CLIMATE CHANGE
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Assumptions on potentials for Carbon Dioxide Removals in the EU

A review of recent European Commission impact assessments

by:
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On behalf of the German Environment Agency

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Abstract: Assumptions on potentials for Carbon Dioxide Removals in the EU

The report analyses and critically reviews assumptions on natural carbon dioxide removal (CDR) and storage potentials with a view to the objectives of the EU Land Use, Land-Use Change and Forestry (LULUCF) and Carbon Removal Certification Framework (CRCF) legislation agreed until February 2024. It reviews selected EU documents that were published over a period of eight years and extracts and analyses information on specific assumptions affecting the potential for natural CDR emerging from different options in the land sector in the EU.

The potential for natural CDR options is an important information for strategic decision making in the field of climate policy. The specific potential per unit area, the absolute potential but also associated costs vary for different types of natural carbon removal and storage processes and regions where these options are being implemented. This is due to biophysical and climatic but also economic and policy conditions.

The report presents an overview of estimated potentials for natural CDR in the European Commission's Impact Assessments. Considerable changes in the level of the potential over time were found that can be referred to differences in assumptions. Comparing these with estimates based on scientific literature shows that potentials from the impact assessments are rather at the lower end of the range. While highest CDR potentials for 2050 in studies underlying the EU legislation assume -400 to -500 Mt CO_2eq, literature studies often operate in the range of -500 to -600 Mt CO_2eq, with one estimate reaching almost -800 Mt CO_2eq.

Kurzbeschreibung: Annahmen über Potenziale zur Kohlenstoffbindung in der EU

Der Bericht analysiert und prüft kritisch die Annahmen zu natürlichen Kohlendioxid-bindungs- (CDR) und -Speicherpotenzialen im Hinblick auf die Ziele der EU-Verordnungen für Landnutzung, Landnutzungsänderung und Forstwirtschaft (LULUCF) und den Zertifizierungsrahmen für die Kohlenstoffbindung (CRCF), die bis Februar 2024 vereinbart wurden. Sie prüft ausgewählte EU-Dokumente, die über einen Zeitraum von acht Jahren veröffentlicht wurden, und extrahiert und analysiert Informationen zu spezifischen Annahmen, die sich auf das Potenzial für natürliche CDR auswirken, das sich aus verschiedenen Optionen im Landsektor in der EU ergibt.

Das Potenzial für natürliche CDR-Optionen ist eine wichtige Information für die strategische Entscheidungsfindung im Bereich der Klimapolitik. Das spezifische Potenzial pro Flächeneinheit, das absolute Potenzial, aber auch die damit verbundenen Kosten variieren für verschiedene Arten von natürlichen Kohlenstoffabbau- und -speicherungsverfahren und Regionen, in denen diese Optionen umgesetzt werden. Dies ist auf biophysikalische und klimatische, aber auch auf wirtschaftliche und politische Bedingungen zurückzuführen.

Der Bericht gibt einen Überblick über die geschätzten Potenziale für natürliche CDR in den Folgenabschätzungen der Europäischen Kommission. Es wurden beträchtliche Veränderungen in der Höhe des Potenzials im Laufe der Zeit festgestellt, die auf unterschiedliche Annahmen zurückzuführen sind. Vergleicht man diese mit Schätzungen aus der wissenschaftlichen Literatur, so zeigt sich, dass die Potenziale aus den Folgenabschätzungen eher am unteren Ende der Bandbreite liegen. Während die höchsten CDR-Potenziale für das Jahr 2050 in Studien, die der EU-Gesetzgebung zugrunde liegen, von -400 bis -500 Mio. t CO_2eq ausgehen, bewegen sich Literaturstudien häufig im Bereich von -500 bis -600 Mio. t CO_2eq, wobei eine Schätzung fast -800 Mio. t CO_2eq erreicht.

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1 Introduction

The potential for **carbon dioxide removals and carbon storage** (CDR) through "Nature-based Solutions" (NbS) is an important information for strategic decision making in the field of climate policy. The specific potential per unit area, the absolute potential but also associated costs vary for different types of natural carbon removal and storage processes and regions where these options are being implemented. This is due to biophysical and climatic but also economic and policy conditions. Potential estimates need to make assumptions on the specification of options to be realistic and relevant for policy making. These assumptions concern land requirements and biomass demand for their implementation, the temporal dynamics of their effectiveness, costs associated with measures including investment costs and opportunity costs, the environmental integrity of measures (including permanence), associated climate risks, and other environmental safeguards, including potential adaptation measures.

Within the EU policy process, Impact Assessments (IA) are carried out to support processes that are expected to have significant economic, social or environmental impacts. These processes can be proposals for new or amended legislation, financial programmes, implementing and delegated acts. The findings are summarised in Impact Assessment Reports that form the basis of policy decisions, such as the decision on the EU Regulation on accounting of GHG emissions and removals from Land Use, Land-Use Change and Forestry (LULUCF) or the recently adopted Regulation on the Carbon Dioxide Removals Certification Framework (EU CRCF).

The aim of this report is to analyse and critically review assumptions on natural carbon removal and storage potentials with a view to the objectives of the EU LULUCF and CRCF legislation agreed until February 2024. We review selected IA documents that were published over a period of the last eight years and extract and analyse information on specific assumptions affecting the potential for natural CDR emerging from different options in the land sector in the EU. The following questions are guiding the analysis:

- What are potentials for natural CDR estimated in the policy documents?
- Which processes for CDR are considered and which assumptions form the basis of the potential assessments?
- What are influencing factors that affect size, spatial and temporal dynamics of the potential?
- And specifically, how have assumptions on the impacts of climate change have been taken into account and how do they constrain the capacity of CDR?

The analysis of assumptions in CDR potential studies is based on available EU and national policy documents. These include Impact Assessments Reports and other background material accompanying EU policy proposals and Communications. The following sources were considered:

- European Commission. (2016). Commission Staff Working Document. Impact Assessment Report: Accompanying the document. Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry into the 2030 climate and energy framework and amending Regulation No 525/2013 of the European Parliament and the Council on a mechanism for monitoring and reporting greenhouse gas emissions and other information relevant to climate change (SWD(2016) 249 final). European Commission.

- European Commission (2018): In-depth analysis in support of the Commission Communication COM(2018)773 A Clean Planet for all. A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. European Commission.
- European Commission (2020): Communication from the Commission to the European Parliament the Council, the European Economic and social Committee and the Committee of the regions, EU-wide assessment of the National Energy and Climate Plans. Driving forward the green transition and promoting economic recovery through integrated energy and climate planning. European Commission.
- European Commission. (2020). Commission Staff Working Document. Impact Assessment Report: Accompanying the document. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions. Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of our people (SWD(2020) 176 final). European Commission.
- European Commission. (2021). Commission Staff Working Document. Impact Assessment Report: Accompanying the document. Proposal for a Regulation of the European Parliament and the Council amending Regulations (EU) 2018/841 as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the collective achievement of climate neutrality by 2035 in the land use, forestry and agriculture sector, and (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review (SWD(2021) 609 final). European Commission.
- European Parliament (2021): DRAFT REPORT on the proposal for a regulation of the European Parliament and of the Council Amending Regulations (EU) 2018/841 as regards the scope, simplifying the compliance rules, setting out the targets of the Member States for 2030 and committing to the collective achievement of climate neutrality by 2035 in the land use, forestry and agriculture sector, and (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review (COM(2021)0554 – C9-0320/2021 – 2021/0201(COD)) (2021/0201(COD)). Committee on the Environment, Public Health and Food Safety, 2021.
- European Commission (2022): Commission Staff Working Document. EXECUTIVE SUMMARY OF THE IMPACT ASSESSMENT REPORT. Accompanying the document Proposal for a Regulation of the European Parliament and of the Council establishing a Union certification framework for carbon removals COM(2022) 672 final, SEC(2022) 423 final, SWD(2022) 377 final. European Commission.
- European Commission (2024): Impact Assessment Report. Accompanying the document "Communication from the Commission to the EU. Securing our future Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society. SWD(2024) 63 final. Strasbourg.

Information gathered from the EU documents is finally compared to scientific studies on CDR potentials and findings from the comparison are discussed including implications for interpretation at the national level.

2 Overview of assumed CDR potentials

2.1 Scope and applied CDR typology

Potential studies on carbon dioxide removals apply different typologies for these. As shown in Siemons et al. (2023), CDR activities differ in the process of capturing CO_2 as well as the storage destinations. Moreover, activities can be grouped by the processes involved but also the level of potential for that depends on the efficiency of removals but also capacities for removal and storage.

The Impact Assessment associated with the EU proposal on a Carbon Removal Certification Framework groups CDR based on where the removed carbon is stored:

- **Permanent storage solutions** that store carbon in geological reservoirs, including Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS).
- **Carbon farming solutions** that enhance carbon store carbon in soils and biomass, such as afforestation and reforestation, agroforestry, forest management but also peatland rewetting and blue carbon.
- **Carbon products** store carbon in materials, e.g. biomass in buildings or Carbon Capture and Utilisation (CCU).

