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Chapter 7 | Current levels of CDR

Carbon dioxide removal (CDR) is already occurring at scale. Conventional methods, principally afforestation/reforestation, currently contribute almost all CDR, although the contribution from novel CDR methods is growing.

Key insights

- The gross amount of carbon dioxide (CO_2) being moved from the atmosphere into durable carbon storage over the last decade as a result of human activity is on the order of 2,200 $MtCO_2$ per year. The uncertainties in this estimate remain large, however.
- Conventional CDR makes up over 99.9% of all current CDR. Estimates of the volumes removed vary according to the approach used. For the period of 2013–2022, models aligned with estimates of the Global Carbon Budget suggest an average of −1,860 (−1,160 to −2,230) $MtCO_2$ per year from afforestation/reforestation. Country-level data on managed forests, adjusted using vegetation models, suggest −2,010 ± 620 $MtCO_2$ per year over the same period, through both afforestation/reforestation and forest management. Both approaches agree on a slight slowdown in the rate of conventional CDR in recent years.
- The countries with the highest levels of CDR through afforestation/reforestation, averaged over 2013–2022, are (in order) China, the US, Brazil and the Russian Federation. Levels in the EU27 as a whole lie between those of China and the US.
- Conventional CDR also includes the transfer of forest carbon to durable wood products. However, some double counting with CDR through afforestation/reforestation or in managed forest exists. The transfer of carbon to durable wood products amounts to −801 $MtCO_2$ per year, averaged over 2013–2022. When the re-emission of CO_2 through the decay of existing wood products is also accounted for, the net sink from this CDR method amounts to −332 $MtCO_2$ per year over this period.
- CDR from novel methods grew from −0.66 $MtCO_2$ per year in 2021 to −1.35 $MtCO_2$ per year in 2023. Improved estimation methods mean this level is lower than that reported in *The State of Carbon Dioxide Removal* 1st edition. Significant gaps and limitations in data remain for novel CDR projects, however.
- The largest current contributions to novel CDR are from biochar (with an estimated −0.79 $MtCO_2$ per year), bioenergy with carbon capture and storage (−0.51 $MtCO_2$ per year), and enhanced rock weathering (−0.03

$MtCO_2$ per year).

- Based on available data, the country with the largest contribution to novel CDR is the US, as it hosts all bioenergy with carbon capture and storage projects that are currently operating. Methods such as biochar and enhanced rock weathering show a broader geographical spread.

This chapter brings together multiple sources of data, harmonizing them to provide a comprehensive and robust estimate of current levels of CDR. However, assessments of current CDR deployment are complex and incomplete. Key limitations and knowledge gaps are discussed (see Box 7.3).

7.1 Estimating current CDR levels

This report measures carbon removed in a given year as the amount of carbon dioxide (CO_2) moved out of the atmosphere by human activity and into a durable type of storage.

As discussed in Chapter 1 (Introduction), this report defines CDR as follows:

Human activities capturing CO_2 from the atmosphere and storing it durably in geological, land or ocean reservoirs or in products. This includes human enhancement of natural removal processes but excludes natural uptake not caused directly by human activities.

This definition establishes three primary criteria for CDR, with important implications for estimating annual CDR volumes:

Capture of atmospheric CO_2. CDR involves the removal of CO_2 from the atmosphere. The capture of fossil CO_2 at the point of emission (e.g. gas power plant) is not included in this definition.

Durable storage. The CO_2 captured from the atmosphere must be stored durably. In this report, durability is defined according to the type of carbon pool into which CO_2 is transferred. The report considers storage in the following pools to be durable: trees, wetlands, soils, biochar, durable wood products (e.g. timber for construction), mineral products (e.g. aggregates), marine sediment, ocean bicarbonate, depleted fossil fuel reservoirs, saline aquifers and mineral rock formations.

Resulting from direct human intervention. It is essential to distinguish CDR from natural carbon sinks. The land and oceans currently take up around half the CO_2 emitted into the atmosphere each year, without humans intervening to cause this uptake, and this does not count as CDR. Calculating the volumes removed through conventional CDR – through, for example, tree planting – also means excluding the component of CO_2 uptake that happens indirectly as a result of human-caused changes to environmental conditions (e.g. climate change, raised atmospheric CO_2 concentrations, nitrogen deposition).

The approach used in this report is to calculate the annual quantities of CO_2 moved out of the atmosphere by processes that meet the definition above. This means the assessment does not look at the full balance of sources and sinks over the life cycle of these CDR activities, which leads to some important caveats:

- All CDR methods involve emissions during the capture and processing of carbon. For some of the projects that make a substantial contribution to current levels of novel CDR, a full life cycle assessment suggests that these emissions are currently similar to, or even outweigh, removals (although the distribution of these emissions between the CDR activity and co-products, such as fuels, depends on the allocation method).[124] It is standard practice for emissions to be reported in national greenhouse gas inventories, allocated to the sector in which they occur. Hence, emissions from heat or electricity required for a CDR activity are reported in a country's energy sector, for instance, and not ignored. Nevertheless, any assessment of the overall effectiveness of CDR should consider these emissions as well as the removals, as given in this chapter.
- After the time of removal, and depending on the type of carbon storage, CDR methods may also involve subsequent re-release of some CO_2.[321] In the estimate presented here of carbon stored annually through wood in construction – which is among the least durable carbon pools – this is accounted for. Re-release, based on standard lifetimes of wood products, is subtracted so as to indicate the size of the net sink. For other CDR methods, however, re-release is not currently accounted for.
- By defining storage durability on the basis of the type of carbon pool rather than the actual duration of storage, the fact that some CDR activities may turn out to be more short-lived – for example because of unexpected disturbance or mismanagement – is not accounted for.

