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Technical appendix

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A7.1 Methods

We combine models, databases, surveys and other sources to estimate current levels of various CDR methods.

Afforestation and reforestation / CDR in managed forests

The methodology used in this report aligns with that in the Global Carbon Budget (GCB) 2023 (Friedlingstein et al., 2023). The GCB uses the average of three bookkeeping estimates to quantify CDR: the Bookkeeping of Land Use Emissions model (BLUE, Hansis et al., 2015), the Houghton and Castanho bookkeeping model (H&C2023, Houghton and Castanho, 2023) and the OSCAR reduced-form Earth system model (Gasser et al., 2020). BLUE incorporates information on land use and land-use changes based on the spatially explicit LUH2 dataset (Hurtt et al., 2020), updated to 2022 (which therefore limits CDR estimates up to and including 2022). H&C2023 is based on estimates from the United Nations Food and Agriculture Organization Statistics (FAOSTAT) and FRA for changes in agricultural areas and wood harvesting (which are also used by LUH2). OSCAR uses a mix of both these datasets.

The models calculate the gross anthropogenic sources and sinks of CO_2 from land use, land-use change and forestry, of which one component is the CDR attributable to A/R activities. All bookkeeping estimates take into account the effects of land-use activities since 1700; this implies that CO_2 removals occurring today due to A/R several decades ago are accounted for. Within the CO_2 fluxes associated with A/R, we include fluxes from expansion of forest area due to planting or due to regrowth after abandonment of agricultural land, but we exclude fluxes from regrowth of forest after natural disturbances (because this is not directly attributable to human activity). We also exclude short-term removals from shifting cultivation (non-permanent reforestation as part of rotational agriculture – a cultivation practice found mostly in tropical areas) and from regrowth after wood harvesting (because this does not imply a change in forest cover – although the harvested wood can represent a carbon transfer as part of other CDR methods; see "Harvested Wood Products", below).

This report also provides a second, largely independent, estimate of CDR in managed forests based on the emissions and removals reported by countries in accordance with the guidelines set by the Intergovernmental Panel on Climate Change (IPCC) for National Greenhouse Gas Inventories (NGHGIs). NGHGIs generally use direct measurements and therefore include both the direct anthropogenic effects (such as land-use change, harvest and regrowth) and most of the impact of indirect human-induced environmental changes (e.g. CO_2 fertilisation, which stimulates plant growth). NGHGI estimates thus include a larger amount of CO_2 removal than bookkeeping model estimates in the GCB, as the bookkeeping models only consider CO_2 removals that happen because of direct human activity (which is a prerequisite for CDR) and not, like the NGHGIs, also removals that happen indirectly as a result of human-caused changes to environmental conditions (Grassi et al., 2018, Friedlingstein et al. 2023) (see Chapter 7, Box 3). Estimates of CO_2 fluxes from direct human activity that draw on NGHGIs can only be achieved through a combination with modelling.

The estimation method used for this report inverts the approach used in Grassi et al. (2023) and subtracts the modelled CO_2 fluxes that are the result of environmental changes in managed forest areas from the CO_2 fluxes reported in NGHGIs under the 'managed forest land' category. Since we exclude HWPs but include 'forest remaining forest' and 'land converted to forest land' under this category, this approach captures CDR not only from A/R (new forest), but also due to improved forest management (already existing forest). In a departure from the first edition of this report, we (i) use the natural CO_2 sink estimates for managed forest from the 18 DGVMs used in the latest GCB (2023) instead of flux estimates based only on OSCAR, to achieve greater consistency with the GCB, and (ii) consider for the global CDR value only those countries where the difference between the sink in managed forest land in NGHGIs and the natural sink from DGVMs (filtered for the area of managed forest) is a net removal.

The estimate of CDR in managed forests derived from the NGHGIs depends on assumptions that are made in the process of taking out the natural fluxes on managed land; the sensitivity is as large as our estimate of CDR itself. That our global estimate is similar to that in the 1st Edition can partly be explained by compensating changes: our estimate of the natural fluxes, using 18 DGVMs instead of OSCAR, is substantially larger in the 2nd Edition. However, at the same time we exclude countries where the difference between the NGHGI flux on managed forest (including natural fluxes) minus the natural fluxes on managed forest from DGVMs yields values that imply a source of CO_2; we interpret this as processes like forest degradation, incompatible with CDR. This choice became relevant for the 2nd Edition as we moved to country level. A further sensitivity relates to the handling of the interannual variability, which differs in NGHGI and DGVMs; the decadal average was used for the DGVMs to avoid artefacts.

