CLC Position Paper:

The EU Needs a Holistic Land Use Plan to Enable Enhanced Carbon Removals

CLC

CLIMATE LEADERSHIP COALITION

Contents

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1 Introduction

While emissions reductions should be the priority, temporary and permanent carbon removals are needed to reach the EU's 2050 climate target and reduce atmospheric CO_2 and other greenhouse gas concentrations to minimise the effects of overshooting 1.5 ºC of warming, which now appears likely.

However, the rate of nature-based carbon removal has been declining within the EU since 2013. This is largely due to aging forests resulting in a weakened carbon sink within the EU [1] but also a result of higher harvesting and more frequent natural disturbances. During the last ten years, the total forest carbon sink has declined by one third, to its lowest level since 1990. Although ageing forests means a reduced carbon sink, it also means a greater amount of carbon is being stored in those same forests. To mitigate climate change, the ultimate aim remains to phase-out fossil emissions, but in land-use context also to remove it in the biosphere, geosphere and hydrosphere, i.e. increase their carbon stock. However, the trend of decreasing forest growth (i.e. a slowing down in the growth of carbon storage) is alarming, and its root causes require better scientific understanding.

To reverse the trend, the European Commission proposed a *certification framework of carbon removals* to incentivise carbon sequestration via carbon farming activities and help reach net zero emissions. The scheme would cover permanent carbon storage, carbon farming and carbon storage within the forest and agriculture sectors, initially on a voluntary basis.

For landowners, a framework of incentives is necessary to stimulate forest management and agricultural practices that are better for the climate. However, at a societal level, the framework does not provide a complete toolbox for long-term transformation. During the coming decades, there will be increasing demand for land, and complementary measures are needed to ensure optimal land-use planning and long-term capacity for carbon sequestration, increased carbon storage in biomaterials and resource allocation for climate-smart research and development.

CLC believes that sound and effective decision making requires a holistic understanding of the different interests regarding land use. A comprehensive understanding of land use for agriculture, forestry and other purposes, as well as the complexity, diversity and long time horizons of both ecological processes and management decisions is needed to understand the EU's long-term capacity to sequester carbon by natural processes.

An ambitious long-term target for land-based carbon removals would provide a starting point. The target should be a basis for incentivising long-term land-use planning, taking into account the slow dynamics of ecological processes and shifts in land-use planning. Our view is that this target should be in the order of 500 Mt CO_2eq beyond 2050 in the current LULUCF sector, including forest and agricultural lands, wetlands and land for settlements, as well as carbon stored in wood products.

The target should be supported by a credible certification framework for land-based carbon removals, holistic long-term land-use planning and incentives for bioeconomy and long-term carbon storage.

In this paper, we will raise the main issues and trade-offs that we consider to be of high importance for long-term carbon sequestration in natural ecosystems and the potential of sustainable bioeconomy and a fossil-free circular economy to support this. We hope that these insights will help the EU Commission to create a framework to scale up the long-term carbon sequestration capacity of natural sinks without compromising on the necessity of moving away from fossil-based raw materials and energy.

In addition, the climate crisis cannot be solved without further advancements in science. Researchers need to enter territories that no one has previously visited. To make this possible, the barriers between silos need to be broken down in decision making, planning and scientific work.

During the recent years CLC has actively been working with carbon sinks and land-use issues. In 2019 we recommended to enhance the role of carbon sinks as part of EU climate policies in our position paper. Two years later we recommended the EU to investigate full potential of land-use and bioeconomy as part of EU climate policies.

2 Why a holistic land use plan?

Without significant emissions reductions and carbon removals the world will exceed its remaining carbon budget and the 1.5 °C target for global warming well before 2050. At current emission rates, the remaining global carbon budget will be exhausted within 10 years. The recent UNEP Emissions gap report 2022 stated that 'broad-based economy-wide transformations are required to avoid closing the window of opportunity to limit global warming to well below 2 °C, preferably 1.5 °C'. **Due to the likelihood of breaching of the 1.5 °C target, we need to be prepared to remove significant amounts of CO_2 from the atmosphere in the coming decades.**

The two options available are technical and natural carbon sequestration. Additional sequestration through either method will take time: carbon capture technology is still in the development phase and natural sequestration is dependent on the relatively slow growth of forests, although the cost of natural sequestration is lower than of technical sequestration (Figure 1). Considering the environmental and social co-benefits of forests (non-private co-benefits), the cost of natural sequestration can turn negative, while the cost of technical sequestration can easily rise into the hundreds of euros per ton. While both methods are necessary, in this paper we focus on natural sequestration. **Whilst natural sequestration is important, natural carbon sinks should not be used as a means of offsetting emissions from other sectors, where emissions reductions should still be prioritised.**

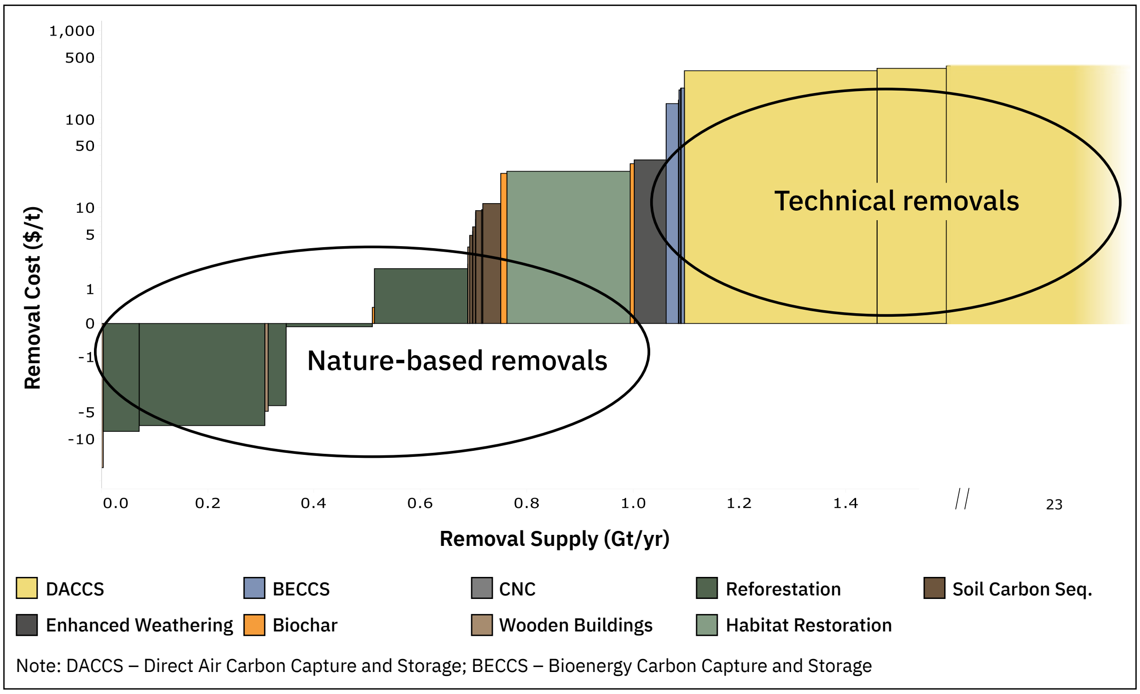

Figure 1. Estimated cost level and global supply of carbon removals in 2030, $/t and Gt/y. (Source: Afry 2022).