Box 7.1 outlines how the assessment approach in this second edition differs from that in the first edition.

Estimating CDR levels from conventional and novel methods

The estimated levels of conventional CDR presented in this edition depend on a combination of information from national greenhouse gas inventories (NGHGIs) and from models used in the Global Carbon Budget (GCB). The estimated levels of novel CDR are generated from a structured approach that aggregates different databases and survey information.

Conventional CDR. This report uses two independent approaches to quantify the volumes removed through *afforestation/reforestation* and in *managed forests* during the last decade (2013–2022). In both cases, models are applied to separate out the fluxes attributable to direct human intervention, consistent with this report's definition of CDR. See Box 7.2 for a further discussion of the GCB and NGHGI data sources.

The first approach uses data from the GCB. Three bookkeeping models (BLUE, H&C2023 and OSCAR) are used in the GCB to estimate gross sources and sinks of CO_2 from land use, land-use change and forestry. One component of these sinks is the CDR attributable to afforestation/reforestation – that is, from expansion of forest area due to planting or regrowth after abandonment of agricultural land. The analysis averages the three models and uses their range as an uncertainty estimate.

The second approach is based on model-adjusted NGHGI data and quantifies CDR in managed forests, which includes CDR attributable to afforestation/reforestation as well as CDR attributable to forest management of already existing forest. The NGHGI estimates of CO_2 fluxes in managed forests have been reanalysed to remove fluxes resulting from indirect human effects and other environmental changes. The size of these natural fluxes is estimated by vegetation models (see the Chapter 7 Technical Appendix for details of the modelling methodology).

Harvested wood products: This report considers that forest management contributes to CDR when biomass is transferred to durable harvested wood products (HWPs). This may not be fully additional to CDR in afforestation/reforestation or in managed forest – some double counting may exist (see Section 7.2). FAOSTAT data on the production of sawnwood and panels are used to estimate this transfer during the last decade. Since these products decay over time, some of the carbon is returned to the atmosphere. An estimate of the net changes in carbon stock in HWPs is therefore calculated as the sum of the carbon transferred into the HWP pool minus the carbon transferred back to the atmosphere via product decay.

Novel CDR. This report provides estimates of CDR levels from bioenergy with carbon capture and storage (BECCS), biochar, bio-oil storage, direct air carbon capture and storage (DACCS), enhanced rock weathering, biomass sinking, mineral products, and ocean alkalinity enhancement. Information was compiled through a systematic review and harmonization of databases from the International Energy Agency, Mission Innovation, CDR.fyi and Ocean Visions, plus surveys by the International Biochar Initiative in partnership with the US Biochar Initiative and the European Biochar Industry Consortium. This was supplemented by data gathered from company websites. Further details are given in the Chapter 7 Technical Appendix.

Box 7.1 Points of departure from The State of Carbon Dioxide Removal 1st edition

This edition of *The State of Carbon Dioxide Removal* presents different estimates than the first. These differences stem from improvements in the estimation methods as well as from actual changes in CDR activity.

Alignment with the Global Carbon Budget

- A new approach has been developed for estimating CDR from afforestation/reforestation, which aligns with the latest GCB, published in 2023. Consistent with the GCB, the estimate of CDR from afforestation/reforestation is now based on results from three bookkeeping models.
- The approach for estimating CDR from managed forests (which includes removals through afforestation/reforestation as well as from forest management) has been refined. The first edition estimated CDR from managed forests by using data reported in NGHGIs,[322] excluding emissions from organic soils. From this estimate, indirect CO_2 uptake in response to

environmental changes was subtracted, using estimates from the OSCAR model.[323] This method aligned conceptually with the GCB definition in that only fluxes directly attributable to land-use activity were counted as CDR. In this second edition, this general approach is retained to provide an estimate of CDR in managed forests, but it is even better aligned with the method used in the GCB as it estimates the induced CO_2 removal using 18 dynamic global vegetation models instead of OSCAR only.

Improved calculations

- This report provides estimates of CDR from afforestation/reforestation and managed forests no longer only as a global total but also spatially and at the country level.
- The report's estimate of carbon transfers from wood to durable HWPs includes a correction to the conversion factors used in the calculation and now also accounts for CO_2 re-release each year from the decay of these products.
- The estimate of CDR volumes from BECCS is smaller in the second edition. This now reflects the actual amounts of CO_2 removed, rather than the targets initially set by the BECCS projects. This adjustment is most pronounced for the Illinois Industrial Carbon Capture and Storage Project, which has managed to store approximately 0.42–0.52 $MtCO_2$ each year,[324] rather than its stated goal of 1 $MtCO_2$ annually.

Greater coverage of locations and methods

- Data on biochar activity in the first edition were confined to market reports within Europe, North America and bamboo plantations in China. This coverage has now been expanded significantly by drawing on new data from the International Biochar Initiative, in partnership with the US Biochar Initiative, which include data from Africa, Asia, Europe, North America, Oceania and South America. The report therefore now has a larger estimate of CDR from biochar, but this is likely still incomplete.
- The report's coverage of enhanced rock weathering has been expanded, drawing on reports from a greater number of companies. Consequently, the report's estimate of CDR levels through enhanced rock weathering is higher.
- The second edition includes new implementation options not previously captured: BECCS derived from the use of biomass in cement production combined with carbon capture and storage, BECCS derived from biological waste-to-energy conversion combined with carbon capture and storage, and ocean alkalinity enhancement.

