“CDR from novel methods contributes 0.1% of current deployment. Conventional CDR on land accounts for over 99%.”

Chapter 6 | Deployment

Chapter team: Carter Powis[i], Stephen M Smith[i]

[i] *University of Oxford*

The amount of Carbon Dioxide Removal (CDR) currently occurring around the world is roughly 2,000 $MtCO_2$ per year, of which almost all comes from conventional methods on land. However, accurately estimating CDR deployment is challenging.

Box 6.1 Key findings

- We estimate the amount of conventional Carbon Dioxide Removal (CDR) currently occurring on land (for example, through afforestation and reforestation) is 2,000 $MtCO_2$ per year.
- Adopting the methods used by countries to report their emissions and removals on land increases this estimate to 6,400 $MtCO_2$ per year. This is because national greenhouse gas inventories use a less strict interpretation of removals from human activity, including indirect effects.
- We estimate an additional 2.3 $MtCO_2$ per year of CDR from novel CDR methods, including Bioenergy with Carbon Capture and Storage, Direct Air Carbon Capture and Storage, biochar, enhanced rock weathering and coastal wetland (blue carbon) management.
- If all novel CDR projects currently under development are completed, the gross amount of novel CDR projects will increase to 11.75 $MtCO_2$ per year by 2025.
- Currently available data for novel CDR focuses on gross removals from projects in Europe and North America, with limited coverage of lifecycle emissions and other geographies. This means our estimate of deployment is likely incomplete.

6.1 Our approach to estimating global Carbon Dioxide Removal deployment

Estimating global Carbon Dioxide Removal (CDR) deployment is challenging, given uncertainty around defining what counts as CDR, data availability and issues with reporting approaches.

Generating an estimate of the amount of CDR currently occurring requires solving three main challenges. The first is defining which activities should be considered as CDR. The second is gathering sufficient data on those activities. The third is developing a reporting approach that addresses the risk of overestimating total deployment in cases where the CDR process takes many years to complete.

Challenge 1: Defining CDR

In this assessment, we adopt the definition of CDR used by the Intergovernmental Panel on Climate Change (IPCC)[38] (see Chapter 1 – Introduction, Section 1.3). We define CDR in this chapter, therefore, as:

> *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.*

Not only does this definition rule out activities which capture fossil carbon, or which do not store atmospheric carbon durably, it also has important implications for the measurement of CDR generated through conventional CDR on land (see Chapter 1 – Introduction, Section 1.5 for definition) and other land management activities. Specifically, carbon removed and stored in the land reservoir can be a result of biomass growth on managed land, of direct human intervention that enhances or creates new biomass (such as forest management or planting trees), or of indirect climate effects (e.g. plant growth stimulation caused by elevated atmospheric CO_2, known as the CO_2 fertilisation effect).[*] According to the IPCC definition, CO_2 uptake not caused directly by human activities does not count as CDR, so an accurate CDR deployment estimate should remove indirect climate effects from land data. For example, the carbon impact of planting new trees should be counted, but the extra carbon stored in those trees due to the CO_2 fertilisation effect should not be.

Challenge 2: Finding sufficient data

Our estimate of current deployment of conventional CDR on land is based on an aggregated and standardised National Greenhouse Gas Inventory (NGHGI) database developed by Grassi et al. (2022)[191]. NGHGIs are reports submitted by countries to the United Nations Framework Convention on Climate Change on an annual basis. They contain country-level estimates of greenhouse gas fluxes to and from the atmosphere from activities that occur in that country. While globally comprehensive, these NGHGI estimates come with two complications that must be addressed. Firstly, NGHGI estimates of fluxes from managed land include emissions as well as removals, meaning the gross volume of CDR is obscured. As an approximate correction for this we removed all non-forest-management fluxes, for example the impacts of deforestation or peat fires. Secondly, NGHGI-managed land estimates include both direct effects of human intervention and indirect effects of increased atmospheric CO_2 (see above). We estimate current CDR deployment with indirect effects removed by applying a correction generated by the OSCAR model[192]. Because land-use storage fluctuates from year to year, we have used the average managed land storage estimate for 2000-2020. For more information on measuring land sink size, see Box 8.2 in Chapter 8 – The CDR gap.