Land-use systems and management will play a crucial role in natural sequestration. Forests play an important role in climate change mitigation, removing one third of the carbon emitted globally into the atmosphere from anthropogenic sources. As they grow, forests absorb carbon dioxide from the atmosphere and store it in biomass and forest soil. Forest biomass can also be harvested and transformed into renewable forest products that can replace fossil-based products and cement. However, from a climate perspective, the substitution effect is not always sufficient to compensate for lost carbon sequestration.

To meet the climate challenge, forests need to be managed in a way that will increase their carbon storage potential and positive climate impact, whilst also taking into account the aerosol and albedo effects. The EU will need to achieve considerable land-based carbon removals to reach its own climate neutrality target by 2050. This will require a significant increase in both forest and agricultural sequestration as well as strengthening of the EU bioeconomy sector. The role of natural sinks will need to further increase towards the end of the century.

To upscale activities that increase carbon removals, the European Commission published its proposal to establish a certification framework for carbon removals. CLC welcomes the Commission's initiative and hopes that it will provide a strong foundation for the long-term support of natural carbon sinks. The aspiration must be to create a functioning market for temporary and permanent carbon removal with the help of forest owners and farmers. The removal must be reliable and traceable.

Resilient and strong natural sinks will be a crucial resource for reducing CO_2 from the atmosphere to minimise time spent beyond the 1.5 ºC warming threshold. **Sound decision making requires a holistic understanding of the different interests regarding land use and the complexity, diversity and long time horizons of both ecological processes and management decisions.**

The carbon storage capacity of soil is many times greater than that of above-soil storage, depending on the soil type, vegetation and climate (Figure 2). To maintain soil carbon storage, we must take care of the forests and vegetation above the soil but also understand the mechanisms of below-ground carbon and its relationship to soil management.

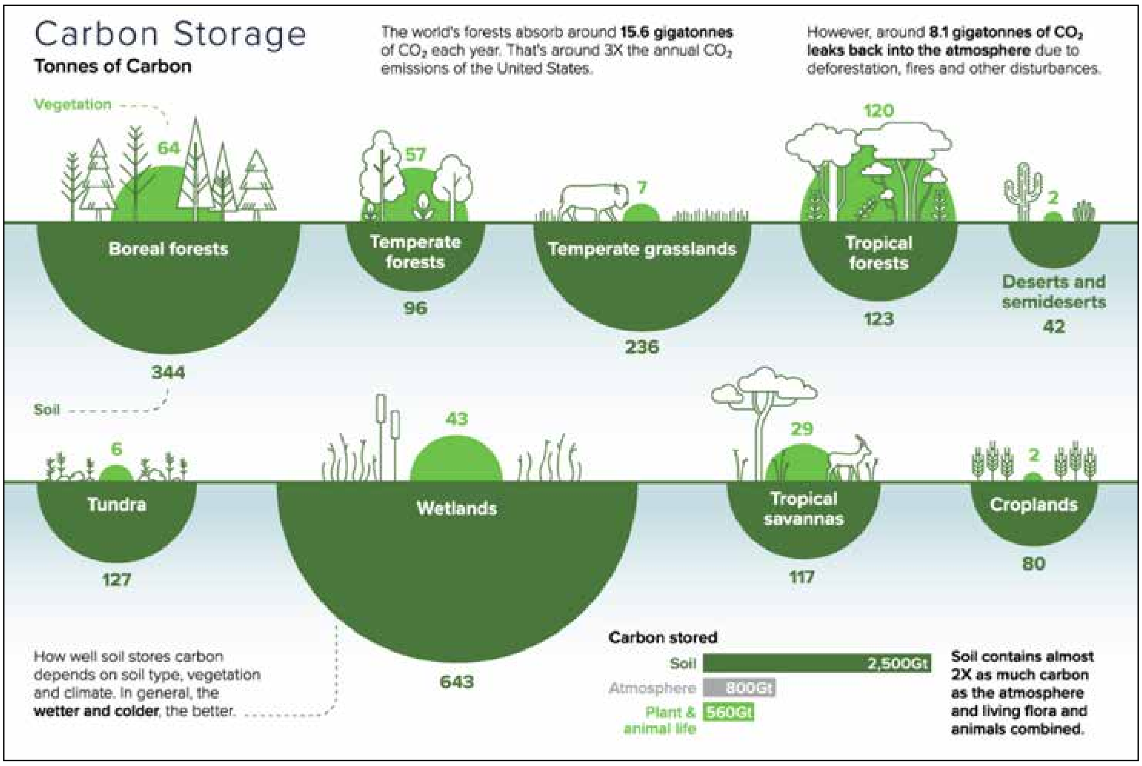

Figure 2. Carbon storage in and above soils, Gt. (Source: IPCC, NASA).

3 Extend the planning horizon beyond 2050 and eliminate sector-specific silos

European carbon sinks are under threat at the time when their carbon sequestration capacity needs to be strengthened. During the last ten years, the EU forest sink has shrunk by a fourth. According to information from member states, around a third of the 2005 EU carbon sink could be lost by 2030. The LULUCF sector may even become a net emitter beyond 2030 [20].

A group of leading forest scientists, including researchers from the EU Commission's Joint Research Centre (JRC), have given a similar warning. According to their research, the EU forest sink will shrink from its current capacity of 290 Mt CO_2eq to 250 Mt CO_2eq by 2050 under current management practices and to 80 Mt CO_2eq by the end of the century [1] (Figure 3). This could mean a significant deterioration in the vitality of European forests and ecosystem services and biodiversity more broadly.

Between 1990 and the early 2010s, the size of the EU carbon sink fluctuated between 210 Mt CO_2eq and 355 Mt CO_2eq. Since then, it has decreased by a third to about 240 Mt CO_2eq. The main reason for the decline is decreased forest carbon sequestering. **Forest carbon sequestration has decreased by a quarter since 2010** (Table 1). According to the European Environment Agency, development has been affected by the increasing maturity of forests, which has reduced incremental sequestration, as well as greater harvest rates and increasing natural disturbances. In Finland, for example, intense felling and a slowdown in forest growth has led to a situation in which the forest sink did not compensate fully for emissions from other land use sectors, with the LULUCF sector having been a net source of emissions in 2021. However, it must also be noted that Finnish forests remain a carbon sink.

Although emissions from agricultural land have decreased considerably since the 1990s, all other categories, except forest land, have remained net sources of emissions.