This analysis focuses on the potential of options involving carbon farming solutions and carbon products (here natural CDR options), as well as permanent storage solutions (technical CDR options) that involve land use (BECCS). Technical solutions without a clear land and biomass relation (DACCS) are referred to as reference for comparison but not analysed in detail.

2.2 General perception of CDR potentials in EU climate policy over time

The review of existing potentials covers policy documents from 2016 to 2024. Over the period of ten years, there has been considerable changes in the perception of CDR potentials.

The 2014 European Council conclusions acknowledged "*the multiple objectives of the agriculture and land use sector, with their lower mitigation potential, and the need to ensure coherence between the EU's food security and climate change objectives". It saw potential in "sustainable intensification of food production, while optimising the sector's contribution to greenhouse gas mitigation and sequestration, including through afforestation*".

The Impact Assessment associated with the proposal for the LULUCF Regulation published in 2016 identified "*untapped potential for emission reduction and enhanced removals through carbon sequestration and substitution of fossil carbon*". Moreover, it stated, "*the importance of both land use and agriculture in terms of climate policy is, therefore, set to increase and additional mitigation efforts both in agriculture and in the LULUCF sector are needed. This is particularly important to prepare for the long-term, as emissions in the period after 2050 may well have to be counterbalanced by higher removals*".

The baseline scenario presented by the European Commission in its LULUCF IA 2016 showed already the "*complex interaction of land uses and their effects on emission and removals from the LULUCF sector*". It stated that the assumed biomass demand and supply factors are associated with considerable uncertainty in the modelling process. In particular the assessment expressed the fear that existing incentives for the use of biomass may "*undermine the historical trend of an* *overall sink for the EU, potentially wasting an opportunity to underpin the EU's longer term commitment under the Paris Agreement*".

CDR options were mostly focusing on the land sector. In the LULUCF IA 2016 it was assumed that potentially credit generation under the continuation of the Kyoto Protocol rules could be as much as 1,980 Mt CO_2 in the period 2021-2030, i.e. about 200 Mt CO_2 per year, including through cropland and grazing land management, afforestation and improved forest management.

In fact, the approach to accounting over emissions and removals in the EU as foreseen in the Kyoto Protocol and specified for EU Member States through the LULUCF Decision of 2013 that provided rules for the second commitment period of 2013-2020, shaped also the assumption on potential for removals from the LULUCF sector. The accounting rules followed the principle of activity-based accounting and therefore allowed for large amount of removals from afforestation. All land afforested since 1990 was accounted for as gross-net, i.e. all emissions and removals reported in the commitment period could generate credits. Forest management activities instead were compared against a forward-looking baseline projection. Emissions and removals from cropland and grassland activities were compared against the level of net emissions and removals in 1990. These rules inflated removals in the accounting. Logically, the integration of natural carbon removals from LULUCF was seen as associated with high risks for mitigation deterrence in other sectors, namely the Agriculture sector. A common accounting of LULUCF net emissions and removals and agricultural non-CO2 emissions (the AFOLU pillar) was discussed as an option in the IA 2016 but dropped due to the anticipated implications.

The Commission concluded that the approach of a combined land sector pillar "*would […] oblige Member States to combine sectors rather than flexibility remaining optional*". Moreover, due to substantial structural changes that the option of the AFOLU pillar would entail, "*it would almost certainly increase administrative burden for Member State authorities.*" It was acknowledged that the option would "*facilitate a more integrated approach of landscape management, and could better reflect the sectors' specificities (e.g., permanence, long time-cycles, inter-annual variability, integrated action for mitigation and adaptation).*" There was also the concern that including LULUCF emissions together with agriculture in the Effort Sharing Decision (ESD) could risk environmental integrity of the framework due to potentially large annual fluctuations in emission and removals from LULUCF.

The adoption of the goal of climate neutrality by 2050 for the EU and the change to a net target for 2030 have both increased the importance of CDR in the EU climate policy architecture. The EU climate law has set legally binding targets for both, reducing emissions, and maintaining and enhancing natural sinks. The law specifies that the EU would "*aim to achieve negative emissions*" after 2050. Moreover, the law includes a dedicated target for net removals of 225 million tons of CO_2 for 2030, as the concrete sinks element for the 55% goal.

The "Fit For 55" package, published in July 2021, combines the European Commission's proposals to revise the EU's climate policy architecture to make the EU ready to meet the new targets. In this package, the role of net removals was further reinforced, mainly with a proposal for the revision of the LULUCF regulation: An EU-wide goal of -310 Mt CO_2 net removals from land use and forestry in 2030 was proposed, considerably higher than the -225 Mt CO_2 which can be accounted to meet the 2030 target of 55% reductions, as laid down by the EU Climate law (European Union 2021). This would be achieved through a differentiated set of binding national targets for the period 2026 to 2030. Moreover, the Commission also proposed to set a combined target for agriculture, land use and forestry from 2031 onwards to achieve net zero emissions in this combined sector by 2035. This target would have created a land-use pillar that includes both LULUCF emissions and removals and non-CO_2 emission from the agriculture sector (also referred to as the AFOLU sector, Agriculture, Forests and Other Land Use). The combined accounting of the two sectors was expected to increase incentives for enhancing natural sinks in LULUCF. Moreover, due to long lead times of measures in the land sector to become effective, the Commission also aimed at providing planning certainty and giving a clear long-term policy direction for the 2028-2035 CAP reform.

In the course of the trilog negotiations between European Parliament, European Commission and the Council, all provisions of the European Commission's proposals that would have initiated a transition to an integrated Agriculture and LULUCF land-use or AFOLU sector after 2030 were removed. The adopted legislation on LULUCF in 2023 did no longer consider AFOLU as an option and abandoned the net zero emissions target of the combined sectors for 2035.

It was the European Commission's Communication on Sustainable Carbon Cycles (COM(2021) 800 final) that stressed the importance of creating an EU internal market for capture, use, storage and transport of CO_2 through innovative technologies and thus widened the scope of removals from natural solutions to technical carbon sinks. The communication defined an action plan to achieve "aspirational goals" for carbon removals, including that:

- by 2028, all land managers should have access to verified emission and removal data to measure carbon farming practices, and all CO_2 captured, transported, used and stored through industrial activities should be reported and accounted;
- by 2030, carbon farming approaches should contribute to reaching the LULUCF target of -310 Mt CO_2 net removals; and
- industrial technologies should remove annually at least 5 Mt CO_2 by 2030 through "front runner projects".

In 2024, the Commission published its Communication the EU 2040 climate target. It concluded that to deliver a reduction of net GHG emissions of 90%, the level of remaining EU GHG emissions in 2040 should be less than 850 Mt CO_2 and carbon removals (from the atmosphere through land-based and industrial carbon removals) should reach up to -400 Mt CO_2, the largest share of the removals still expected from natural sinks in the EU.