Box 7.2 Land-use emissions and removals in national inventories

While the GCB measures emissions and removals by land-use activities in a way that is aligned with the definition of CDR in this report, NGHGIs have adopted a different scope and approach. This box describes the implications of these differences for estimating CDR volumes.

National greenhouse gas inventories. Under the UNFCCC, countries report land-related emissions and removals from human activities in their NGHGIs. The methods used to compile NGHGIs are different from the bookkeeping models used in this report and in the GCB. NGHGIs are typically based on direct observations, which cannot distinguish the CO_2 sink attributable to direct human activities from that which is attributable to indirect effects induced by human-caused changes to environmental conditions. Only the sink attributable to direct human activities can be considered CDR.

Managed land. The IPCC guidelines for NGHGIs therefore proposed the concept of *managed land* as a basis for reporting human-caused emissions and removals.[325] Managed land is land where human interventions and practices have been applied to perform productive, ecological or social functions. In most countries' NGHGI submissions, the majority of emissions and removals within managed land areas are assumed to be due to human activity – including those caused indirectly as a response to changes in environmental conditions (e.g. rising atmospheric CO_2 concentrations, climate change, nitrogen deposition).

Because of the way that NGHGIs calculate emissions and removals, countries could in theory claim greater removals by categorizing larger areas of forest land as managed, without actually changing land use. Globally, about 80% of the total forest area is reported as managed forest land in NGHGIs. Only a relatively small expansion of managed forest has occurred since the 1990s, mostly in Brazil and the Russian Federation. According to the IPCC guidelines for NGHGIs,[325] it is good practice to describe the processes that led to re-categorization when moving previously unmanaged land to the managed land category. In other words, countries should not move lands in their NGHGI categories without evidence of an actual change in the status of the land.

Global Carbon Budget. In contrast to the NGHGIs, the GCB calculates human-caused emissions and removals based on land-use activities instead of areas. It separates out changes due to environmental conditions, attributing these to natural drivers. Direct effects from human activity are estimated by bookkeeping models. These estimates are independent of the area that each country has designated as managed land.

Consequences of the NGHGI approach versus the GCB approach. The estimates in NGHGIs of the total net CO_2 sink from managed land are therefore larger than the CDR estimates in the GCB.[326] As the reasons for the discrepancy are known, it is possible to convert estimates between the two definitions (see Section 7.2).[327,328]

Estimates from NGHGIs of CO_2 fluxes in managed forests suggest net removals of around −6,500 ± 1,135 $MtCO_2$ per year over the past decade.[327] When these estimates are reanalysed to remove natural fluxes – as estimated by models – global removals are reduced to −2,010 ± 620 $MtCO_2$ per year. See the Chapter 7 Technical Appendix for details of the modelling process. These removal rates have remained stable over the last two decades (see Figure 7.1).

The different scope of NGHGIs as compared with the GCB also has implications for the alignment of NGHGIs with scenarios (see Chapter

8 – Paris-consistent CDR scenarios, Chapter 9 – The CDR gap), the measurement of conventional CDR for policy planning and net zero targets (see Chapter 5 – Policymaking and governance, Chapter 9 – The CDR gap), and for the monitoring, reporting and verification of projects (see Chapter 10 – Monitoring, reporting and verification).

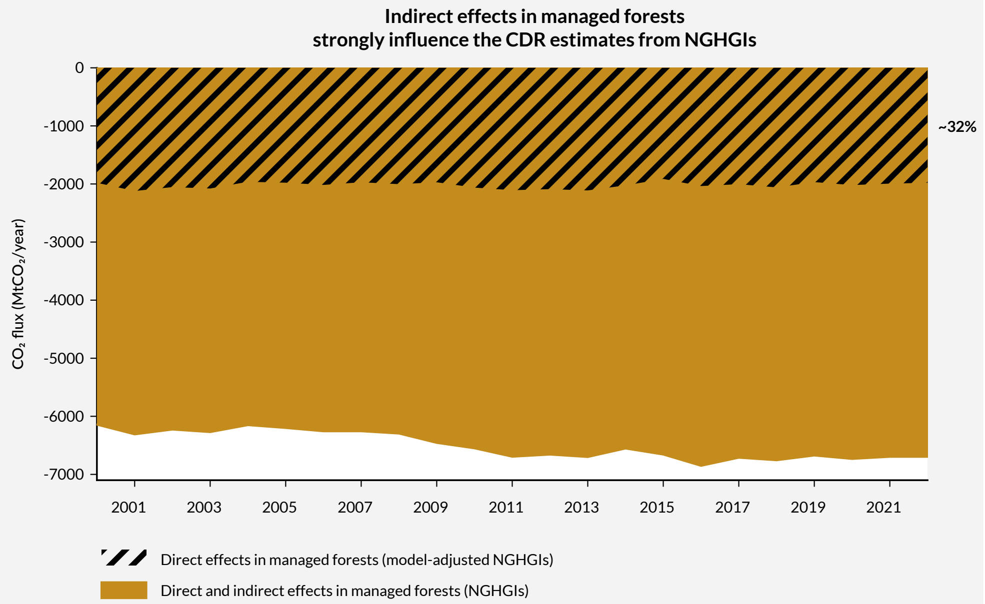

Figure 7.1 *Estimated global net carbon dioxide (CO_2) sink in managed forests from national greenhouse gas inventories (NGHGIs) (excluding emissions from organic soils) combined with modelling to factor out natural fluxes. The fluxes directly attributable to land-use activities ("direct effects", which is CDR as per the definition used in this report; black-hatched area) only account for 32% of the total average NGHGI CO_2 sink reported by countries (gold-shaded area). Countries' reported estimates include natural fluxes in response to environmental changes, as well as fluxes directly attributable to human land-use activities.*