	Land-based emissions, Mt CO_2eq*							Change, Mt CO_2eq		
	1990	1995	2000	2005	2010	2015	2020	1990/2000	2000/2010	2010/2020
Forest land	-338.1	-426.9	-397.0	-414.8	-433.2	-390.8	-291.7	-58.9	-36.1	141.4
Cropland	66.7	54.8	47.0	41.8	36.7	30.2	22.3	-19.6	-10.3	-14.3
Grassland	47.0	32.8	46.0	32.5	31.2	21.5	18.5	-1.0	-14.7	-12.7
Wetlands	16.2	16.8	16.8	20.3	20.2	22.0	21.4	0.6	3.4	1.2
Settlements	25.7	27.4	25.4	31.3	27.8	27.5	27.3	-0.3	2.4	-0.6
Other land	1.3	5.1	2.3	1.7	1.7	1.6	1.6	1.0	-0.6	-0.1
Harvested wood products	-28.6	-17.1	-11.5	-16.5	-23.9	-27.1	-41.3	17.1	-12.4	-17.3
TOTAL	**-208.8**	**-311.5**	**-286.0**	**-300.8**	**-292.2**	**-316.2**	**-241.0**			

* Negative number indicates carbon sink, and positive number carbon source

Table 1. Development of land-based emissions by LULUCF land use categories, Mt CO_2. (Figures: EU 27 CRF tables).

Reversing the declining trend of carbon sinks will require climate-smart land management, such as afforestation, i.e. extension of forested areas, to increase sequestration in existing ecosystems. It may be tempting to limit the felling of mature trees to temporarily increase the carbon sink, but such a strategy in the long-term leads to exacerbating the problem of aging forests, increasing the likelihood of natural disturbances and reducing carbon uptake. In addition, there is a need to reduce emissions from agricultural land via suitable management practices.

Information box 1.

Drivers of the declining forest carbon sink – which is most prominent?

Weakening of the EU forest carbon sink is a result of a number of different factors:

The aging of EU forests has resulted in slowing average growth and carbon sequestration. The age structure of forests is a big factor in causing changes in tree growth. In young forests, growth is fastest in trees between 20 and 40 years old and is still relatively fast in those aged between 40 and 60. After that, growth begins to slow down.

More alarming is a decrease in the annual growth rate, biological growth rate, which has been detected for pine, spruce and birch in Northern Europe.

In addition, a growing frequency of large-scale forest disturbances has been observed during recent years, including extreme droughts, heat waves, extensive bark beetle outbreaks and more extensive forest fires. The increased frequency of disturbances is a result of a warming climate and the northward migration of climatic zones.

Roundwood felling, including for forest-based bioenergy, has increased considerably during the last 10 years and is also a significant driver behind the decreasing carbon sink [35].

But what role do these factors play in driving this change? Which are the main drivers and what should be done to reverse the trend? These are crucial questions that should be answered at the EU level by taking into account the diversity of forests and their management across the EU. One-size-fits-all policy solutions may lead to unintended negative consequences due to, e.g., land use history, geographical and climate differences and forest ownership patterns.

In addition, a growing frequency of large-scale forest disturbances has been observed during recent years, including extreme droughts, heat waves, extensive bark beetle outbreaks and more extensive forest fires. The increased frequency of disturbances is a result of a warming climate and the northward migration of climatic zones.

As an example, in many parts of Germany disturbances are linked to the choice of tree species planted over recent decades. Previously oak-dominated natural stands have been replaced with spruces, which are sensitive to drought and secondary pests, and this has caused widespread diebacks [38].

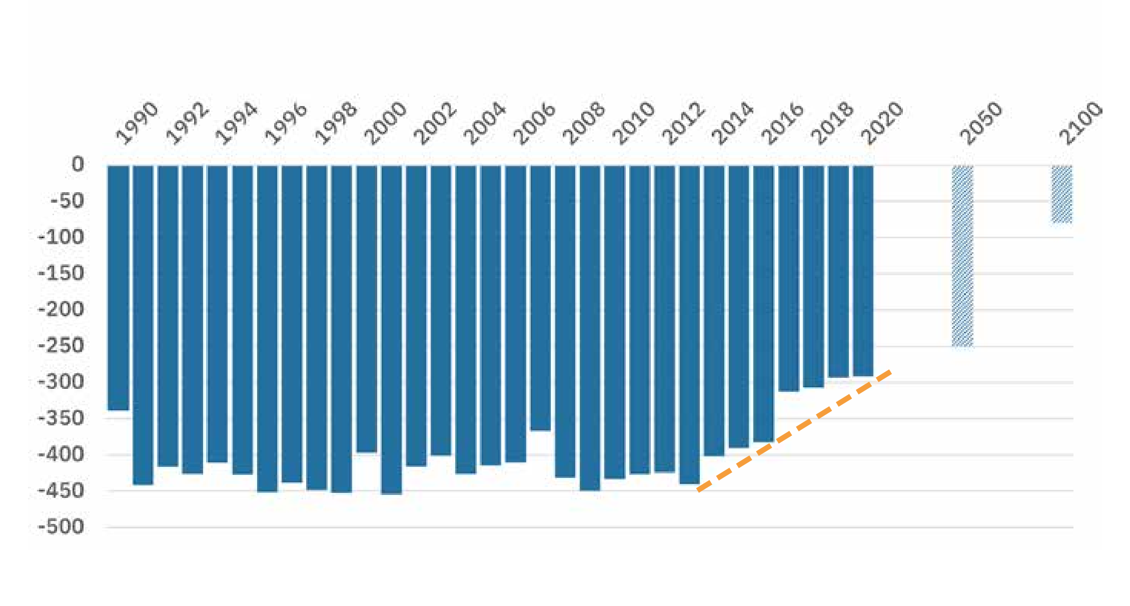

Figure 3. Development of EU carbon sinks in the forest category of LULUCF from 1990 to 2020 and the projected development under current management practices, Mt CO_2eq. (Source: EU 27 CRF tables [5], Pilli et al. [1]).

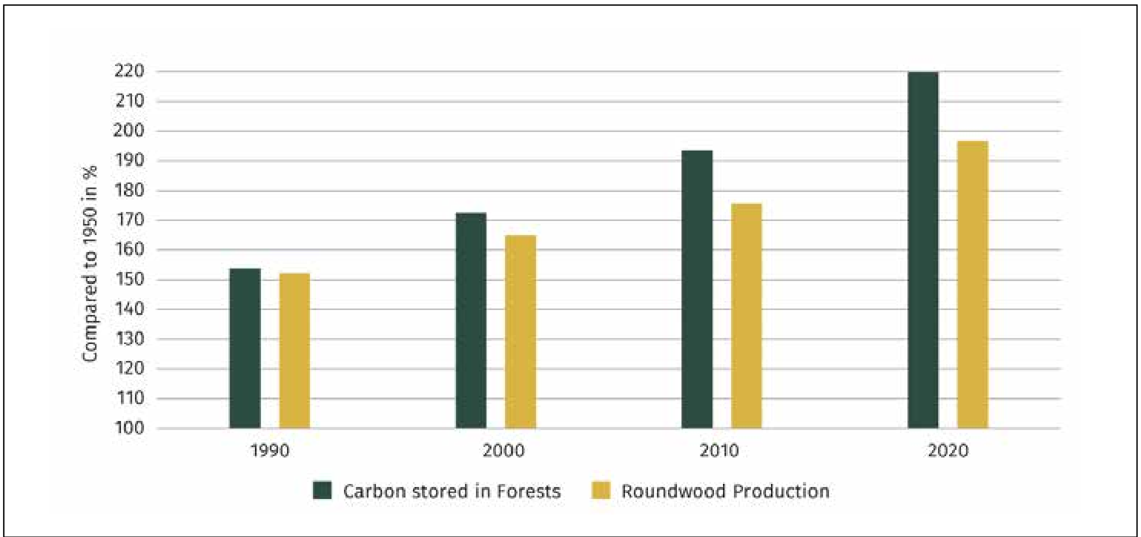

Figure 4. Development of carbon storage and roundwood production from forests in the EU compared to 1950, %. (Source: EFI 2022).