2.3 Potentials and main assumptions for EU CDR options

2.3.1 LULUCF Regulation (2016)

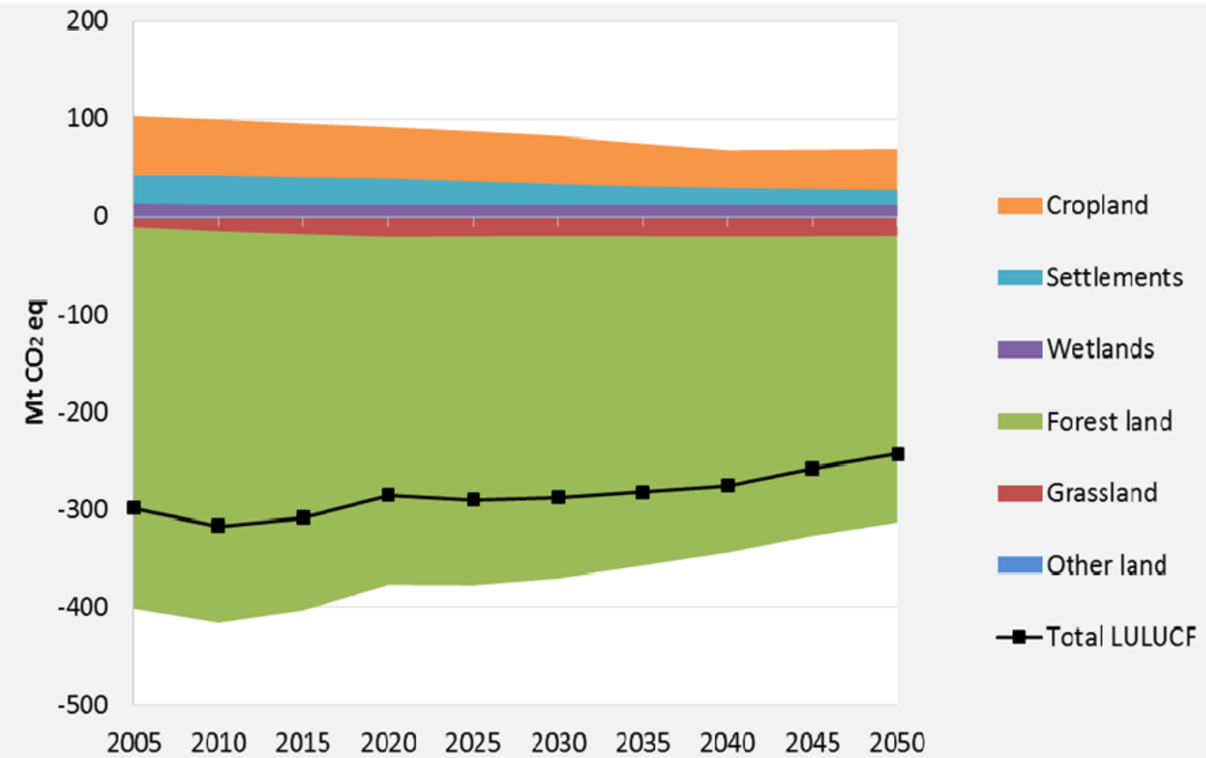
The Impact Assessment for the proposal for including LULUCF in the EU climate policy framework of 2016 (SWD(2016) 249) focused on different options for including the LULUCF sector into the Effort Sharing Decision (ESD) with various degrees of flexibilities. The underlying 2016 reference scenario estimated that without an integration of net removals by the LULUCF sector would amount -288 Mt CO_2 by 2030 (see Table 1 and Figure 1). In 2005 net removals were reported to be at -299 Mt CO_2. While the sink in existing forests was estimated to be reduced by more than 100 Mt CO_2 from -354 to -242 Mt CO_2, new forests (afforestation, increasing by about 55 Mt CO_2) and the reduction of deforestation emissions (by about 40 Mt CO_2) were assumed to result in net removals from total forest land at about -320 Mt CO_2, a slight decrease compared to 2005 (-337 Mt CO_2). Also the pool of harvested wood products was expected to grow more slowly with the net increase dropping from -54 Mt CO_2 in 2005 to about -30 Mt CO_2 in 2030.

Table 1: Assumed LULUCF emissions and removals in the EU Reference scenario for 2005 (reported) and 2030 (projected) in Mt CO_2

LULUCF categories	2005	2030
Total LULUCF	-299.1	-288.0
Forest land	-337.1	-321.0
Forest management	-353.7	-242.1
Afforestation	-46.2	-99.0
Deforestation	62.8	20.0
Cropland	61.0	49.8
Grassland	-9.3	-18.6
Wetlands	13.9	12.4
Settlements	28.0	20.2
Other land	-1.7	-1.7
Harvested wood products	-53.8	-29.2

Source: SWD(2016) 249

Figure 1: Development of EU28 emissions and removals from the LULUCF sector



Source: SWD(2016) 249

The IA identified a number of reasons for the decline in forest-based removals in the projection of the EU Reference scenario. The report pointed to the increasing forest age in EU countries as one of the reasons. Older forests approach a steady state where gains due to growth are balanced by losses due to decay. Natural removal rates in mature or unmanaged forest would gradually approach zero while forest harvest rates would increase due to a larger share of tree reaching harvest age. In fact, total harvest was assumed to increase from 516.3 Mm^3 in 2005 to 564.8 Mm^3 in 2030. The share of wood harvested for energy increased from 91.2 to 159.3 Mm3. In 2015 bioenergy was the biggest renewable energy source and is projected to remain so up through to 2030. A driver for the biomass demand for energy was seen in the Renewable Energy Directive. In 2013, biomass use for heat, power and transport represented over 60% (or 105 Mtoe) of the overall EU renewable energy consumption. Under the 2016 Reference scenario, bioenergy consumption in the EU was projected to grow by 20% between 2015 and 2020 and stabilise until 2030.

The assumed trend of increased land-take for settlements was also mentioned as a concern to achieve net removals in the future, despite the fact that trends of deforestation were projected to decline from 62.8 to 20.0 Mt CO_2. Unfortunately, the impact assessment did not display assumptions on area changes underlying the projected emissions and removals, making reconciliation of potential causes for the observed trends difficult.

The integration of the LULUCF sector into the ESD was considered an instrument to increase net removals from LULUCF with an increasing demand for credits to compensate for emissions from other sectors covered by the ESD. The IA in 2016 estimated a "credit generation potential" from afforestation, cropland and grazing land management of additional (i.e. accounted) 94-96 Mt CO_2 per year over the period 2021 to 2030 at a cost of €20 per tonne of CO_2. Estimates for forest management were not presented because the methodology did not include such measures in the cost estimates.

2.3.2 A Clean Planet for all - European strategic long-term vision (2018)

In 2018 the IA for the Communication COM(2018)773 provided a more advanced representation of the LULUCF sector and associated land requirements and costs for increasing natural removals. The IA presented a series of scenarios achieving a contribution to a 1.5 degree target, including scenarios 1.5TECH, 1.5LIFE and 1.5LIFE LB with specific focus on the sector.

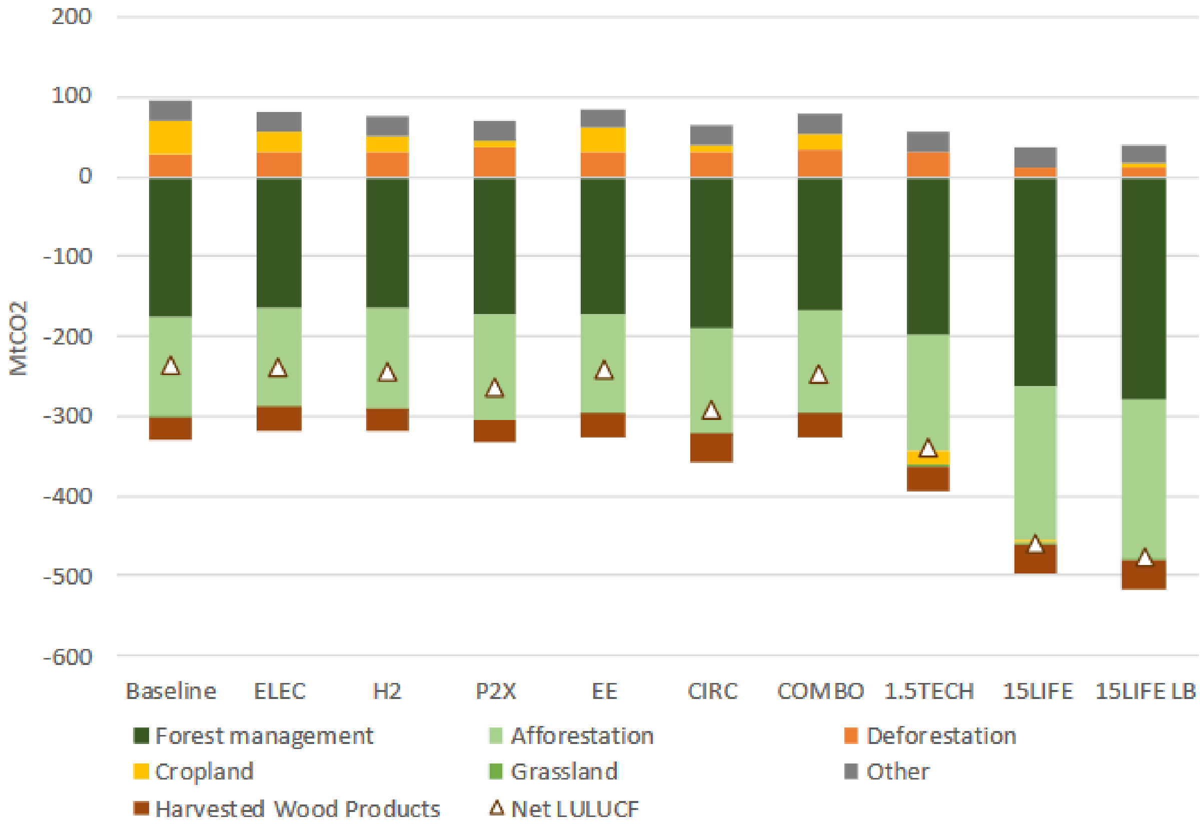
The 1.5LIFE assumed an important role for circular economy, changing consumer preference and a high incentive to enhance the natural land sink. The 1.5LIFE-LB combined this with much more use of technology options available in 1.5TECH leading to reduced biomass demand. The IA found that biomass demand to help to decarbonize the EU economy can have significant impacts on the land sector as all scenarios projected an increased amount of land dedicated to the production of energy crops. The 1.5TECH scenario was among those with highest energy crop requirements assuming that about 29 Mha of land for new energy crops. The scenario with lowest energy crop requirements (1.5LIFE-LB) expected about 9 Mha of land being used for new energy crops. Available areas were found in unused grassland where the model established lignocellulosic grasses (mainly switchgrass) for the production of second-generation biofuels.