Accounting for the relationship between CDR methods involving biomass and the atmospheric CO_2 budget

It is important to avoid double counting when estimating the CO_2 removed from the atmosphere by different CDR methods or implementation options. Depending on the method or option, the CDR refers to the time of CO_2 removal from the atmosphere or to the time carbon is transferred to a durable pool. But it may be the same carbon in both cases. This requires a choice of when in time the CDR is accounted for or else there is a risk of double counting. Several novel CDR methods (notably biochar, BECCS and bio-oil with storage) involve the biological capture of atmospheric CO_2, similar to conventional CDR, before transferring the biomass carbon into a different form of durable storage. Similarly, CDR through the transfer of biomass to durable HWPs is a conventional CDR method that involves biological capture of atmospheric CO_2 at an earlier time, where it may have been counted already under CDR through afforestation/reforestation or in managed forests.

Novel CDR derived from annual crops. If the biomass used for CDR is derived from annual crops, the crops themselves are not a durable store of carbon. This means the carbon was likely captured from the atmosphere in the same year as the transfer to durable storage, and the carbon is not otherwise counted within conventional CDR.

Novel CDR derived from woody biomass. In contrast, CDR methods that use woody biomass are transferring carbon from one durable pool to another. In this case, the most carbon was likely captured in the years preceding the point of transferral. Novel methods that use woody biomass include biochar made from woody feedstocks (which contribute about two-thirds of all biochar CDR in 2023). In principle, BECCS and bio-oil with storage could also use woody biomass; however, this report has found no current projects that do so.

For novel methods using woody biomass, this report therefore does not count CDR activity in a given year as a removal of atmospheric CO_2 in that year, but as a transfer of carbon from existing (biological) durable storage to another durable carbon pool (see Figure 7.5).

Conventional CDR through transfer of carbon to HWPs. Transfer of carbon to HWPs is considered CDR when the HWPs are durable. However, it is not entirely additional to CDR through afforestation/reforestation or CDR in managed forests:

- The woody biomass harvested for CDR may come from existing forests that have been managed over the long term. In this case, it is additional to CDR through afforestation/reforestation.
- If, however, the woody biomass comes from recently afforested or reforested areas, there will be some double counting in carbon removal between those CDR methods.

This report's estimates of carbon transfer to HWPs represent the sum of the CO_2 removed from the atmosphere during the years of biomass growth prior to harvest. Thus, the carbon removal due to transfers into long-term storage cannot be directly compared to the annual atmospheric CO_2 changes due to CDR.

Besides the issue of double counting with other CDR methods or options, it is disputable if HWPs taken from an existing forest qualify as CDR. This report defines CDR as resulting from direct human intervention. In the case of an existing forest, the carbon was removed from the atmosphere through natural processes. The CDR criterion that the removal must be attributable to human intervention thus applies only to the time of transfer to the durable carbon pool, not (or only in hindsight) to the time of the removal from the atmosphere. In the extreme case that HWPs are created from a forest that has been permanently cleared, CDR may occur through transferral to durable storage without an actual additional removal of CO_2 from the atmosphere.

7.2 Current global levels of CDR

On the order of 2,200 million tons per year of CDR is taking place already. Almost all of this comes from conventional CDR, with only an estimated 1.35 million tons per year (i.e. less than 0.1%) from novel CDR.

Current levels of conventional CDR

Estimates from the two approaches used in this assessment – model-adjusted NGHGIs and bookkeeping models – show broad agreement. Conventional CDR is currently predominantly due to afforestation/reforestation:

- ***Afforestation/reforestation.*** Annual global CDR through afforestation/reforestation amounts to −1,860 $MtCO_2$ (−1,160 to −2,230 $MtCO_2$; full range across models), averaged over 2013–2022, based on the latest GCB bookkeeping estimates (see Figure 7.2).
- ***CDR in managed forests (through afforestation/reforestation plus forest management).*** Annual global CDR in managed forests amounts to −2,010 ± 620 $MtCO_2$ per year over the same period, based on NGHGIs after indirect effects have been subtracted.

The two approaches disagree on the trend over the last 20 years, however, with bookkeeping models estimating a slight increase and adjusted NGHGIs estimating stable numbers. They do both agree on there being a slowdown in the last few years.