Carbon sequestering capacity is greatest in young forests, but carbon storage capacity is greatest in mature forests (Figure 5). From a carbon sequestering perspective, it is of utmost importance to ensure the long-term health and vitality of European forests. The most important measure to ensure healthy forests is active management and increased forest biodiversity.

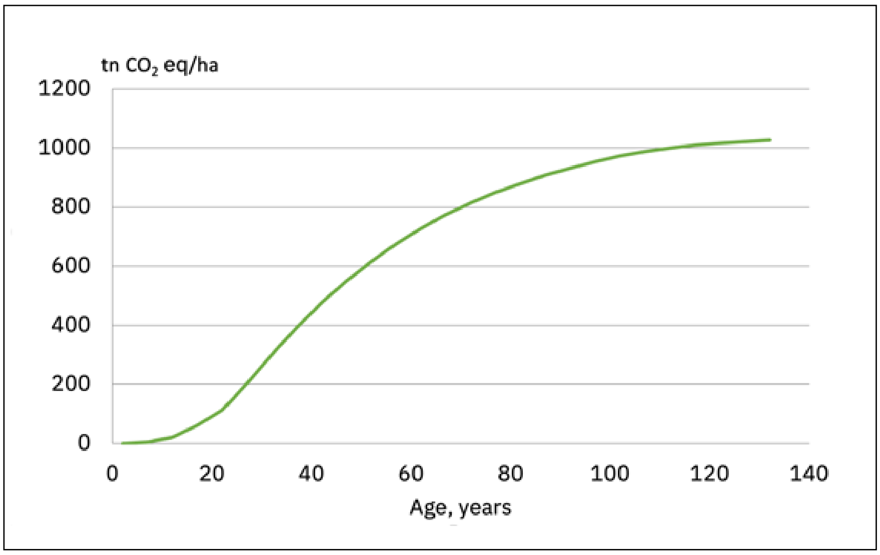

Figure 5. Accumulation of carbon in a boreal forest stand in southern Finland, t CO_2eq/ha. (Data source: Natural Resources Institute Finland, Motti software).

CLC believes that to deal with the challenge of a weakened carbon sink in a long-term and sustainable way, the planning horizon must be extended beyond 2050. There are three reasons for this.

1. Strengthening forest sinks is a slow process. Depending on latitude, it might take decades before being effective (Figure 5).
2. Given the recent changes in the climate and projected future conditions, it is unlikely that tree species will be able to migrate at a sufficient pace to keep up with rapid climate change. This is a threat to biodiversity as well as carbon sequestration. The transition towards more resilient forests should be started in a timely manner to maintain the capacity of carbon sinks.
3. A significant additional demand for land use is seen from many sectors in the coming decades. Foresight work and related action is essential to enable the growth of natural carbon sinks.

The latter in particular requires the abandonment of administrative silos to allow for holistic planning.

In the short term, it is possible to enhance natural sequestration by reducing harvest levels and extending the forest rotation period. However, this may have an unwanted impact on forest resilience, as discussed in in Chapter 5.

4 Create an effective land use plan

The recent UN Biodiversity Conference in Montreal concluded in a global commitment to preserve 30 per cent of the earth by 2030 and meet 21 other targets. The fact is that we have converted half of the earth's habitable land for agriculture. This has contributed to a reduction in biodiversity and increased CO_2 emissions. So, what does the Montreal Commitment mean for the EU?

Land use within the EU closely resembles the global picture; currently forests cover slightly more than a third of EU territory, whereas agricultural land accounts for almost half. However, there are differences between member states, not only in terms of forest coverage but also ownership patterns and other issues. At the EU level, the trend of converting land for agricultural use has passed, although here too there are differences between member states. During the last three decades, land area converted back to forests has reached about 8 million hectares. On the other hand, the urban area, 'settlements', has increased by some 6 million hectares. However, the increase in forest areas has slowed from almost 4 million hectares between 1990 and 2000 to 1.5 million hectares in the 2010s, whereas the increase in land area for settlements has remained more stable at about 2 million hectares for each decade. The increased land for forests and settlements has mainly come from use changes of agricultural land.

	Area, Mha							Change, Mha		
	1990	1995	2000	2005	2010	2015	2020	1990/2000	2000/2010	2010/2020
Forest land	159,0	160,8	162,8	164,4	165,4	166,1	167,0	3,8	2,6	1,5
Cropland	135,2	133,4	131,4	128,7	127,0	125,1	124,1	-3,8	-4,4	-2,9
Grassland	99,3	98,2	97,4	97,5	96,8	96,6	95,9	-2,0	-0,6	-0,9
Wetland	25,4	25,5	25,5	25,6	25,8	25,9	26,0	0,1	0,3	0,2
Settlements	24,4	25,4	26,4	27,5	28,7	29,9	30,8	2,0	2,4	2,1
Other	16,0	16,1	15,8	15,6	15,5	15,6	15,6	-0,2	-0,3	0,1
TOTAL LAND AREA	**459,3**	**459,3**	**459,3**	**459,3**	**459,3**	**459,3**	**459,3**			

Table 2. Development of land area by land categories, Mha. (Figures: EU 27 CRF tables).

	Land-based emissions, Mt CO_2eq*							Change, Mt CO_2 eq		
	1990	1995	2000	2005	2010	2015	2020	1990/2000	2000/2010	2010/2020
Forest land	-338.1	-426.9	-397.0	-414.8	-433.2	-390.8	-291.7	-58.9	-36.1	141.4
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Grassland	47.0	32.8	46.0	32.5	31.2	21.5	18.5	-1.0	-14.7	-12.7
Wetlands	16.2	16.8	16.8	20.3	20.2	22.0	21.4	0.6	3.4	1.2
Settlements	25.7	27.4	25.4	31.3	27.8	27.5	27.3	-0.3	2.4	-0.6
Other land	1.3	5.1	2.3	1.7	1.7	1.6	1.6	1.0	-0.6	-0.1
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* Negative number indicates carbon sink, and positive number carbon source

Table 3. Development of land-based emissions by LULUCF land use categories, Mt CO_2. (Figures: EU 27 CRF tables).

The coming decades will see increasing need for different land uses that will have to be balanced against the aim of increasing carbon sinks. Firstly, a decentralised low-carbon energy system, based on intermittent solar and wind power and eventually hydrogen, will require much more land than our current centralised system. For example, depending on the eventual share of solar power in the European energy system, the area required for solar power generation could correspond to more than *50 per cent* of current EU urban land by 2050 *[16]*. This alone would multiply annual land take. In addition, there is a need to improve energy transmission infrastructure for both power and hydrogen, which will also require considerable areas of land.

Secondly, the EU biodiversity strategy 2030 aims to protect nature and reverse the degradation of ecosystems. This is also required by the Montreal Biodiversity agreement[1]. The need to protect biodiversity may limit the use of the most efficient carbon sequestering management practices on land areas protected by the strategy. Thirdly, land is needed for urbanisation and essential infrastructure, which have been the main drivers behind land-use change during the last decade.