The land becomes available due to assumed changes in consumption patterns with lower climate impacts, following a shift and reduction in meat consumption that frees land formerly used for producing feed. The switch to dedicated energy crops instead of using forest feedstocks allowed to limit negative impacts on the forest sink maintain the overall LULUCF sink in all scenarios.

The Baseline scenarios describes the anticipated development of emissions and removals from LULUCF without incentives to enhance the sink or reduce emissions (Figure 2). From the reported net sink of -314 Mt CO_2 in 2016, many of the presented scenarios expected a decline in net removals. However, all scenarios maintained a net sink of at least -230 Mt CO_2 until 2050. The IA considered scenarios that aim to reach GHG neutrality in 2050. These scenarios included also specific incentives to enhance the LULUCF sink. These were generated by introducing a CO_2 price. It was assumed to be strongest for 1.5LIFE (80€/t CO_2) and 1.5LIFE-LB (70€/t CO_2) and relatively limited for 1.5TECH (30€/t CO_2).

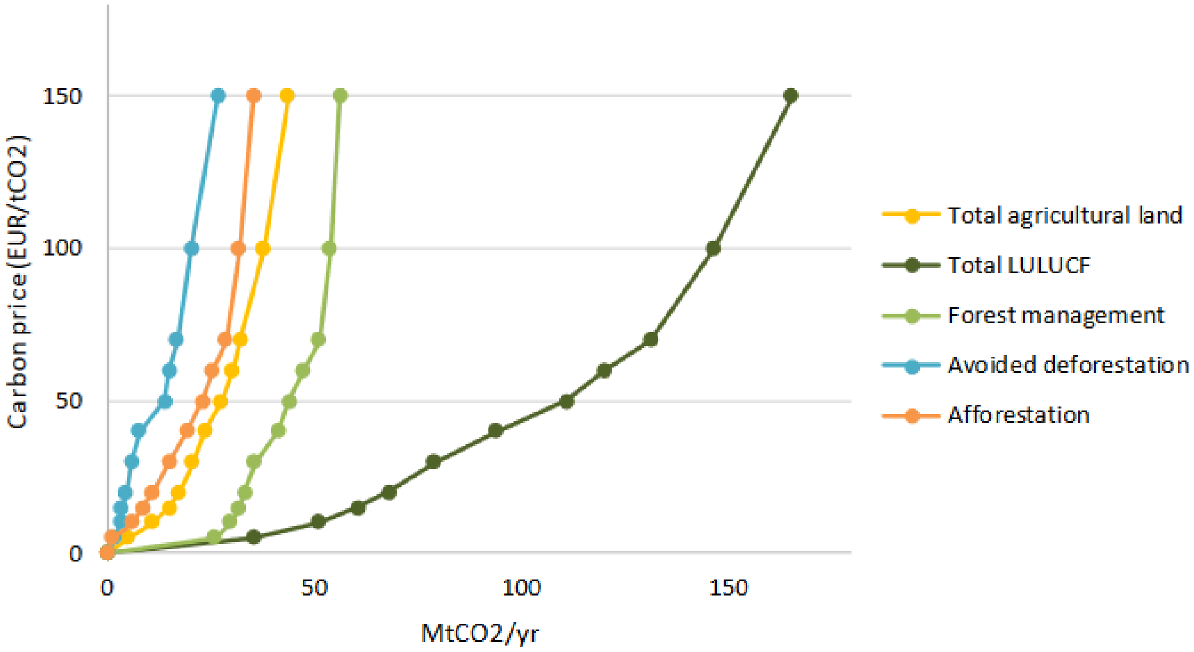
The strong expansion of energy crops in 1.5TECH coupled with the implementation of agricultural practices aiming at improving the soil carbon sequestration turned cropland into a net carbon sink by 2050, while the total LULUCF sink in the EU reached almost 400 Mt CO_2 (Figure 2). In the 1.5LIFE scenarios, more land becomes available for afforestation, and this combined with the incentive to enhance the sink allows it to increase to -500 Mt CO_2. This allows a reduction of the reliance on BECCS and other CDR technologies to achieve net zero GHG scenarios.

Figure 2: LULUCF emissions across the scenarios developed in 2050 (2018)



Source: COM(2018)773

Figure 3: Potential for natural CDR at different CO_2 prices for the year 2050 as assumed in IA 2018



Source: COM(2018)773

The IA of COM(2018)773 estimated how potentials for natural CDR from LULUCF change with changes in carbon prices. As it can be observed from Figure 3, a CO_2 price of 150 EUR in 2050 could increase the forest sink by almost 120 Mt CO_2 and the total LULUCF sink by more than 160 Mt CO_2 compared to the baseline, i.e. a situation without a price on CO_2. A CO_2 price of 70 EUR applied to activities in the LULUCF sector could already enhance the net sink by 130 Mt CO_2.

The IA also put natural CDR into perspective of technical solutions. It highlighted the advantage of DACCS regarding area requirements. It estimated that capturing 100 Mt CO_2 annually with direct air capture would require between 4 kha and 15 kha, versus 3 to 6 Mha for BECCS and 14 to 33 Mha if the removals would have to be achieved with afforestation.

Due to high costs and energy demand, DACCS was not included in any of the scenarios of the IA 2018. However, the 1.5TECH scenario built substantially BECCS to offset the residual emissions (in particular non-CO_2 emissions from agriculture) to reach GHG neutrality by 2050. This was in contrary to the 1.5LIFE and 1.5LIFE-LB scenarios that achieved a deeper reduction of emissions. The 1.5LIFE-LB scenario had a relatively high reliance on synthetic fuels as an alternative to advanced biofuels (due to lower level of biomass availability).

2.3.3 Climate Target Plan (2020)

The Climate Target Plan COM(2020) 562 presented an EU-wide, economy-wide GHG emissions reduction target by 2030 compared to 1990 of at least 55%. It was the first target of the EU that included both emissions and removals. In the baseline underlying the IA for the Communication, it was assumed that the LULUCF sink could further decline to 225 Mt CO_2 by 2030. This was due to "*unchanged land use practices and further increases in harvesting, in part driven by age class impacts of maturing managed forests*". In fact, for the first time natural hazards became more prominent in an IA. The Communication stated that "*significant risks for the sink of rising negative impacts from […] changing climate as well as increasing economic demand for forest biomass*" are to be expected. It called for reversing the observed trend that would require "*significant short-term action due to long lead times, especially in forestry*". Useful measures for increasing net removals mentioned included enforced forest protection and more sustainable forest management as well as sustainable re- and afforestation and improved soil management including through the restoration of wetlands, peatlands and degraded land. The Impact Assessment estimated that this could reverse the current trend of a diminishing EU land carbon sink already by 2030, increasing it again to levels below -300 Mt CO_2. By 2050 the assessment assumed that in a combined AFOLU sector, agricultural land (i.e. cropland and grassland) would not emit CO_2 anymore. Together with substantially increased removals from forest land the entire LULUCF sector would achieve a net sink of -425 Mt CO_2eq.

The Communication clearly pointed to bioenergy as a major threat to natural sinks in the EU. It called for use of biomass for energy within tight sustainability constraints to ensure environmental impacts to be minimised and the land sink to strengthen and improve. Moreover, to limit impact on biodiversity, the use of whole trees and food and feed crops for energy production should be minimised.

The Communication suggested integrating agriculture non-CO_2 GHG emissions into LULUCF and creating a new regulated sector covering agriculture, forestry and land use. It states that such a sector would "have the potential to become rapidly climate-neutral by around 2035 in a cost-effective manner, and subsequently generate more removals than GHG emissions". It laid the basis for the revision of the LULUCF rules in 2021 where finally a separate target for LULUCF was introduced.