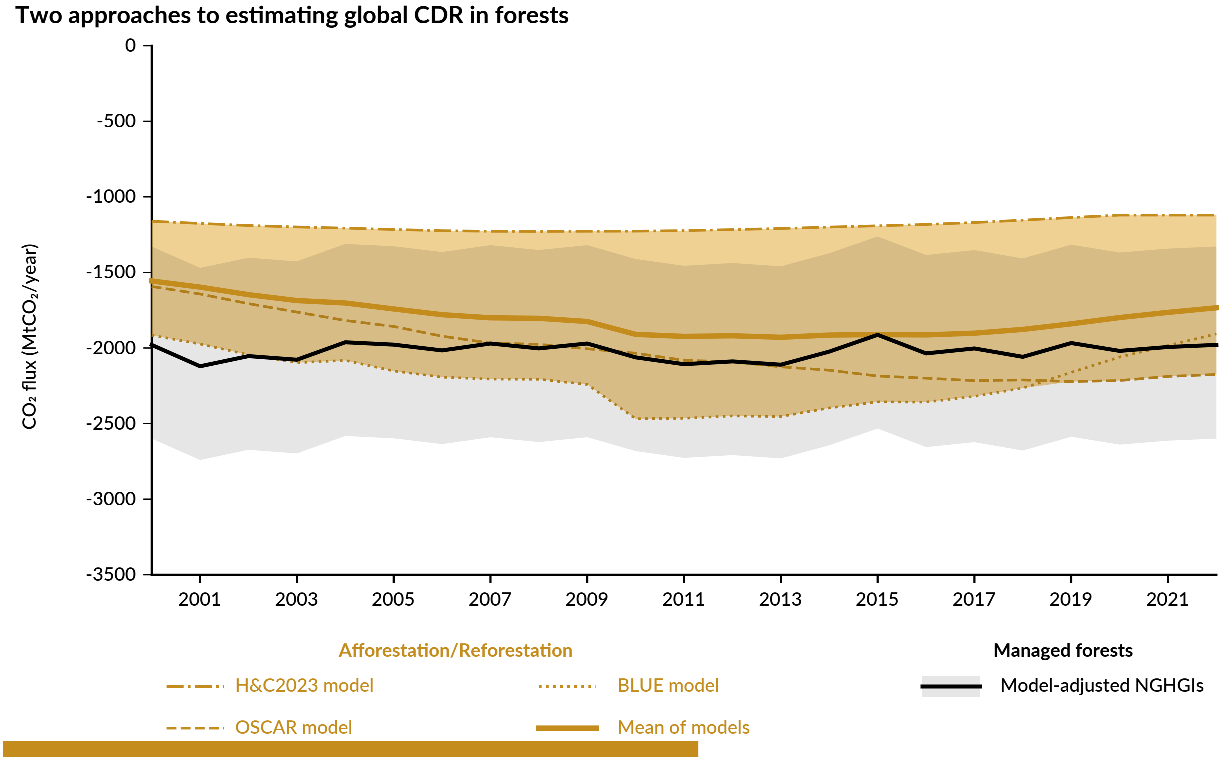

Figure 7.2 *Comparison of estimates of carbon dioxide removal (CDR) in forests. The gold lines show global CDR through afforestation/reforestation based on three bookkeeping models (BLUE, H&C2023 and OSCAR) and their mean; gold shading indicates the range across these bookkeeping model estimates. The black line denotes CDR in managed forests derived from national greenhouse gas inventories (NGHGIs), excluding emissions from organic soils, after modelled natural carbon dioxide (CO_2) fluxes have been subtracted; grey shading around the black line indicates the uncertainty in this estimate.*

At the country level, the largest CDR through afforestation/reforestation occurs in China, followed by the US, Brazil and the Russian Federation (Figure 7.3, top panel). Across the EU27 countries collectively, CDR through afforestation/reforestation falls in between that in China and the US. Together, these contribute 44% of global CDR from afforestation/

reforestation. Spatially, the largest CDR through afforestation/reforestation is found in Europe and East Asia, with substantial contributions also from several tropical regions, North America, India and parts of the Russian Federation (Figure 7.3, bottom panel). While the global-level estimates generated by the three bookkeeping models are similar, they differ more substantially at the country level.[329] The conversion between estimates based on bookkeeping models and NGHGIs also works at the country level, yet not perfectly, with country-specific reasons explaining the discrepancies in individual countries.[330]

The transfer of carbon to durable HWPs amounts to −801 MtCO_2 per year, averaged over 2013–2022. The net flux of durable HWPs, considering also the re-release of CO_2 through their decay, amounts to −332 MtCO_2 per year, averaged over 2013–2022.