Carbon sequestration in the agricultural sector should be increased to reach climate neutrality by 2050 and net removals beyond that[2]. Wider implementation of climate-smart management practices and afforestation of abandoned and marginal agricultural land could represent the first steps towards this goal. Increasing the use of alternative food production would also reduce the need for agricultural land, thus releasing land for afforestation. If properly planned and incentivised, this does not have to decrease income for landowners.

CLC believes that an effective land use vision is needed as a framework for long-term planning of the future bioeconomy. Such a vision would steer EU's Common Agricultural Policies (CAP) policies and incentives for farmers and foresters to provide clear economic benefit for those who switch their practices towards a reduced environmental footprint.

As a response to the Montreal Commitment, EU biodiversity strategy and weakening carbon sinks, we need to start reducing our agricultural footprint and expand our natural handprint globally. In this regard, the EU can serve as a pioneering example by starting discussions and planning.

An inevitable question is about future diets. However, soils under cultivation need crop rotation of deep-rooting perennial crops like grasses for animal feed. The needs of soil health and the role of manure in nutrient cycling should not be forgotten.

1 Kunming-Montreal post-2020 Global Biodiversity Framework.
2 CLC policy brief: *Agriculture and food production in the beginning of the transition* on CLC website.

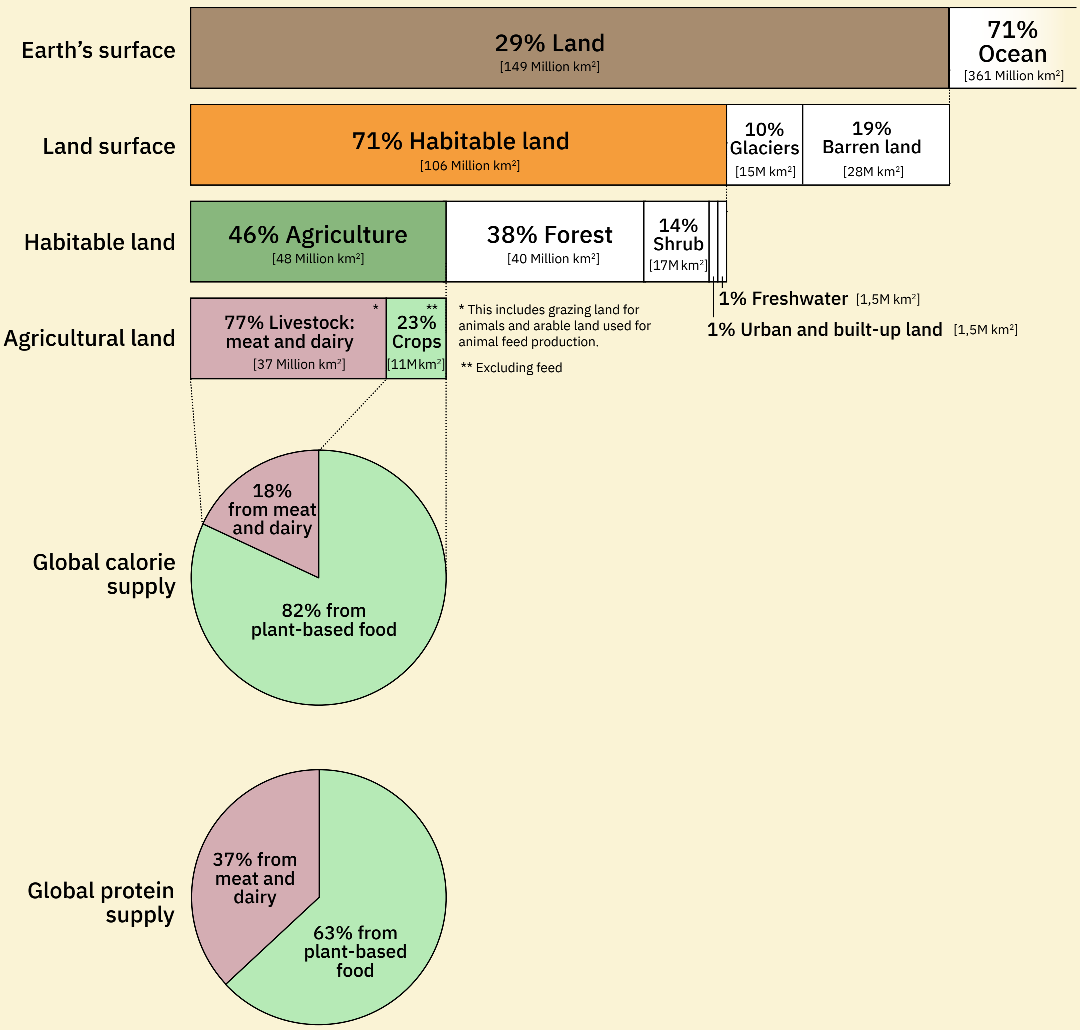
Information box 2.

Land use for food production

Globally, half of all habitable land is used for agriculture and almost 80 per cent of that is for pastures and to grow crops for animal feed. While livestock takes up most of the world's agricultural land it produces a minority, about one fifth, of the world's calories.

In the EU, the widespread use of agricultural land for livestock farming makes it difficult to increase nature-based carbon sinks.

CLC believes that within the EU we must start a discussion on how to feed our population sustainably and with reasonable self-sufficiency while enabling increased carbon sequestration.



(Data source: FAO, OurWorldinData.org)

5 Improve forest resiliency and biodiversity to secure existing carbon sinks

To maintain the capacity of forests to act as a carbon sink, the EU must also take care of their health and vitality. The predicted trend for continued warming and the likely intensification of natural disturbances, such as wildfires, windstorms and insect attacks, threaten key ecosystem services such as carbon sequestration and biodiversity conservation in the near future. Climate change and biodiversity loss are closely interconnected and share common drivers in the form of human activity. The mutual reinforcing of climate change and biodiversity loss means that finding sufficient solutions to either issue requires consideration of the other [34].

For centuries, forest managers have favoured relatively few tree species for timber and fuelwood production, as well as other amenities. As a result, European forests deviate substantially from natural vegetation. In Europe, economically important tree species have for centuries been planted outside of their natural distribution area to increase timber yields [31], which has increased their vulnerability to disturbances. Forest management has typically simplified forest structures by focusing on only a few tree species. Increasing species diversity in temperate and boreal forests improves the resilience of forests to disturbance and other risks [33]. A diversity of tree species is related to greater forest productivity and is thus important for both adaptation and mitigation.

The present rate and scale of climate change exceeds the speed of natural tree species migration. Active management is therefore needed to enable the future existence of forests and their sustainable management [13].

Forest management practices can actively shape the mix of species in forests to make them more resilient to change through planting or introducing naturally regenerating species that are thought to cope better with changing local conditions [6]. Active management to support increased forest resilience and biodiversity should be prioritised within the EU.