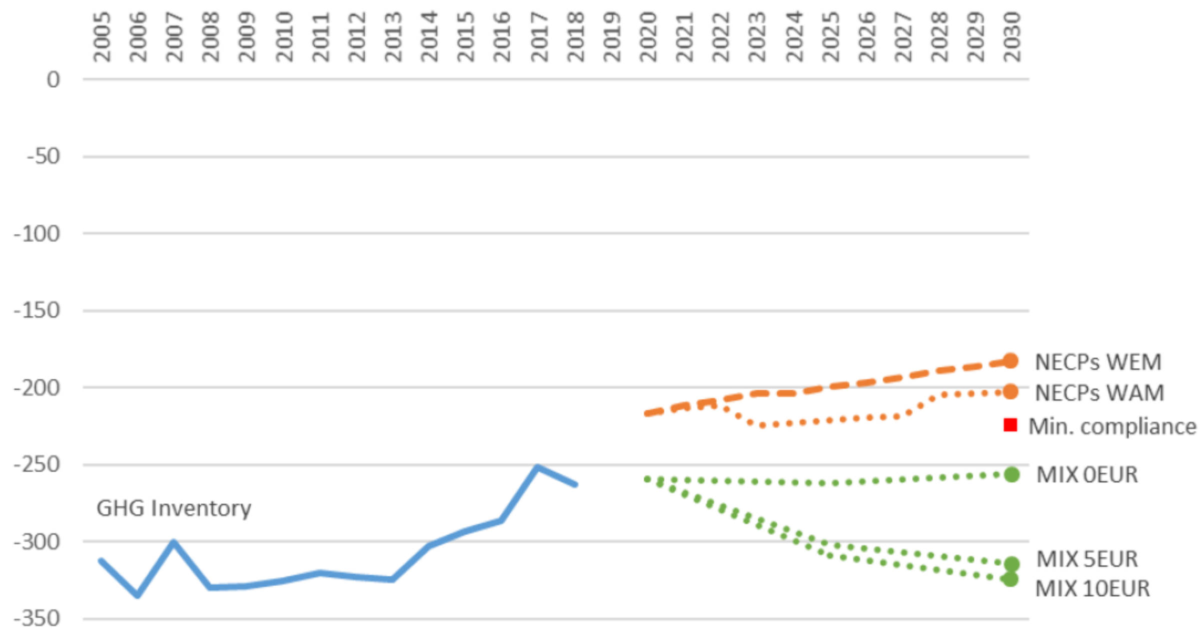
2.3.4 Revision of the LULUCF Regulation (2021)

As basis for the legislative proposal for the revision of the LULUCF Regulation, the European Commission presented potentials for natural carbon removals in another IA (SWD(2021) 609). The Commission's 2020 Reference scenario projected a net sink of -258 Mt CO_2 in 2030 for the LULUCF sector. Building on the 1.5 TECH scenario, one of three scenarios of the European Commission's 2018 IA expected to lead to GHG neutrality in 2050, an EU target of -310 Mt CO_2 for 2030 was derived. It assumed a carbon price of EUR 30/t CO_2eq and rather limited additional incentives to improve the land use sink. Instead, the focus was put on technical carbon removals to achieve net zero GHG emissions. For example, it assumed an increase in the use of CCS technology to achieve greater reductions in remaining emissions. It also primarily applied BECCS and storage of biogenic CO_2 in materials (see above).

The two other scenarios - 1.5LIFE and 1.5LIFE-LB - assumed a significantly higher price level for CO_2 of 70-80 EUR/t CO_2. This was expected to lead to increased investments in afforestation and forest sink enhancing measures, increasing the net sink to -465 Mt CO_2 and -480 Mt CO_2, respectively, by 2050. Reflecting a series of drought years from 2018 to 2020 that affected several European countries and caused massive damage to forests, the assessment expected that global warming will likely increase disturbances from fires and insect outbreaks in increasingly large areas of Europe. Such combined impacts are likely to affect forests in the EU considerably.

However, the assessment relied on rather outdated reported numbers for 2018 that even showed a rebound of removals compared to 2017, a year which was heavily affected by forest fires in Italy and Portugal. It stated that "*while the impact of natural disturbances will be noticed at the level of individual land managers and small Member States, the overall impact on total removals at the EU level is expected to be limited over the next 10 years*". LULUCF removals were projected to remain at the level of 2018 at no additional cost. Moreover, a much higher level of removals (above -300 Mt CO_2 in 2030) could still be achieved via a range of relatively inexpensive near-term mitigation actions (e.g. improved forest management, set-aside of organic soils), even considering the likely increased pressures on forests and harvesting rates due to the higher demand for short-lived products and bioenergy.

Figure 4: Historic development and projections for LULUCF net removals from a range of different sources



Source: SWD(2021) 609

In the IA, LULUCF projections from National Energy and Climate Plans (NECPs) with existing measures (WEM) or with additional measures (WAM) were compared to projections without a carbon price (MIX 0EUR) and at a carbon price of 5 and 10 EUR/tCO2 (MIX 5EUR and MIX 10 EUR). Figure 4 shows that, if Member States carry out the planned policies and measures indicated in their National Energy and Climate Plans, they would not meet the minimum level of removals required by the LULUCF Regulation that was estimated to amount to-225 Mt CO_2. This was in contrast to the Commission's scenario projection that expected an achievement of the target at no additional cost, or even an increase of net removals above -300 Mt CO_2 at a CO_2 price of 5 EUR or 10 EUR). However, the assessment remained rather vague regarding the concrete measures included in the scenario.

2.3.5 Communication on Sustainable Carbon Cycles (2021)

The Commission's Communication on Sustainable Carbon Cycles COM(2021) 800 finally stressed that significant investments are needed to realise potentials for increasing net removals in the EU. The investments would enable business models for land managers to develop carbon farming approaches and create an EU internal market for capture, use, storage and transport of CO_2 through innovative technologies. The communication also defined action plans to achieve the aspirational goals for carbon removals:

- by 2028, all land managers should have access to verified emission and removal data to measure carbon farming practices, and all CO_2 captured, transported, used and stored through industrial solutions should be reported and accounted;
- by 2030, carbon farming approaches should contribute to reaching the LULUCF target of -310 Mt CO_2 net removals; and

- industrial technologies should remove annually at least -5 Mt CO_2 by 2030.

The assessment included the scenario ECOSYS that assumes priority is given to the enhancement of the carbon removals through the restoration of ecosystems. This is also a scenario where changes in lifestyle and consumer choices were expected to be beneficial for the climate. Therefore, it included less carbon intensive diets that free land for the regeneration of natural ecosystems. The scenario INDUS instead relied more on large scale deployments of industrial solutions to capture, recycle and store CO_2.

An observation of the assessment was that for achieving EU climate-neutrality it is required that industrial removals capture at least -300 Mt CO_2 in scenario ECOSYS and more than -500 Mt CO_2 for INDUS for storage or supply carbon products.

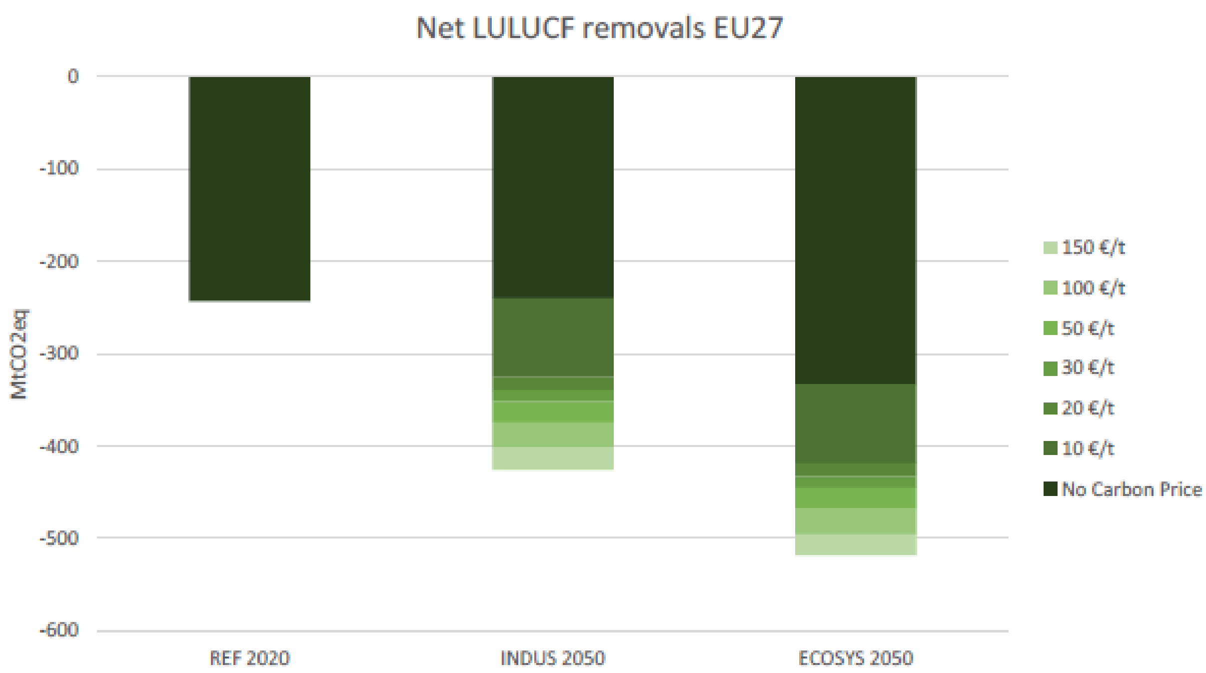
2.3.6 Carbon Removal Certification Framework (2022)

A year after the Communication on Sustainable Carbon Cycles the Commission published its proposal for an EU-wide Carbon removal Certification Framework (CRCF, SWD(2022) 378). Figure 6 presents the LULUCF sink projected for the scenarios INDUS and ECOSYS at various carbon prices aiming to incentivise action in the sector. The potential at "No carbon price" corresponded to the level of net removals with no specific measures deployed to support the enhancement of carbon removals in ecosystems.