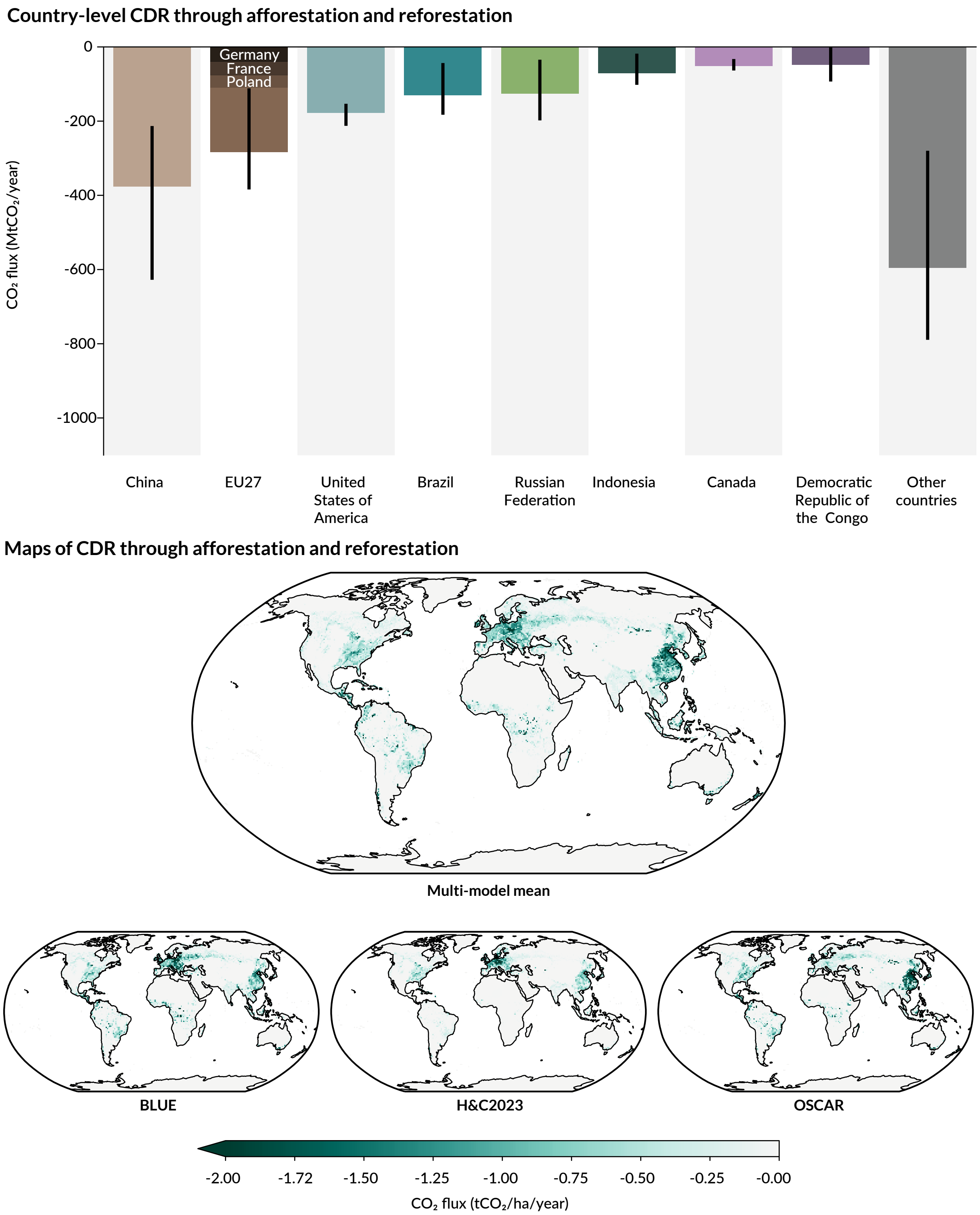

Figure 7.3 *Carbon dioxide removal (CDR) rates in forests ranked by country (and the EU27 countries collectively) (top panel) and global maps of carbon dioxide (CO_2) fluxes due to afforestation/reforestation (bottom panel). Values in both panels show averages over 2013–2022. Bars in the top panel indicate the multi-model mean of the bookkeeping models BLUE, H&C2023 and OSCAR, and whiskers represent the full spread across their estimates. Country names in the EU27 bar indicate the three EU27 countries with the largest afforestation/reforestation fluxes. The maps in the bottom panel show data for the bookkeeping models BLUE, H&C2023 and OSCAR, and their multi-model mean. BLUE provides spatially explicit data, whereas H&C2023 and OSCAR provide country-level data. The H&C2023 and OSCAR data have therefore been spatially distributed based on the CDR patterns of BLUE: for each country, the spatial pattern of the CDR flux density (i.e. flux per grid cell area) in BLUE is used, and the pattern is scaled such that the countrywide CDR estimate matches the H&C2023 and OSCAR CDR estimates in the respective country (see Schwingshackl et al., 2022, for details).*[330]

Current levels of novel CDR

In contrast to the gigaton scale of conventional CDR, the level of CDR from novel methods grew from an estimated −0.66 $MtCO_2$ per year in 2021 to −1.35 $MtCO_2$ per year in 2023 (see Figure 7.4).

The analysis shows that biochar currently provides −0.79 $MtCO_2$ per year, and BECCS −0.51 $MtCO_2$ per year. DACCS contributes −0.004 $MtCO_2$ per year, and enhanced rock weathering approximately −0.03 $MtCO_2$.

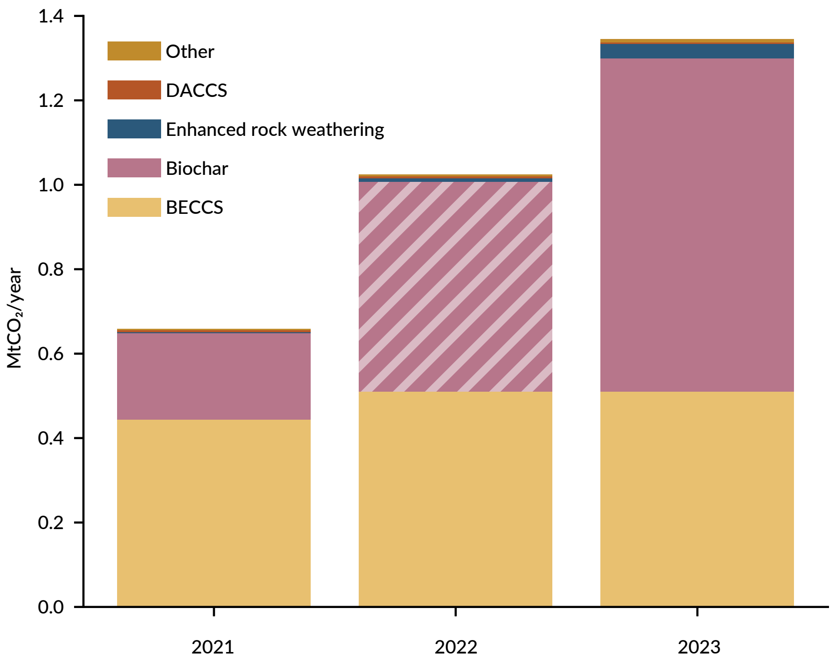

Figure 7.4 *Global carbon dioxide removal levels through novel methods. Shaded bar for biochar in 2022 represents linear interpolation from actual 2021 and 2023 data. BECCS = bioenergy with carbon capture and storage; DACCS = direct air carbon capture and storage.*