However, actions to enhance forest resilience and carbon sequestration should be taken fast. Forest carbon sequestration is a dynamic process that starts slowly, peaks after several years and eventually reaches saturation once forests reach maturity. In northern latitudes, peak sequestration is reached after 30–50 years, whereas in the south it is reached earlier (Figure 2). Conclusively, changes towards climate-smart management practices do not lead to immediate results.

Information box 3.

Forest migration – should we assist migration?

Forest trees have considerable adaptive capacity, but the scale of climate change exceeds the natural migration and adaptation capacity of tree species. The suitability of species is difficult to predict as we do not know how well trees will acclimate to adverse conditions. Considerable assisted migration will be required to ensure continued carbon sinks and carbon sequestering.

But this process carries risks, including the accidental introduction of insects and diseases to new places where they may wipe out entire native populations.

How should we approach assisted migration, what are the risks of unmanaged assistance and what are the risks if we do not provide assistance? The EU should initiate discussion and promote research to assess the pros and cons of planned concrete actions on this topic.

6 Create a framework to incentivise landowners and adopt a reliable and transparent monitoring platform

CLC welcomes the Commission's *Certification of Carbon Removals* initiative and hopes that it will also provide the basis for a long-term market for carbon removals that promotes healthy maintenance of forests.

While it is important to have a robust and credible certification framework for carbon removals, a sufficient price level and demand also need to be ensured for removal units. In this case, it might be necessary to consider approving units to cover emission reduction obligations in trading and non-trading sectors to some extent.

In addition to the results-based voluntary carbon removal scheme, we would also highlight the need to enhance action-based carbon sequestration via existing schemes and funding programmes like the EU's common agricultural policy (CAP) scheme, Regional Development Fund and Horizon Europe Research and Innovation Programme. This would enable increased sequestration before the market-based framework reaches the required effectiveness.

If the the CAP subsidies were to be directed towards carbon removals, it would provide significant support to landowners who remove carbon from the atmosphere. As an example, if changes in management practices sequestered an additional 20–40 million tons CO_2eq within a decade, the credits for landowners could reach hundreds of millions of euros.

An essential part of the incentive framework will be a monitoring and verification scheme for carbon sequestering. Robust, reliable and transparent verification tools for forest biomass and carbon are needed for the carbon incentive scheme. A single platform that is open and shared will enable the quantification of carbon with comparable results. This will help policymakers make better decisions based on more accurate data. It will also support policy implementation at the national and international levels through improved reporting and verification capabilities. Companies require means to respond to increasing carbon verification requirements and tools to assess carbon resources and carbon trading.

Developments in observation technologies, e.g. the Eddy Covariance technique[3], laser scanning as well as satellite, drone and other data gathering technologies, have already provided revolutionary ways to monitor carbon stocks in natural systems with a sufficient, ±5 per cent, level of accuracy[4] and cost. However, to ensure reliability, land-based measurements are needed to calibrate remote sensing data. Land-based measurements are based on the National Forest Inventory monitoring systems for carbon stocks, which differ from country to country. The inventory systems should be harmonised to support technology-based monitoring with consistent land-based measurements across the EU. Furthermore, reliable observations on carbon removals should be developed further, requiring both in-situ and remote observations. Development of the Eddy Covariance technique to determine exact CO_2 and other greenhouse gas fluxes is necessary to support satellite-based and other remote sensing assessments of carbon sinks.

3 Eddy-Covariance is a key atmospheric measurement technique to measure and calculate vertical gas fluxes within atmospheric boundary layers, for example above the tree canopy.
4 VTT, one of Europe's leading research institutions.

Developing practical and affordable equipment and methods within a reasonable time frame is realistic if sufficient funding is earmarked for this purpose. **We believe that determined and focused investment in promising measurement technologies could provide this missing toolset within a few years, enabling reliable and frequent carbon accounting to monitor incentive systems for farmers and forest owners.** Observations need to be linked to methods of economic optimisation to provide robust and cost-efficient analysis of viable management options, accounting for the provision of wood for industry and efficient mitigation of climate change simultaneously.

7 Set long-term target for nature-based carbon removals

For the strengthening of carbon sinks to be made concrete, a long-term target for net carbon removals is needed in addition to a framework of incentives.

CLC believes that the target should be ambitious enough to incentivise the development of removal practices. Setting an ambitious long-term target for carbon sinks will also serve the Commission's objective of strengthening the biodiversity and resiliency of European ecosystems. CLC believes that the target for removals should be in the order of 500 Mt CO_2eq for beyond 2050.

Table 4 illustrates how a long-term target for EU land-based carbon sinks could be constructed. The figure presented is, by its very nature, more of a vision than a target tied to any particular year. We have reviewed the best available sources on the potential to strengthen sinks, and we believe that this figure can be achieved, provided agricultural land is transformed from a source of emissions into a carbon sink and the amount of carbon stored annually in wood products is significantly increased.

The first observation is that all measures for increasing land-based carbon sinks will involve a rethink for a large number of economic actors. The main actions include a focus on climate-smart forest management practices, a shift from marginal agricultural lands towards forests, i.e. afforestation, and new agricultural methods and diets. All of these measures require a better scientific basis and are slow to implement.

Secondly, even if started immediately, some of the most important actions, such as increased forest growth, will only provide significant benefit towards 2050. On the other hand, the introduction of new bio-based materials may provide faster and greater emissions reductions (through the substitution of materials with a high carbon footprint) depending on the development of new technologies.

Thirdly, there is significant uncertainty over predictions of important future parameters such as forest growth.

CURRENT DEVELOPMENT BASED ON PILLI ET AL					
Forest carbon sink under current practices	**2020**	**2030**	**2040**	**2050**	**2100**
Current management practices					
Mean forest growth, m^3/ha	5.7	5.3	4.9	4.5	1.5
Forested area, Mha	168	168	168	168	168
Net removals, Mt*	**-292**	**-278**	**-264**	**-249**	**-83**
DEVELOPMENT BASED ON CURRENT EMISSION LEVELS					
Other LULUCF categories, current development**					
Agricultural soil emissions, Mt	41	41	41	41	41
Harwested Wood Products (HWP), Mt	-41	-41	-41	-41	-41
Other LULUCF emissions , Mt	50	50	50	50	50
TOTAL LULUCF, Mt CO_2	**-242**	**-228**	**-214**	**-199**	**-33**
ADDITIONAL MEASURES BASED ON EFI ANALYSIS					
For forest category, Mt***	**2020**	**2030**	**2040**	**2050**	**2100**
Expand forest area		-15	-32	-60	
- additional area to be afforested, Mha		5	8	15	
Forest management practices, Mt		-20	-61	-120	
Forest reserves, Mt		-5	-10	-15	
Additional measures in forest sector, total Mt CO_2		**-40**	**-103**	**-195**	
ADDITIONAL MEASURES PROPOSED BY CLC					
For agricultural soils*****		-25	-46	-60	
Additional carbon sink in HWP category		-13	-16	-20	
wooden constructions*****		-10	-16	-20	
bioplastics					
textiles					
Additonal measures in agriculture sector, total Mt CO_2		**-38**	**-62**	**-80**	
TOTAL TARGET FOR EU, COMPILED BY CLC, Mt CO_2		**-310**	**-403**	**-507**	