The "No carbon price" level of LULUCF sink for the scenario INDUS is lower than the removals projected in the EU Reference scenario 2020 due to the greater use of bioenergy. Instead, in the ECOSYS scenario the LULUCF sink benefits from a lower demand in bioenergy and from the higher availability of land for restoration of agriculture land driven by changes in the food consumption pattern.

The land-use modelling presented in the IA suggested that there is potential to increase net removals from LULUCF by about 185 Mt CO_2 by 2050 at a maximum marginal cost of EUR 150/t CO_2.

Figure 5: Potential for LULUCF sink enhancement at various CO_2 prices in different scenarios in 2050



Source: SWD(2022) 378

2.3.7 EU 2040 climate target and path to climate neutrality (2024)

In 2024, the European Commission presented an IA that sketches pathways to 2050 including suggestions for EU-wide targets for 2040 (SWD(2024) 63). Within these scenarios, LULUCF net removals are projected to contribute significantly over 2030-2050 with net removals of around -320 MtCO2-eq (see Table 2). The role of technical solutions until 2040 is still considered marginal in the baseline scenario. This is despite the need seen by the Commission for large-scale deployment. However, they became more significant by 2040 in scenarios that aim to meet higher climate targets, ranging between -50 Mt CO_2 and -75 Mt CO_2. In 2050, in order to reach GHG neutrality, the assessment estimates that industrial removals of more than -100 Mt CO_2 are needed to complement removals in the LULUCF sector.

The four main scenarios developed in the IA follow different rationales. **S1** assumed a continuation of existing decarbonisation trends up to 2040. This means improvement of energy efficiency, electrification of energy demand, and deployment of renewables in the power system. Bioenergy was expected to have a moderate increase by 2040 compared to 2022 levels, and stabilisation over 2041-2050. In the LULUCF sector, only small increase of forest land at the expense of grassland was assumed. **S2** was constructed in a similar way. It included a wider diffusion of novel technologies by 2040 (carbon capture, e-fuels). **S3** assumed an even faster and wider uptake of novel technologies. In both scenarios bioenergy was expected to increase until 2040 and decline thereafter. For LULUCF a higher land-use change with bigger increase of forest land, additional wetland and cropland was expected in both scenarios.

Table 2: Comparison of industrial and LULUCF removals assumed in the year 2040 in the 2024 IA for different scenarios. Net emissions in Mt CO_2eq

Source or sink	S1	S2	S3	LIFE
Net GHG emissions	**1051**	**578**	**356**	**353**
of which from the land sector*	133	-45	-46	-150
of which from agriculture	*351*	*302*	*271*	*209*
of which from energy and industry**	918	593	402	503
Carbon capture	**86**	**222**	**344**	**278**
Carbon removals	**-222**	**-365**	**-391**	**-387**
of which industrial removals	-4	-49	-75	-27
of which LULUCF net removals	-218	-316	-317	-360

Source: SWD(2024) 63. * Emissions from agriculture and net removals from the LULUCF sector. ** Includes other non-land sectors like waste management as well as industrial carbon removals.

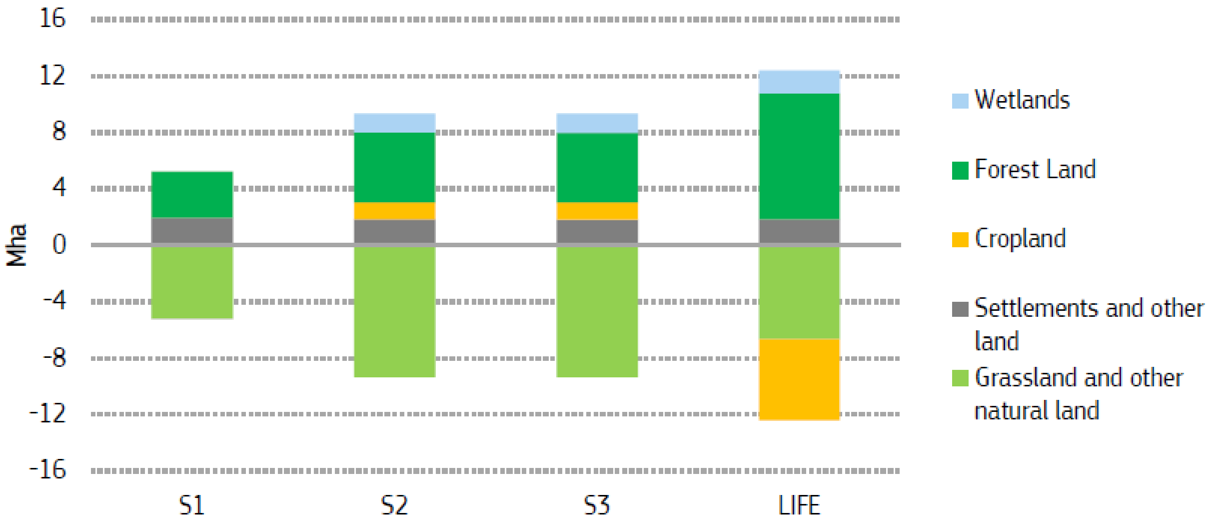
Based largely on S3, the **LIFE** scenario assumed more sustainable lifestyles and a move towards a more circular and shared economy. For the LULUCF sector the scenario implied more available land for carbon farming and high-diversity elements such as set aside and fallow land with natural vegetation through land-use change in grassland and cropland.

The assessment expected that in 2040 total cropland remains unchanged in S1 and increases by 1.2 Mha in S2 and S3, because around 80% of the required area for lignocellulosic crops comes from cropland currently used for first generation biofuels (7.5 Mha) or other cropland (1.9 Mha,

Figure 6). The total potential for lignocellulosic crops is however limited. A higher use of biofuels for road transport, maritime transport and aviation than displayed in the scenarios would have a much bigger impact on land use change or food production, because no further areas from first generation lignocellulosic crops could be substituted.

For LULUCF, additional nature-based removals such as improved forest management, afforestation or rewetting are applied in S2 and S3 by 2040. The associated average annual cost in these scenarios amount to EUR 2.5 billion in 2031-2040 and EUR 2.8 billion in 2041-2050.

Figure 6: Changes in land use expected between 2020 and 2040 in different scenarios

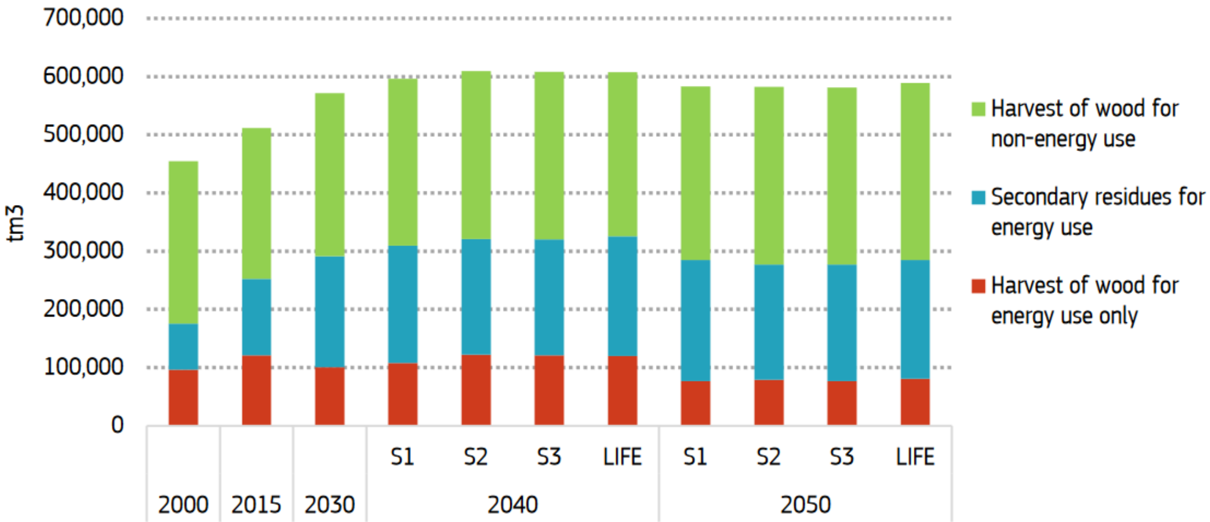


Source: SWD(2024) 63

As in earlier IA, the potential for natural CDR is dominated by the forest sink. Its strength depends on the relationship between forest increment and forest mortality and harvest amounts. Figure 7 presents the anticipated evolution of wood harvest in the EU over time.