The implementation of novel CDR methods appears to remain concentrated in Europe and North America, though it is beginning to spread beyond. For BECCS, the Illinois Industrial Carbon Capture and Storage Project facility in the US is the largest and longest-running installation globally. This facility has been reaching −0.43 to −0.52 $MtCO_2$ per year from the capture of CO_2 during corn ethanol production since 2017. In 2022, another BECCS project started delivering CDR in the US: the Red Trail Energy bioethanol initiative (which reached −0.08 $MtCO_2$ in that year).[324]

Biochar has a substantially wider geographic distribution than BECCS. North America contributes an estimated 48% of the CDR from biochar; Europe follows with 17%; Asia contributes 16% and South America 11%; and Africa and Oceania contribute 8% and 1%, respectively. There was substantial growth in CDR delivered through biochar in 2023, especially in South America and Oceania, where levels increased by approximately 350 and 400 times, respectively, compared with 2021. Europe saw an estimated twelvefold increase in biochar CDR, and in Africa, removal volumes nearly tripled. These changes highlight both the rapid growth and regional variations in biochar deployment.[3]

3 *While this report draws on survey data available only for 2021 and 2023, biochar has a long-standing history.*[331]

For DACCS, the Orca facility in Iceland remains the largest operational plant globally. This facility came online in 2021 and has a capacity of 4 kt of CO_2 per year. Enhanced rock weathering is also capturing atmospheric CO_2 at the kiloton scale, although it is distributed more widely around the world than BECCS and DACCS. Companies such as UNDO, GreenSand, AgSeq and Mati have reported delivering CDR via enhanced rock weathering, with operations spread across Australia, Canada, India and the UK.

Several other novel CDR methods contribute on a smaller scale, with reported removals of just under 8 kt of CO_2 per year in removals. These novel methods include bio-oil storage, mineral products (capture of atmospheric CO_2 within demolished concrete aggregate), biomass sinking and ocean alkalinity enhancement.

A significant upswing in novel CDR is expected in the coming months. According to projections made by the International Biochar Initiative and the US Biochar Initiative, CDR from biochar is expected to reach over seven times the current deployment rate by 2025. The development pipeline also suggests a potential increase of over 2.5 times the 2023 CDR levels through BECCS and DACCS by the end of 2024. Noteworthy projects include the Blue Flint Ethanol plant in North Dakota, US, that started operations in late 2023; the Climeworks Mammoth plant in Iceland, designed to capture −0.036 $MtCO_2$ annually; and the STRATOS project by 1PointFive in Texas, US, targeting the capture of up to −0.5 $MtCO_2$ per year from mid-2025. Longer-term – but less reliable – company announcements suggest an even higher growth trajectory for novel CDR (see Chapter 3 – Demonstration and upscaling).

Figure 7.5 summarizes the current levels of conventional and novel CDR. It includes both the perspective of CO_2 removal from the atmosphere and the perspective of transfer of carbon to a durable pool. If summed together, they suggest current CDR of approximately −2,200 $MtCO_2$ per year, although how they relate to each other has been discussed in Section 7.1