We provide an uncertainty estimate for CDR in managed forests based on a combination of the uncertainties for the NGHGIs and the DGVMs. The NGHGI uncertainty is estimated as in Grassi et al. (2017). The DGVM uncertainty is based on the uncertainty value for the natural land sink provided by the GCB 2023 scaled to the non-intact forest sink.

Durable Wood Products

Here we consider that forest management contributes to CDR when biomass is transferred to durable product pools via harvested wood products (HWP). Following the approach by Powis et al. (2023) we take data from the FAOSTAT (2024) Forest Product Statistics database, counting only the categories "sawnwood" and "wood-based panels" as being durable enough to count as CDR. We convert from the volume of harvested wood into tons of CO_2 following the tier 2 methodology in the IPCC Guidelines for NGHGIs (IPCC, 2019). Using the FAOSTAT global values of sawnwood and wood-based panels is more complete than countries' HWP data in NGHGIs, which do not account fully for international trade (IPCC 2019).

Since even durable wood products decay over time, some of the carbon is returned to the atmosphere. We provide year-on-year estimates for (i) the carbon transferred to durable products and (ii) the carbon actually stored in the HWP pool. For (ii), the carbon stock at the beginning of the data series (1900) is assumed to be in steady state, the inflow is defined by the annual production equal to (i), and the outflow is determined through a first order decay function, using specific half-life coefficients based on the default IPCC values (IPCC 2019). The total HWP net carbon 'sink' is equal to the sum of the annual carbon stock changes of all commodities. While durable HWP may constitute a form of CDR, care should be taken in adding these numbers to annual estimates of CO_2 removed from the atmosphere to avoid double-counting (see "Accounting for the relationship between CDR methods involving biomass and the atmospheric CO_2 budget" in Chapter 7).

Novel CDR Approaches

Our methodology for compiling data on novel CDR methods used a structured approach to aggregate different sources. This involved extracting information through a systematic review of established databases and surveys, supplemented by gathering data directly from individual websites. Where data were either not accessible or required verification, direct engagement with relevant companies and projects was undertaken. Furthermore, to gather specific information on various approaches, a specialised survey was disseminated.

In estimating CO_2 removals from biochar production, our methodology draws on global production volumes derived from a comprehensive survey conducted by the IBI and the USBI. Our calculation specifically excludes biochar that is produced for use as bio-coal. Conversion of global biochar production volumes to carbon amounts was achieved by applying fractions of carbon content for various biochar categories, as outlined by Woolf et al. (2021), based on the type of feedstock. The resulting carbon quantities were then converted into equivalent CO_2 quantities by applying a conversion factor of 3.67.

For the assessment of deployment levels of other novel CDR methods the data were directly sourced from the references listed in Table 1. For detailed data and information on specific assumptions underlying our analysis, please refer to the data portal, which can be accessed at the *State of CDR website.*

A7.2 Data sources

The following data sources were used to compile our estimate of CDR deployment:

CDR Technology	Source	Reference
Afforestation and reforestation / CDR in managed forests	Global Carbon Budget, NGHGIs	Friedlingstein et al., 2023, Grassi et al. 2023
Durable wood products	FAOSTAT	FAOSTAT Database,
BECCS	IEA CCUS Database, CDR.fyi, CCUS database by Mission Innovation, State of CDR research	IEA Database CDR.fyi Mission Innovation
Biochar	Survey conducted by the International Biochar Initiative (IBI) in partnership with the US Biochar Initiative (USBI); Survey conducted by the European Biochar Industry Consortium	Survey conducted by the IBI and the USBI
Bio-oil storage	CDR.fyi, State of CDR research	CDR.fyi
DACCS	IEA CCUS Database, CDR.fyi, CCUS database by Mission Innovation, State of CDR research	IEA Database CDR.fyi Mission Innovation
Enhanced rock weathering	CDR.fyi, CCUS database by Mission Innovation, State of CDR research	CDR.fyi Mission Innovation
Biomass sinking	CDR.fyi, State of CDR research	CDR.fyi
Mineral products	CDR.fyi, State of CDR research	CDR.fyi
Ocean Alkalinity Enhancement (OAE)	Ocean Visions mCDR Field Trial Database	Ocean Visions Database

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Table 1. Summary of the key sources.

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