Wood harvest increased significantly after 2000 mainly due to increased demand for energy. The increase is expected to continue until 2040. Total harvest of wood is expected to be about 15% to 20% higher in 2040 compared to 2015. In 2050 direct harvest for energy from forests will be as low as in 2000. This is also because a larger amount of harvest for non-energy purposes is associated with more supply of secondary residues from wood processing.

Figure 7: Harvest of wood for energy and non-energy use in different scenarios and time horizons



Source: SWD(2024) 63. Note: "Secondary residues used for energy use" are forest residues that were initially harvested for material use (e.g., from the production of sawnwood) but then used for energy production.

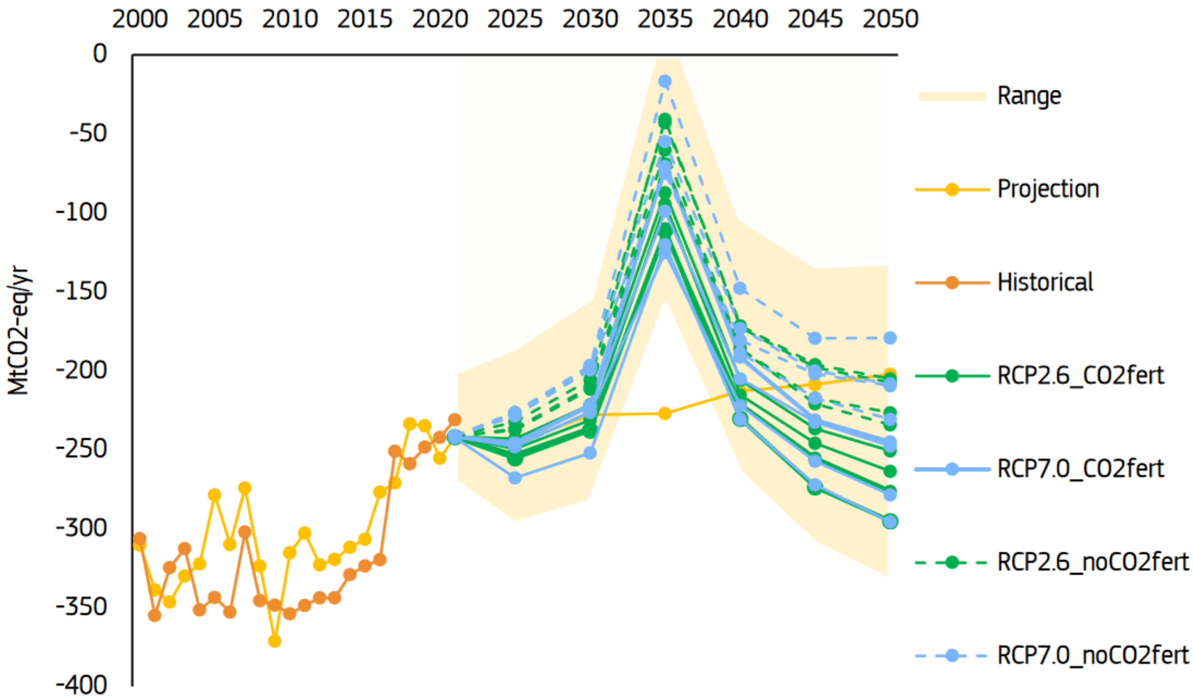
For the first time the model cluster employed for conducting the IA explicitly considered climate change feedbacks on natural emissions and removals. The land-use model included in its projection of forest growth natural disturbances like wind damage, wildfires, and insect outbreaks.

Wind was found to be the most important disturbance agent, in terms of the total damage, especially in Central and Northern Europe, accounting for approximately 50% of the total damage by the end of the century. However, wind disturbances are only to a small degree affected by climate change. Areas expected to be most affected by wind are in the mountain forests of Central Europe, especially in France, Germany, Austria, Czechia and Slovakia, but also in Sweden. As expected, **wildfires** were the dominating disturbance type in Mediterranean countries. With increases in temperatures and a reduction in precipitation these were expected to increase in frequency and severity. For temperate forests of Central Europe **insect damage** is expected to maintain an important driver of disturbance dynamics. Overall, insect damage is expected to account for about 25% to 30% of the total damage until 2100.

Figure 8 presents the results of modelling experiments simulating uncertainties associated with different assumptions on climate change drivers and a series of possible extreme events in 2035 for LULUCF net removals. As a consequence of these effects, net removals drop to a range between -160 and +30 Mt CO_2 at the time of the disturbance. After the event the net sink recovers relatively quickly in the course of a few years (-105 to -265 Mt CO_2). Overall the combination of uncertainties and extreme events causes the potential range of net removals to widen considerably, resulting in a range between-130 to -330 Mt CO_2 in 2050.

The authors state that such modelling exercises need to be interpreted with caution as assumptions on the severity of events, the share of wood that can be harvested after the event and replace otherwise planned harvests, the speed of forest recovery and other aspects are highly uncertain. While the model assumes that damaged stands are restored within one year, replanting and afforestation may instead take several years. However, the results indicate that natural disturbances can significantly perturbate the expected temporal development of the net LULUCF sink.

Figure 8: Climate change impacts and extreme events on LULUCF net removals

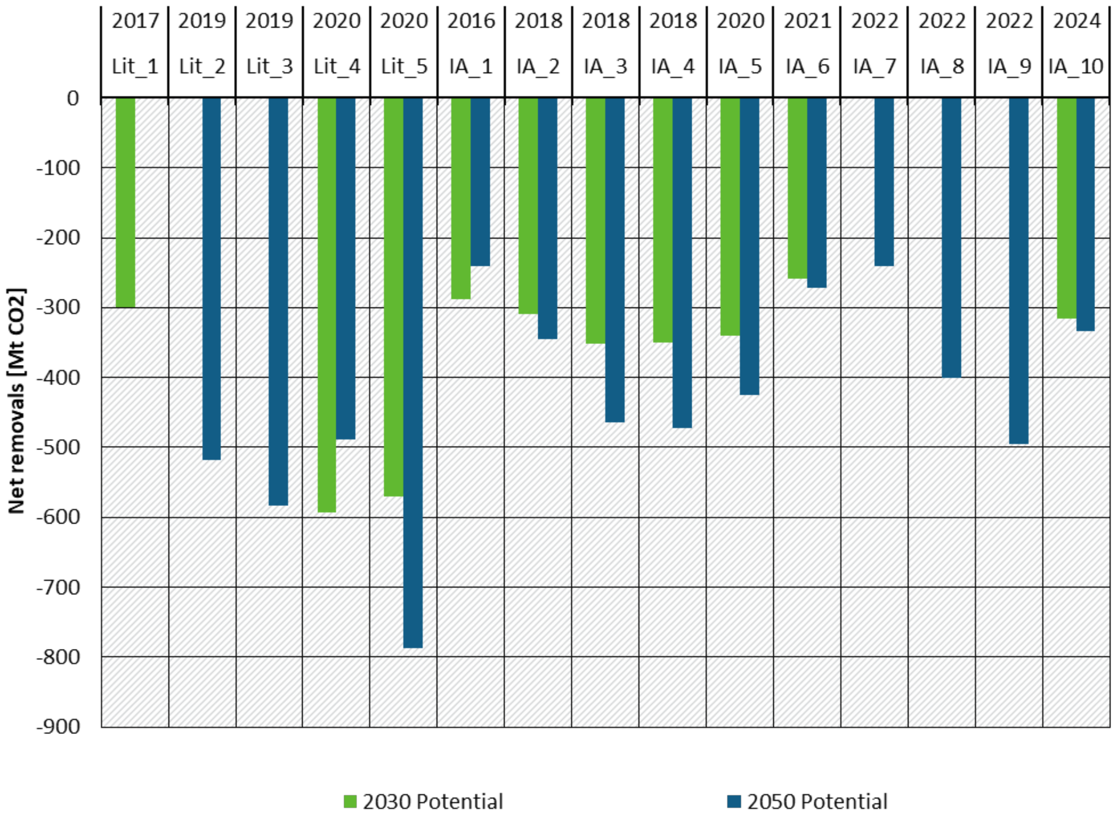


Source: SWD(2024) 63

3 Discussion

The overview of estimated potentials for natural CDR in the European Commission's Impact Assessments over the last years reveals that there are considerable changes in the level of the potential over time. However, there are also quite wide ranges in the estimates due to differences in assumptions. Comparing these with estimates based on scientific literature shows that potentials from IAs are rather at the lower end (Figure 9, Table 3). Highest potentials in IAs achieve -400 to -500 Mt CO_2. Studies that can be found in the literature often operate in the range of -500 to -600 Mt CO_2, with the highest estimate expecting even almost -800 Mt CO_2.