Data availability regarding the deployment of novel CDR projects is currently very limited - including for Bioenergy with Carbon Capture and Storage (BECCS), Direct Air Carbon Capture and Storage (DACCS), biochar, enhanced rock weathering and coastal wetland (blue carbon) management. With no centralised repository of projects, information on deployment must be drawn from fragmented data sources, including CDR sale records and contracts, carbon offset registries, and NGO or corporate databases and reports. Here, we have systematically combined and cleaned 20 publicly available CDR databases and registries to develop a comprehensive view of present-day deployment of these CDR projects[8,23,47,86,193–207].

* Following the approach of National Inventory reporting, for the purposes of this analysis, we consider (1) biomass growth on managed land and (2) direct human intervention on managed land to be one and the same – in other words, we assume all biomass on managed land is managed.

Challenge 3: Developing an effective measurement approach

Developing an estimate of the net removal achieved through current deployment of CDR is challenging from a reporting perspective. Firstly, most CDR projects do not report total lifecycle emissions. Secondly, some CDR methods provide removal of CO_2 over multiple years, and approaches for reporting the carbon removed and stored by such methods can overestimate their total impact (see Box 6.2). While the first issue is critical, it is not one that is possible to solve here. We resolve the second by following a "stock-and-flow" based accounting approach[193]. This measures CDR where and when it actually occurs by differentiating between two types of CDR activity: carbon sinks (carbon that is removed from the atmosphere and stored in a non-atmospheric reservoir in a given year) and carbon transfers (carbon that is moved between one non-atmospheric reservoir and another in a given year).

Box 6.2 Avoiding overestimation in Carbon Dioxide Removal deployment estimates

The climate impact of Carbon Dioxide Removal (CDR) activity is determined by removals out of – and any emissions into – the atmosphere over the whole lifecycle of the CDR method. This considers not only the carbon captured but also other factors, such as emissions associated with the construction of facilities, energy use and other inputs, and the fate of the stored carbon over time. Removals and emissions take place over different time periods for different CDR methods, as they involve different sequences of transfers through carbon pools (sometimes extended over multiple years), different inputs during the process (in terms of fuels and materials) and different final storage pools with differing durability of storage.

For this reason, there are two problems when estimating removals resulting from present-day CDR deployment. Firstly, the quantity of CDR reported by most projects is the gross quantity transferred from the atmosphere to the final carbon pool, excluding production emissions and any re-release of previously stored carbon. As such, any estimate of climate impact using reported data will be an overestimate of the actual net volume of CO_2 being removed from the atmosphere on an annual basis.

Secondly, when a CDR method involves conversion of atmospheric carbon into other forms, there may be a separation between when the CDR activity is recorded as occurring, and the actual timing of removal from the atmosphere. For example, in cases such as Bioenergy with Carbon Capture and Storage (BECCS) or the production of durable harvested wood products (HWP), the CDR activity tends to be reported in the year of biomass conversion to an energy product or wood product, rather than the time the carbon was transferred from atmosphere to plant (Figure 6.1). These will be one and the same for BECCS when using annual crops, but not forest biomass and other perennial crops. As such, these volumes run the risk of being double-counted if CDR methods make use of biomass that has also been recorded as a sink in prior years.