* Net removals in line with Pilli, R. et al 2022, https://bg.copernicus.org/preprints/bg-2022-35/bg-2022-35.pdf
** CRF tables; current levels are expected to remain
*** Additional measures in forest category Nabuurs, G.-J. et al., 2017, https://www.mdpi.com/1999-4907/8/12/484
**** CLC estimate based on https://www.nature.com/articles/s41598-017-15794-8 and discussion with Natural Research Institute Finland
***** CLC estimate

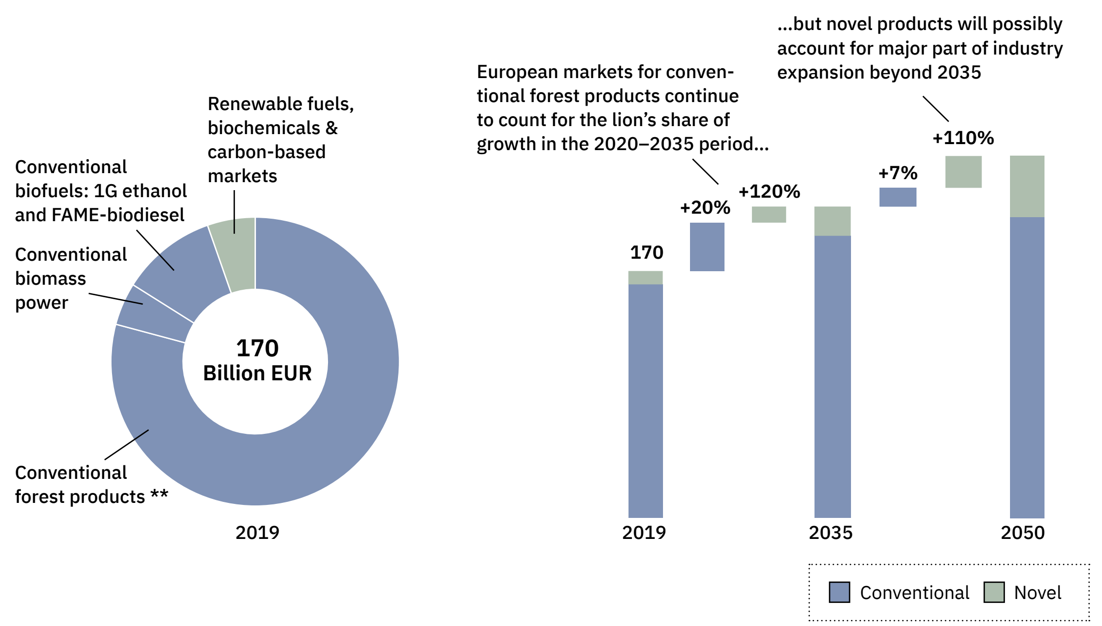
Table 4. Development of EU carbon sinks between 2020 and 2100, with and without enhanced sequestration, Mt CO_2eq.

In summary, CLC strongly believes that the current trend of diminishing land-based carbon sinks (LULUCF) can be reversed and that carbon sinks can be significantly increased. Immediate and strong actions are needed and should be planned and incentivised. In fact, due to the aging structure of European forests, a well-planned increase in harvesting is likely necessary. Due to the nature of forestry, the results of the above policy changes will only be seen in the long term.

8 Create a significant and visionary bioeconomy within the EU

The size of the European bioeconomy[5] is currently (2019) about 660 billion euros, representing 5% of the EU's total GDP and employing more than 8% of the EU workforce. The forest-based bioeconomy is around 120 billion euros. A large part, about 85%, of the raw material comes from EU forests.

It is estimated (AFRY) that the forest-based bioeconomy will grow some 20% by 2035. This growth will be mainly driven by conventional forest products, but an increasing share is expected to come from new cellulosic-based (mainly wood) materials. By 2050, the sector is predicted to grow a further 20%, with most of this forecast to come from new products. New bio-based products have a higher value added than traditional products and are designed to substitute materials with a high carbon footprint.



* Illustration scenario of global market size 2019-2035-2050

** Conventional forest products include sawntimber and products, wood-based panels, graphic papers, packaging papers and boards, and specialty papers, tissue & hygiene products and MMCF textile fibres

Figure 6. Expected development of demand for forest products by 2050, billion euros. (Source: Afry 2023).

Between 1990 and 2020, use of solid biomass more than doubled [35]. Most of this increase occurred after 2002, when the EU's first renewable energy directive, which actively promoted biomass, went into effect.

5 https://knowledge4policy.ec.europa.eu/visualisation/eu-bioeconomy-monitoring-system-dashboards_en

In the Nordic countries bioenergy mainly comprises the combustion of wood side streams from the forest industry. For environmental reasons, the use of wood for bioenergy should not be increased. Consumption of traditional forest products, such as writing paper, is also decreasing, thus reducing raw material needs. On the other hand, demand for other traditional products like packaging boards, sawn timber and more advanced wood-based building products will increase. The production of products like advanced biofuels and new materials will require an increased supply of raw material.

The wood-paying capacity varies significantly between end uses, and over time this gap will increase. Future uses of wood will change considerably as new high value end products crowd out lower value end uses.

CLC believes that a sufficient supply of raw materials can be secured within the EU for an industry based on promising new technologies, assuming that wood is used primarily for purposes other than burning for energy.

Wood-based construction materials provide long-term carbon storage. Wood-based construction materials, like Cross-Laminated Timber, are examples of existing alternatives to carbon-intensive materials such as concrete. These engineered wood-based materials can be used as load-bearing components for building frames, replacing concrete or steel. Other bio-based composite materials are already used in many applications such as wind turbine towers, and in the near future turbine blades will also be made of wood.

A whole new family of bio-based materials is emerging. These materials and products are moving from lab scale to production scale. These materials typically substitute traditional materials with a high carbon footprint such as plastics or synthetic textiles.

Another example of novel bio-based materials is lignin-based anode materials, which would replace non-renewable synthetic graphite. Sustainable alternatives for graphite to use in batteries would help reduce emissions from graphite production but also provide mid-term carbon storage and extend the supply of critical minerals for the green transition.

A more technically challenging but potentially revolutionary example is bio-based carbon fibre. Such a material could be available in 10–15 years, and besides being revolutionary would provide longer term storage for biogenic carbon. It is estimated that up to 60% of automobile parts could be replaced by bio-based carbon fibre-reinforced polymers, offering enormous weight-saving potential thus reduced energy consumption [3].

Some of these materials and products are estimated to store carbon only temporarily without a long-term climate benefit. However, the substitution effect of replacing petrochemical-based materials is very significant and should be accounted for when calculating carbon emissions.

From the perspective of forest-related science, the discussion above can be summarised as follows. With regard to the conflicting roles of forests as carbon sinks and a source of raw materials, scientific research responding to the following questions is desperately needed:

1. How can we predict, as accurately as possible, the potential of carbon sinks and the total climate impacts of the land use sector, including all radiative forces and potentially effective feedback mechanisms?

2. How can we increase forest carbon sinks and storage at the same time as the demand for other forest services is increasing?

3. How can we improve forest resilience vis-à-vis the adverse impacts of climate change and related biotic and abiotic stressors such as insects entering new geographic areas?