Figure 9: Overview of natural CDR potentials and main assumptions in the literature and in European Commission Impact Assessments



Source: Own compilation, Oeko-Institut

Table 3: Overview of natural CDR potentials and main assumptions in the literature and in European Commission Impact Assessments

No.	Study author and name	Categories	2030 Potential Mt CO_2/ year	2050 Potential Mt CO_2/ year	Main assumptions
Lit_1	Nabuurs et al. 2017	afforestation, forest restoration, harvested wood products	-300		Measures like enhanced thinning of stands leading to additional growth and higher quality raw material, regrowth with new species, planting of more site-adapted species, and regeneration using faster growing species would even increase harvest potential from 522 to 557 Mm^3 per year.
Lit_2	UBA 2019	afforestation, forest restoration, harvested wood products, peatland restoration, grassland protection		-518	Increase forest area by 16 Mha; stabilising forest harvest rate at 70% of increment; increase the share of longer-living wood products; conversion of 50 % of cropland on organic soils to wetlands, forests and grasslands; reduction of grassland conversion on organic soils to zero, on mineral soils to 50 %; no net land take of infrastructure and settlements by 2050.
Lit_3	Build Up 2019	afforestation, forest restoration, reduced cropland and grassland management intensity		-584	Reduced land degradation; 24 % less land required to produce food (multi-cropping, etc.); 76 % of surplus land is afforested, 20 % converted to grasslands; forest harvest intensity lowered by 25 %.
Lit_4	Welle et al. 2020	forest restoration	-593	-488	Forest harvest intensity is reduced to 60 % by 2030 and to 50 % between 2030–2050.
Lit_5	EUCALC 2020	afforestation, bioenergy, area protection, forest restoration	-570	-787	Afforestation of 114 Mha grassland and cropland, increasing bioenergy capacities, improved diets and alternative protein sources, improved forestry practices and land management, improved hierarchy for biomass end-uses, and set aside 50 % of area for protection.
IA_1	SWD(2016) 249	LULUCF	-288	-240	2016 EU Reference scenario. Total wood harvest was assumed to increase from 516.3 Mm3 in 2005 to 564.8 Mm3 in 2030
IA_2	COM(2018)773	LULUCF	-310	-345	1.5TECH, assuming that about 29 Mha of land for new energy crops
IA_3		LULUCF	-351	-464	1.5LIFE, assumed an important role for circular economy, changing consumer preference and a high incentive to enhance the natural land sink
IA_4		LULUCF	-350	-472	1.5LIFE LB, combined 1.5LIFE with 1.5TECH, reduced biomass demand,

No.	Study author and name	Categories	2030 Potential Mt CO_2/ year	2050 Potential Mt CO_2/ year	Main assumptions
					about 9 Mha of land being used for new energy crops
IA_5	COM(2020) 562	LULUCF	-340	-425	LULUCF+, Scenario including additional actions to increase the net LULUCF sink to meet the EU 2035 land sector and 2050 overall neutrality targets. It includes optimisation of forest management, afforestation and improving soil management including through rewetting and restoration.
IA_6	SWD(2021) 609	LULUCF	-258	-271	EU Reference 2020, projection of "Business as usual" in the EU based on data in 2020
IA_7	SWD(2022) 378	LULUCF		-240	2020 EU Reference scenario
IA_8		LULUCF		-400	INDUS, CO2 price of 100 EUR/t CO2
IA_9		LULUCF		-495	ECOSYS, CO2 price of 100 EUR/t CO2
IA_10	SWD(2024) 63	LULUCF	-316	-333	S2/S3, bioenergy expected to increase until 2040 and decline thereafter. Strong increase of forest land, additional wetland and cropland. Strong emphasis on technical options.
IA_11		LULUCF	-360		LIFE, more sustainable lifestyles and move towards circular and shared economy, more land available for carbon farming and afforestation

Source: Own compilation, Oeko-Institut

One important aspect is the degree of integration of competing options in the assessments. While integrated scenarios, like the IAs usually result in lower total sink potentials due the consideration of competition between options and market effects. Studies that estimate the potential as the sum of different options are not considering that these might compete for the same land and that the combined potential can be lower than that of the sum of individual options (Böttcher et al. 2021). Table 4 presents an overview of estimates for individual options with different ranges that should not be summed to get estimates of total removal potentials. In that sense, assessment with integrated tools as set up in the Commission's IAs are well suited for providing more realistic overviews of total removals.

Table 4: Overview of natural CDR potentials for EU in 2050 based on individual options.

Assessment variable	Range of specific mitigation potential in t CO_2/ha/year	Range of total mitigation potential in Mt CO_2/year
Increase forest area	2.2-7.7	77-210
Restore carbon stocks in forests	0.9-2.5	150-400
Increase carbon storage in harvested wood products	0.16-0.28	22-44*
Expand agroforestry coverage	0.01-7.3	8-235
Maintain and enhance carbon in mineral and agricultural soils	0.5-7	9-58
Conserve carbon in organic soils and restore wetlands	<23.5	>48
Protect and restore saltmarshes and seagrass meadows	0.11-5.5	unknown

Source: Böttcher et al. 2021

A general challenge of IAs is the lack of detail at national level. For case studies in Germany and Finland, Böttcher et al. (2022) compared mitigation cost assumptions in IAs with national data. Unfortunately, national level data on costs are not displayed in the Commission's Integrated Assessment Report making a direct comparison impossible. National level results are usually only available for the underlying EU Reference scenarios, i.e. the baselines assuming no carbon price. Still this information can be used for interpreting IA results for the national level. In the case of Germany discussed by Böttcher et al. (2022) the EU Reference scenario 2020 projected increasing net removals from LULUCF. This implies that the national target of about 30 Mt CO_2 derived from the IA in 2020 could be achieved at no additional costs. This is in contrast to national assessments and also earlier IA estimates in 2016 expected a stabilization at rather low level. In the case of Finland the comparison of national projections with IA data suggested that in the Commission's estimate the expected sink was rather underestimated.

4 List of references

Böttcher, H.; Gores, S.; Hennenberg, K.; Reise, J.; Graf, A. (2022): Analysis of the European Commission proposal for revising the EU LULUCF Regulation, Commissioned by Agora Energiewende. Oeko-Institut. Online available at https://www.oeko.de/fileadmin/oekodoc/Assumptions_LULUCF_Proposal.pdf.

Böttcher, H.; Reise, J.; Zell-Ziegler, C.; Liste, V.; Frelih-Larsen, A.; Herb, I. (2021): Options for Strengthening Natural Carbon Sinks and Reducing Land Use Emissions in the EU (Working Paper). Oeko-Institut. Online available at https://www.oeko.de/fileadmin/oekodoc/Options_natural_sinks_EU.pdf.

Build Up (2019): The CTI 2050 Roadmap Tool. Online available at https://www.buildup.eu/en/learn/tools/cti-2050-roadmap-tool, last updated on 18 Sep 2019, last accessed on 10 May 2021.

EUCALC (2020): Transition Pathways Explorer. Online available at https://www.european-calculator.eu/transition-pathways-explorer/, last accessed on 10 May 2021.

European Union (2021): European Climate Law; EUR-Lex; Summary of: Regulation (EU) 2021/1119 establishing the framwork of achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'). European Union (ed.). Online available at https://eur-lex.europa.eu/EN/legal-content/summary/european-climate-law.html, last updated on 13 Jun 2024, last accessed on 13 Jun 2024.

Nabuurs, G. J.; Philippe Delacote; David Ellison; Marc Hanewinkel; Lauri Hetemäki; Marcus Lindner; Markku Ollikainen (2017): By 2050 the mitigation effects of EU forests could nearly double through climate smart forestry. In: Forests 8 (12), p. 484. DOI: 10.3390/f8120484.

Siemons, A.; Böttcher, H.; Liste, V.; Jörß, W. (2023): Short typology of carbon dioxide removals: How best to differentiate methods and technologies for establishing and enhancing carbon sinks?. Oeko-Institut. Umweltbundesamt (ed.). Online available at https://www.umweltbundesamt.de/sites/default/files/medien/11850/publikationen/factsheet_short_typology_of_carbon_dioxide_removals.pdf, last accessed on 18 Sep 2023.

UBA - Umweltbundesamt (2019): GHG-neutral EU2050 - a scenario of an EU with net-zero greenhouse gas emissions and its implications, Full report. In collaboration with Duscha, V.; Wachsmuth, J.; Eckstein, J. and Pfluger, B. Online available at https://www.umweltbundesamt.de/sites/default/files/medien/1410/publikationen/2019-11-26_cc_40-2019_ghg_neutral_eu2050_0.pdf, last accessed on 24 Aug 2020.

Welle, T.; Leinen, L.; Bohr, Y., E., M., B.; Vorländer, A., K. (2020): Waldvision für die Europäische Union. Naturwald Akademie im Auftrag von Greenpeace (ed.). Online available at https://naturwald-akademie.org/wp-content/uploads/2020/11/Waldvision-fuer-die-Europaeische-Union.pdf, last accessed on 22 Nov 2022.