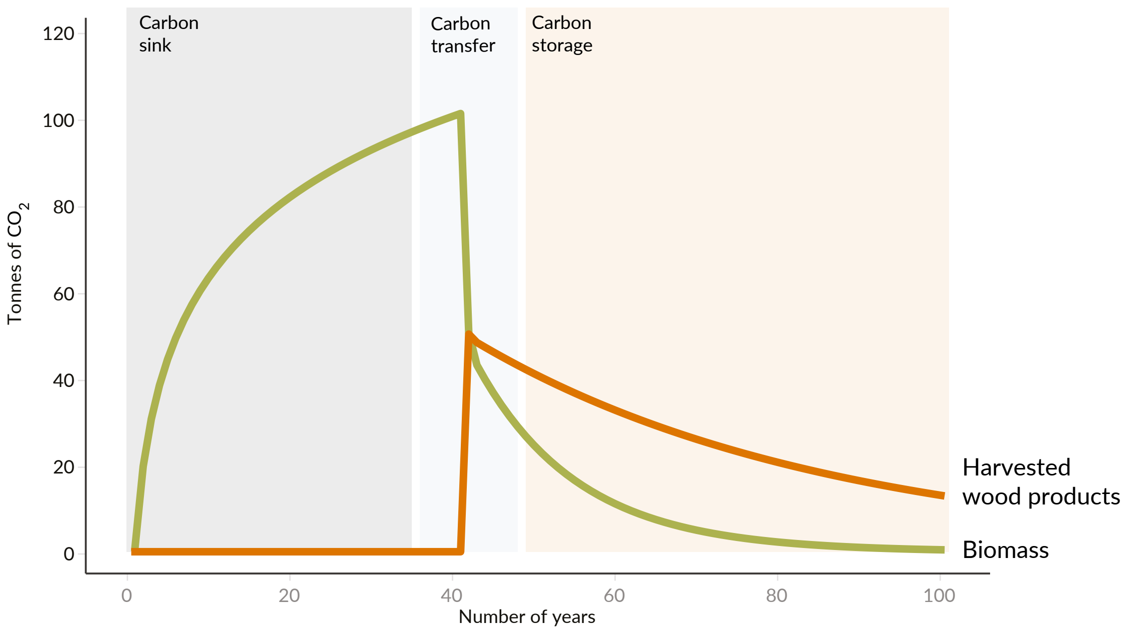

Figure 6.1. *An illustrative carbon dioxide (CO_2) removal and storage pathway for the production of harvested wood products (HWPs). During the carbon sink phase, carbon is removed and stored incrementally by biomass growth in forests[208]. During the carbon transfer phase, a portion of stored carbon is transferred from forest biomass to HWPs, with the remainder deposited as deadwood[209]. During the storage phase, both the deadwood and HWP decay to the atmosphere, though at different rates[210].*

While it is not currently possible to resolve the lifetime emissions reporting issue here, it is possible to resolve the issue of double-counting by multi-year CDR processes. We do this by adopting a stock-and-flow reporting system193, which splits CDR into two complementary but separate activities mapped onto the various pools of the global carbon cycle:

- The first activity is termed "carbon sinks" and is defined as activities which remove carbon from the atmosphere and durably store it in a non-atmospheric pool in the same year.

- The second activity is termed "carbon transfers" and is defined as activities which transfer carbon from one non-atmospheric pool to another in the same year.

In so doing, carbon removed from the atmosphere is always recorded as a carbon sink in the year in which it actually occurs, and activities such as the production of durable HWPs are recorded separately as carbon transfers in the year they are produced, a sum which is useful for tracking changes in carbon storage but which is reported separately from carbon sinks to avoid double-counting.

According to our estimates of current CDR deployment, all identified BECCS and biochar projects use annual crops or forest residues as inputs. For both of these carbon sources, the carbon sink and transfer are considered to occur in the same year. While forest residues have, technically, grown over many years before deposition, they are commonly assumed to behave the same way as annual crops because, like annual crops, the amount of deposition and decay in a given year is about equal, so they are neither a net source nor a sink of carbon. Hence, the only current CDR method with carbon removal and carbon transfers occurring in separate years is the production of durable HWPs.

