life cycle of trees, it is highly likely that tree mortality rates will continue to increase globally (see Sect. 4.1.2; McDowell et al. 2020). Thirdly, as a result of complex biogeochemical processes, the carbon budget of a forest is highly sensitive to any kind of disturbance. Soil disturbances regularly occur in the context of tree planting, converting young forests to conspicuous sources of CO_2 (Luyssaert et al. 2008, 213). Particularly severe and contradictory climate effects are to be expected when natural carbon reservoirs and biodiversity-rich wetlands or unmanaged grass-

lands are afforested (Scurlock and Hall 1998; Baldocchi and Penuelas 2019; Veldman et al. 2019; Ekardt et al. 2020). Besides a loss of SOM, natural vegetation gets lost, threatening biodiversity (Baldocchi and Penuelas 2019; Veldman et al. 2019).

- Furthermore, deforestation with successive afforestation might not maintain the same effects on warming and cooling as former old growth intact forest ecosystems might have done. Despite the fact that forested lands as part of the LULUCF sector in Europe (see Sect. 5.2.2) are still a strong sink in most of the EU Member States, a declining sink capacity has been recently measured due to increasing demand for timber and biomass for bioenergy as well as natural disturbances (EEA 2019, 30). According to the statistics of the FAO, the sink capacity of forested land in 2020 has already declined by nearly 50% compared to 2015 (FAO 2020b, 5). Naudts et al. (2016) claim in that respect that afforestation and forest management in Europe thus far did not contribute to the mitigation of climate change. Instead, not sustainably managed forests functioned as a net source of carbon (Naudts et al. 2016).
- All of this takes us to a more overarching point (see on the following Wieding et al. 2020 with regard to geoengineering and to the IPCC in general; Ekardt 2021). Discussions about figures and scenarios as such are far less binding for sustainability research than is often assumed. Rather, it is crucial to analyse the background assumptions of various calculations in detail. This is often difficult because sometimes assumptions are not openly revealed or are even completely opaque. In any case, scenarios on potentials are not norms, nor are they forecasts – they are merely projections.

Notwithstanding, assuming favourable natural constraints for tree cover and a sustainable forest management, successful tree planting projects that are evaluated after a longer time span of 50 or even better more than 100 or 200 years, might develop as a net carbon sink, especially if the interacting tree species reflect the natural, potential vegetation and are not regularly disturbed by logging (Erb et al. 2018; Naudts et al. 2016; Lawson and Michler 2014). Compared to the goal of reaching zero net emissions in less than two decades or even clearly before 2035, this is, however, a long time-span and will not substitute for mitigation measures with immediate effect such as phasing out fossil fuel based emissions (Ekardt et al. 2018b; Baldocchi and Penuelas 2019; Büntgen et al. 2019; Wieding et al. 2020).

Short-term carbon pool gains by afforestation might only be achievable if former agriculturally used and widely degraded land is managed sustainably and possibly afforested. This is because, especially under intensive arable land use, SOM content tends to decrease and soil disturbances are regularly higher than under a forest cover (Post 2002, 200; Lal 2005; Fließbach et al. 2007; Scotti et al. 2013; De Mastro et al. 2019; Fuss et al. 2021; Harris et al. 2021). This leads to another potential conflict associated with large-scale afforestation: food security. Particularly small-scale farmers could be (further) deprived of their land in the course of afforestation, potentially increasing dependency on food imports which might cause food prices to rise sharply (Kreidenweis et al. 2016; Griscom et al. 2017; Doelman et al. 2020).

Therefore, integrating trees into diversely managed agricultural systems seems to be more convincing than to afforest agricultural land on a large scale. This could generate urgently needed resilient food systems that locally contribute to reach food sovereignty, mitigate climate change and preserve biodiversity (Ausseil et al. 2014; IPBES 2019; Gómez-González et al. 2020). Agroforestry systems or sowing catch crops to diversify agricultural practices are first starting points here (Stubenrauch 2019; Gentsch et al. 2020; Gómez-González et al. 2020). Agroforestry binds carbon in vegetation and soil through the combination of trees or other woody plants and arable crops or animal husbandry and thus stores more carbon than agriculturally used land without trees (Nair et al. 2009; De Stefano and Jacobson 2018).