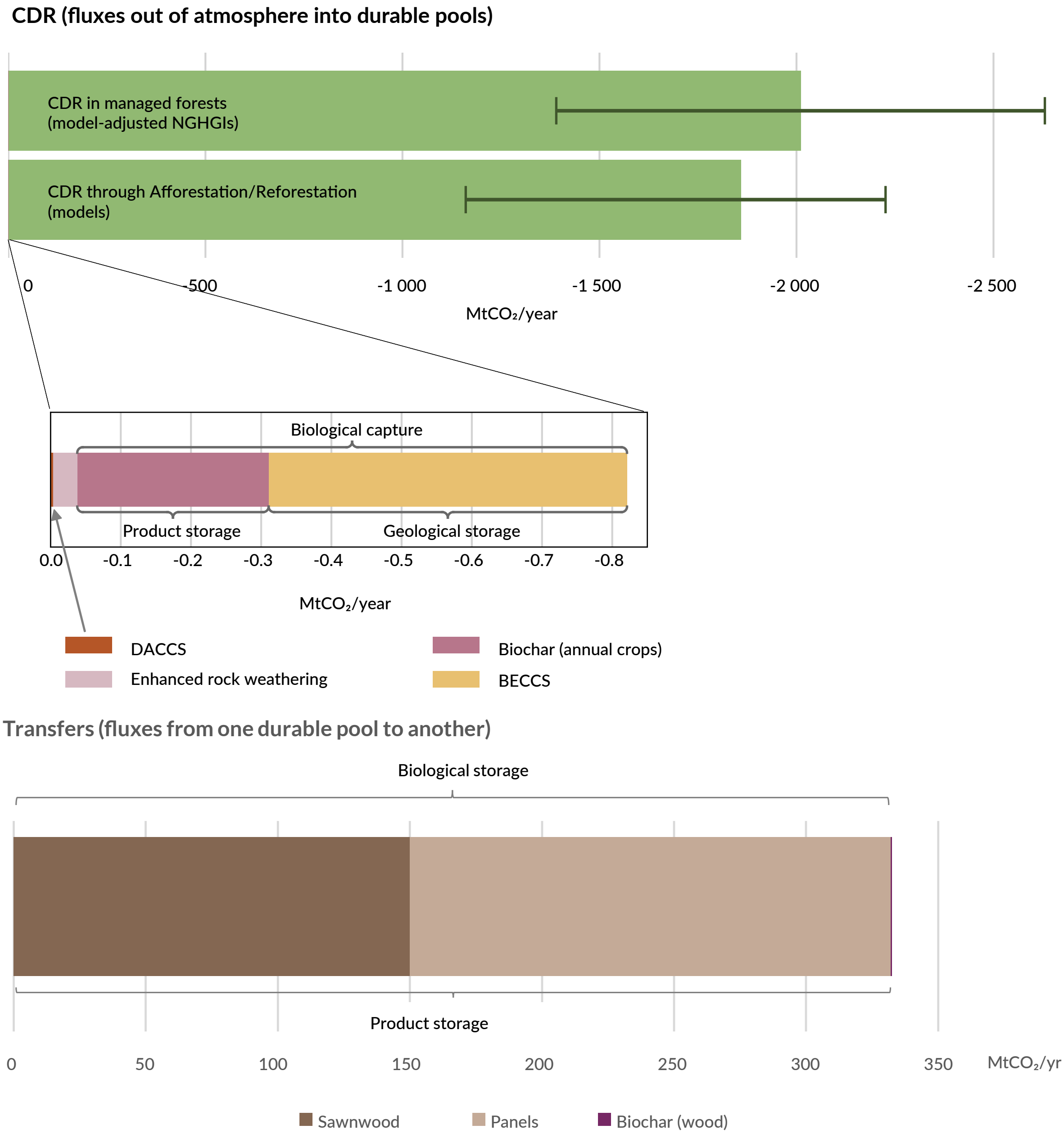

Figure 7.5 *Summary of current carbon dioxide removal (CDR) deployment, based on average levels of conventional CDR during 2013–2022 and on estimates of novel CDR in 2023. The top panel shows carbon dioxide (CO_2) moved from the atmosphere into durable storage. The middle panel shows a zoom-in for novel CDR: biochar (from annual crops), bioenergy with carbon capture and storage (BECCS), enhanced rock weathering, and direct air carbon capture and storage (DACCS). Brackets on the top and bottom of the bar indicate the capture and storage types involved (not shown: afforestation/reforestation involves biological capture and storage; DACCS and enhanced rock weathering both involve geochemical capture and mineral storage). The uncertainty bar for CDR through afforestation/reforestation in the top panel indicates the spread across the three bookkeeping model estimates. The bottom panel shows the average levels, during 2013–2022, of CO_2 recently captured from the atmosphere and transferred from one form of durable storage to another. The brackets on top indicate the origin of the captured carbon, and the brackets below indicate the final storage pool.*

Box 7.3 Limitations and knowledge gaps

This report has identified areas on which future assessments can build, including:

- *Precision of afforestation/reforestation estimates:* The uncertainties in quantifying CDR due to afforestation/reforestation are substantial: the lowest and highest global estimates differ by a factor of two. A key obstacle to better constraining this number is that it is impossible to directly observe the CO_2 exchanges between land and atmosphere, or the underlying carbon stock changes, in particular in soils.
- *Distinguishing CDR from natural fluxes:* A clear separation between the effects of human activity on land and indirect responses to environmental conditions is challenging. Distinguishing between these effects requires models, but these are simplifications of complex land processes, and the input data and parameters they use have wide error margins.[332]
- *Making NGHGI and bookkeeping model estimates comparable:* The CDR estimates from model-adjusted NGHGIs and from bookkeeping models are not entirely comparable. The first includes improved management of existing forests as well as afforestation/reforestation. It may be possible to improve comparability by distinguishing between these two CDR methods in the NGHGI data, based on their "land converted to forest land" category. This would be limited to afforestation/reforestation that took place within the last 20 years, however, and would only cover certain countries.
- *Accuracy of NGHGI-based CDR estimates*: In removing the natural fluxes on managed land to derive estimates of CDR from the NGHGIs, assumptions have had to be made. These assumptions sometimes have sensitivities as large as the estimate of CDR itself. For example, country-level analysis requires a decision on how to interpret cases where the managed land appears to be a source of CO_2 rather than a sink (once the modelled natural flux has been subtracted from the NGHGI flux). These cases have been interpreted as reflecting processes like forest degradation, and hence this report has not included them as CDR.
- *Accuracy of novel CDR estimates:* The report's assessment of novel CDR levels is derived largely from self-reporting by individual (often commercial) projects. This is because almost all novel CDR methods currently lack internationally agreed approaches to monitoring, reporting and verification (see Chapter 10 – Monitoring, reporting and verification).
- *Accounting for re-release of CO_2:* Re-release of stored CO_2 is accounted for some, but not all, of the least durable CDR methods. For the estimate of carbon transfers through HWPs, emissions from decay of existing wood products are subtracted from new inputs in each given year. For the estimate of CDR levels through afforestation/reforestation, changes in durability – such as through an increasing rate of wildfires or droughts – are not considered because the bookkeeping models exclude the effects of changes in environmental conditions. The estimate of CDR in managed forests based on model-adjusted NGHGI data captures such changes to some extent. For all other CDR methods, it is implicitly assumed that all captured carbon remains stored – no re-release of CO_2 is accounted for.
- *Data gaps in tracking CDR activity:* Not all current activities that may

qualify as CDR are quantified in this report, owing to a lack of data. Among the likely largest contributors are peatland and coastal wetland restoration, agroforestry, and soil carbon sequestration in croplands and grasslands. The estimate for biochar in particular is incomplete. While the global survey data used in this report mark a significant improvement over previous data sets, these data still likely underrepresent the true scale and distribution of biochar production. Notably, the location of the survey organizers in North America may have led to higher representation in this region and lower representation in regions such as Africa, Asia and South America. This is particularly true for biochar produced for soil amendment purposes, especially in small-scale operations using portable kilns or similar setups, which may not be tracked systematically.

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