6.2 Current CDR deployment

Virtually all current CDR comes from conventional methods on managed land. Only a tiny fraction results from novel CDR methods including BECCS, biochar, DACCS, enhanced rock weathering and coastal wetland (blue carbon) management.

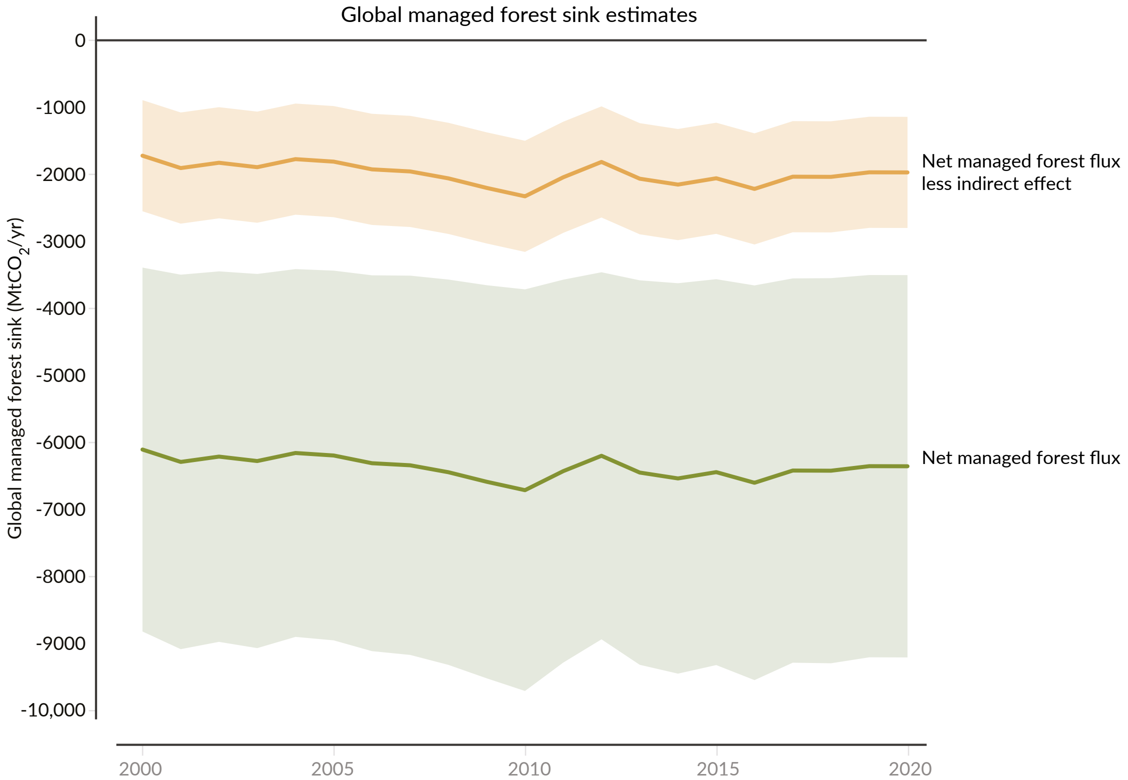

Figure 6.2. *Estimates of Carbon Dioxide Removal (CDR) from managed land during 2000-2020. Storage from net managed forest flux, including indirect climate effects, based on National Greenhouse Gas Inventory data (green). Storage from net managed forest flux, minus indirect climate effects (orange). Shaded regions indicate the range of measurement uncertainty.*

We estimate society is currently generating roughly 2,000 $MtCO_2$ per year of gross CDR (carbon that is removed from the atmosphere and stored in a durable non-atmospheric pool). Of this total, almost all comes from managed land.