Keeping all this in mind, the idea of fighting climate change through planting trees alone must be generally questioned: The effects might be much lower than hoped for or even adverse, as the carbon-sink capacity of young forests and the availability of land are overestimated while land competition and potential trade-offs regarding food security as well as the need for biodiversity protection are underestimated (Black 2011, 150 et seq.; Hennig 2017; Ekardt 2019 Ch. 1.3; Palmer 2021). If reforestation and afforestation are considered as climate change mitigation measures by providing negative emission potentials, the manifold ecosystem functions of forest ecosystems and their resilience, next to site-specific natural and socio-economic conditions, require the utmost attention (Verkerk et al. 2020; Yousefpour et al. 2018; Seidl et al. 2017; Büntgen et al. 2019; Luyssaert et al. 2008; Forest Europe 2008; European Commission 2019). In other words: The climate mitigation potential of large-scale afforestation, partly overlapping with reforestation, varies widely in particular in the short term – and is regularly overrated (see also Table 4.1). Afforestation should only be considered if natural (and cultural) site-conditions are favourable and trade-offs regarding biodiversity and food security remain low. This is, however, regularly not taken sufficiently into consideration, contrasting human rights and the CBD. The IPCC therefore attributes only a medium confidence to the climate mitigating effect of afforestation and reforestation measures, in contrast to the high confidence regarding the potential of measures further listed in Table 4.1.

Table 4.1 Estimated global climate effect of different mitigation options according to assessments of the IPCC (2019a, b, c, 585, 586, 588)

Climate change mitigation option (selection)	Potential (Gt CO_{2e} year^{-1})	Confidence
Forest management	0.4–2.1	Medium
Reduced deforestation and forest degradation	0.4–5.8	**High**
Reforestation and forest restoration	1.5–10.1	Medium
Afforestation[a]	0.5–8.9	Medium
Increased soil organic carbon content	0.4–8.6	**High**
Dietary change	0.7–8.0	**High**
Reduced food waste	0.8–4.5	**High**

[a]Estimates are partly overlapping with reforestation

4.2.3 Interim Conclusion and Derivable Policy Implications

The natural scientific data highlights that preserving existing forests and halting not only deforestation, but essentially also the degradation of forest ecosystems as well as their restoration are more reasonable than large-scale tree planting at any cost. Like this, gains in ecosystem resilience, biological diversity and climate change mitigation as well as adaptation are achieved, and the latter become connected (Schoene and Bernier 2012; Elliot et al. 2013; European Commission 2019, 4; Verkerk et al. 2020). Thus, the protection of old-growth, intact forests ecosystems and stopping the accelerating forest degradation and its above-mentioned drivers should be given a high priority concerning policy interventions. Besides, policies will need to focus on the sustainable restoration of degraded forest ecosystems to support the natural capacity of forest ecosystems and re-instate ecological processes. In this way, not only biodiversity and climate come along together, but also a renewable resource pool to substitute fossil-fuel based materials is maintained in the long-term. To support this process, a "global system of dynamic monitoring" (Cook-Patton et al. 2021) that aggregates and controls restoration projects and uses advanced remote sensing methods is needed (Cook-Patton et al. 2021). Apart from that, the aforementioned can only be accomplished if drivers of deforestation and forest degradation are successfully addressed by policy interventions in the future (see Sect. 4.1.2).

The critical review of natural scientific data above showed that GHG bound in forest ecosystems are highly volatile and reversible and therefore much more difficult to capture than those of fossil-fuel emissions (Tubiello et al. 2021). The amount of additional carbon sequestered depends on a large number of mutually reinforcing or even opposing factors which impede exact measurement or prediction (Junfang et al. 2012, 2019). It can be concluded that both measurability and the prediction of the carbon storage capacity of forest ecosystems under future climatic conditions will be extremely challenging (Steffen et al. 2018; McDowell et al. 2020). When trying to depict the additional carbon storage potential, tree-specific and site-specific conditions have to be taken into account, which themselves are influenced by changing climatic conditions and further anthropogenic interventions (Naudts et al. 2016; Zhao et al. 2019). Site-specific soil conditions interact with vegetation and precipitation and are highly sensitive, so that forest ecosystems might even seasonally change from a carbon sink to a source. A large number of small actors, difficulties in verifying single emission sources as well as problems with the monitoring occur additionally.