4. How can we maintain forest biodiversity?

5. How can we conduct robust and cost-efficient analysis of economically and ecologically optimal forest management options, simultaneously accounting for the provision of wood for industry, efficient mitigation of climate change and conservation of biodiversity.

6. How can we produce wood-based products using less virgin raw material, energy and water? Circular economy plays an important role in this and biocarbon is a developing topic. Research in this category is seeking ways to produce more from less.

7. How can we produce new materials that replace fossil-based materials in a cost-efficient manner out of wood? How can we produce medicinal products out of wood-based raw materials?

8. How can we increase the supply of new types of raw-materials using with biotechnics created synthetic wood fibre molecules?

9. Will climate change and biodiversity loss reduce forest growth, and what other factors may be at play?

10. Improving measurement technologies, data analysis (incl. AI) and global measurement networks is key to tracking the impacts of the different measures to mitigate climate change described above. How can we maximise utilisation of big comprehensive data sets and improve data mining and AI methods? Some kind of accreditation system is also required.

Increased R&D funding in the bioeconomy sector is required for the development of new innovative low-carbon and carbon storage solutions. We have to be able to produce comprehensive and reliable data on climate change, emissions, natural and technological carbon sinks, the impacts of climate on nature, the impacts of mitigation measures, etc. Data should be open and produced on a national, EU and global scale. The EU can use its leverage to enhance co-operation between universities, research centres and businesses. All silos need to be broken in decision making, planning and scientific research. Greater openness, means greater influence, quality and impact.

9 Conclusions and recommendations

Carbon removal is needed to reach the 2050 EU climate target and decrease atmospheric CO_2 concentration to minimise the effects of overshooting the 1.5 ºC global warming target, which now seems likely. While both technical and natural sequestration are needed, this paper focuses on natural sequestration. In addition, we provide suggestions for means to accelerate scientific research in relevant fields. During the last ten years, forest carbon has declined by one third, to the lowest level since 1990. Under current management practices, the EU forest carbon sink will continue to shrink to one fourth of its current size. An important factor in the long-term evolution of the forest carbon sink is the ongoing ageing process of European forests, mostly determined by past management.

CLC believes that to reverse the current trend of shrinking EU carbon sinks, the EU should take a holistic long-term view of land use and bioeconomy. To reverse the trend, the following actions are needed:

1. **The EU must have a holistic, long-term vision for its land use sector and the bioeconomy.** The planning and legal framework with regard to the land use sector is fragmented and often 'siloed'. A holistic land use vision is needed. Regulation regarding zoning and environmental protection are not sufficiently coherent. Although a long-time horizon is required due to the slow nature of biological processes, there are actions that can be taken immediately to match the urgency needed to respond to climate change (e.g. longer rotation periods).

2. **There needs to be an ambitious target for EU land-based carbon sinks beyond 2050.** The target should be ambitious enough to incentivise long-term planning of land use, taking into account the slow dynamics of ecological processes and land use planning. It is CLC's view that this target for the whole land use sector (LULUCF) should be in the order of 500 Mt CO_2eq, compared to the 2020 level of 240 Mt CO_2eq.

3. **The EU needs a long-term plan for land usage according to a holistic vision.** Reversing the declining trend of carbon sinks will require the extension of forested areas, i.e. afforestation, conversion of marginal agricultural lands and controlled expansion of areas for infrastructure. However, during the coming decades there will be increasing demand for land use that will have to be balanced against the aim of increasing carbon sinks and improving biodiversity.

4. **Climate change will alter the ecological conditions of European forests causing stress and likely reducing growth. This requires new thinking regarding forest management, including biodiversity management.** Climate change will lead to substantial changes in forest-based carbon sequestration due to shifts in tree species, increased natural disturbance and changes in productivity. It is crucial to optimise the balance between forest rejuvenation and sufficient carbon storage in forests to adapt forests to the environmental challenges of the future climate while maintaining forest growth and carbon sequestration. EU forests show symptoms of stress, due to both climate change and poor management, and it is crucial that the reasons for this are better understood and studied to form a basis for corrective actions. The key actions will include new improved forest management practices. These practices will differ within EU countries due to different climate zones, mainly temperate and boreal. Therefore, an EU-wide forest policy should not mean similar actions in all areas but rather provide a common sustainability framework to follow.

5. **Active forest management in production forests should be prioritised to support increased resiliency and biodiversity within the EU.** Forest management practices in production forests can actively shape the mix of species in forests to make them more resilient to climatic change through planting or introducing naturally regenerating species that are thought to cope better with changing local conditions. At the same time, actions to stop biodiversity loss through restoration of degraded areas and conservation of old growth forests should be pursued.

6. **Accurate measurement and carbon accounting is feasible and available as a basis for new ways to incentivise land owners.** A determined and focused investment in modern measurement technologies could bring forth the missing toolset that would allow reliable and frequent carbon accounting and verification to incentivise farmers and forest owners. This requires the assessment of cost-efficient climate change mitigation options.

7. **A shift in the use of wood and biomass from low value-added bioenergy towards the use of raw materials for new bioproducts that substitute hydrocarbon-based products is needed.** New bioproducts provide long-term carbon storage and are also often recyclable and biodegradable. We should make a shift to a higher-added-value product portfolio, in other words produce more from less wood material. Decreasing the use of wood for combustion in the EU will ensure greater availability of raw material for future high-end bioproducts.

8. **The EU should strive to become the hub for new innovative bioproducts and bioeconomy.** The EU has the technological skills, land and raw materials to support such a development. The bioeconomy sector could and should be based on growing and sustainable resources that can be managed to form a growing natural carbon sink. The EU bioeconomy is already a significant source of economic welfare and employment and can become a truly innovative example of sustainable growth.

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Appendix I:

CURRENT DEVELOPMENT BASED ON PILLI ET AL					
Forest carbon sink under current practices	**2020**	**2030**	**2040**	**2050**	**2100**
Current management practices					
Mean forest growth, m³/ha	5.7	5.3	4.9	4.5	1.5
Forested area, Mha	168	168	168	168	168
Net removals, Mt*	**-292**	**-278**	**-264**	**-249**	**-83**
DEVELOPMENT BASED ON CURRENT EMISSION LEVELS					
Other LULUCF categories, current development**					
Agricultural soil emissions, Mt	41	41	41	41	41
Harwested Wood Products (HWP), Mt	-41	-41	-41	-41	-41
Other LULUCF emissions , Mt	50	50	50	50	50
TOTAL LULUCF, Mt CO_2	**-242**	**-228**	**-214**	**-199**	**-33**
ADDITIONAL MEASURES BASED ON EFI ANALYSIS					
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Expand forest area		-15	-32	-60	
- additional area to be afforested, Mha		5	8	15	
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bioplastics					
textiles					
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*** Additional measures in forest category Nabuurs, G.-J. et al., 2017, https://www.mdpi.com/1999-4907/8/12/484
**** CLC estimate based on https://www.nature.com/articles/s41598-017-15794-8 and discussion with Natural Research Institute Finland
***** CLC estimate

Table 5. EU-27 carbon sinks in 2020 and development with additional measures beyond 2050, Mt CO_2eq.

CLIMATE LEADERSHIP COALITION