All of this does not only demonstrate that forests are in serious danger of being overestimated regarding their climate protection capabilities. Moreover, the highly heterogeneous empirical findings indicate the same massive governance problem that we call the problem of depicting (see Chap. 2) and that have already played a major role in our earlier contributions on land use in general, on biodiversity and especially on peatlands (Ekardt and Hennig 2015; Hennig 2017; Ekardt et al. 2018a, 2020). This has to be considered when thinking about optimally designed policy instruments concerning forest governance since, for example, economic instruments need a governance unit, which is easy to grasp, in order to function well (Ekardt 2019; Weishaupt et al. 2020; Garske and Ekardt 2021). Insofar as drivers such as fossil fuels or animal husbandry are addressed, such a unit is available; however, insofar as additional specific rules for forests are to be formulated, this is lacking. Whether successful forest policies should rather be driven by economic or command-and-control instruments or a specific mix of both opens up a new research question that will be evaluated in the following. In any case, to reconcile different policy areas concerning biodiversity protection, climate protection and biomass use and to implement coherent policies in line with the targets of the PA and the CBD will be of paramount importance for successful policy interventions in a post-fossil world. One policy field can never be dealt with without the other. They all have to focus on the implementation of a sustainable, climate-smart and biodiversity conserving circular economy.

4.3 Interim Conclusion

In this chapter, it was shown that the preservation of intact forest ecosystems is indispensable to protect the climate and biodiversity in the long term, and not least the health and well-being of humanity as a whole.

Despite this, the destruction of the last intact ecosystems (especially primary and old-growth forests) is actually increasing at a rapid pace. This applies particularly to tropical forests but also to the last European primeval forests. The cause lies in humankind's insatiable hunger for resources, whether it be woody biomass or arable land for the production of beef and feedstuffs such as soya and palm oil, or materials such as rubber, etc. The transition to a post-fossil society and the partial replacement of fossil fuels with woody biomass is additionally driving this development and therefore requires appropriate legal containment in order to finally achieve sustainable resource and forest management. Apart from that, demand-sight mitigation measures that steer consumption patterns (particularly but not only) in the western world concerning meat and biomass consumption and to implement frugality are highly necessary.

At the same time, the chapter critically reviewed the potentials of afforestation and reforestation in climate mitigation, often presented as the new saviour concerning the aim to fulfil the commitments of the Paris Agreement and reach climate neutrality in the future. It became clear that ultimately only biodiverse and thus resilient forests can be a carbon sink in the long term. In the short term, however, the carbon storage capacity of newly planted forests is almost negligible. In contrast, due to necessary interventions in the soil, young forests are regularly initially a source of CO_2 and do not function as a sink. Potential trade-offs with regard to food security, biodiversity protection, e.g. of species-rich grasslands and wetlands, and the total amount of land available also come into play. In addition, existing forests worldwide are currently reducing their original sink capacity and releasing more CO_2 into the atmosphere. This is due to changing environmental conditions, such as long dry seasons, often coupled with unsustainable forest management. Overall, the expected future sink capacity of newly planted or existing forests is therefore often overestimated.

Nevertheless, monitoring and measuring GHG fluxes in forest ecosystems as accurately as possible is a necessary prerequisite for policy approaches based on this (see Chap. 5). In this context, it became clear that it is very challenging to accomplish this. To date, it is hardly possible to achieve an accurate measurement of GHG fluxes in forest ecosystems and to monitor the development of forest ecosystems in a globally comprehensive and accurate manner. The so-called problem of depicting is therefore large in the case of forest ecosystems, which are influenced by a wide range of factors. Efforts to reduce this problem of depicting as best as possible are therefore necessary. However, the problem of depicting will always remain to a certain extent, which in turn has to be considered in the choice of policy instruments.

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