NGHGI data indicates total global removals from managed forest land of around 6,400 ± 2,800 $MtCO_2$ per year, averaged over 2000-2020. Removing indirect climate effects, we arrive at an estimate of 2,000 ± 900 $MtCO_2$ per year for conventional CDR on land (Figure 6.2). This is smaller than a comparable estimate derived from bookkeeping models, which puts direct forest removals at 3,300 ± 1,100 $MtCO_2$ per year. The difference is likely due to inclusion of shifting cultivation (cutting forest for agriculture, then abandoning), which leads to large emissions and removals within each year. We exclude this activity from our estimate. The remaining 2.3 $MtCO_2$ of gross carbon sinks comes from novel CDR methods. The breakdown for different CDR methods is as follows: 1.82 $MtCO_2$ from BECCS, 0.5 $MtCO_2$ from biochar production and 0.01 $MtCO_2$ the combined result of all other methods, including DACCS, enhanced rock weathering, coastal wetland (blue carbon) management and others (Figure 6.3).

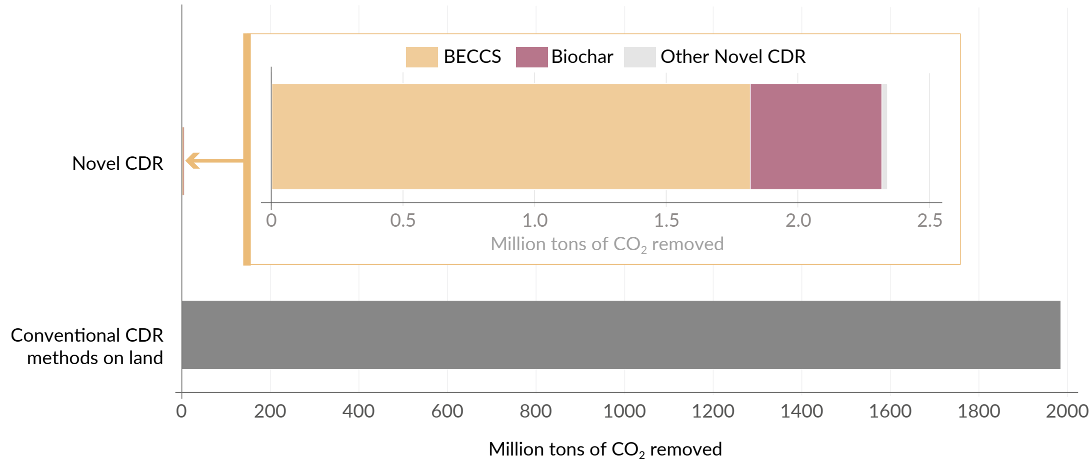

Figure 6.3. *Estimate of current Carbon Dioxide Removal (CDR) deployment. Definition: Bioenergy with Carbon Capture and Storage (BECCS).*

Furthermore, we estimate the volume of carbon transfers currently generated each year is about 223 $MtCO_2$. All 223 Mt are generated through the production of durable harvested wood products (HWPs), specifically sawnwood and wood panels, which transfer carbon from forest stock into durable wood products (Figure 6.4).

6.3 Future CDR deployment

There are a number of CDR projects in development that will become operational over the course of this decade, the pace of which can be used to estimate future growth.

It is possible to forecast CDR deployment, assuming no new projects are started and all in-development projects are completed. Under this assumption, atmospheric removals generated using non-land-management CDR projects will grow from 2.3 $MtCO_2$ per year in 2022 to 11.75 $MtCO_2$ per year by 2025, driven almost entirely by the completion of the Summit Carbon Solutions BECCS project, which involves bringing online 30 coupled ethanol-production BECCS plants and associated geological storage. By 2025, the annual volume of atmospheric removals using methods other than BECCS, DACCS and biochar will remain well below 1 $MtCO_2$ per year in volume.

Another way to project future CDR deployment is to extrapolate current deployment data. This approach is informative as it is unrealistic to assume there will be no additional CDR project development beyond 2025. To provide an approximate range of what might be expected, we fit both linear and exponential trends to the 2020-2025 deployment data for each CDR method as plausible upper and lower bounds. Under these assumptions, by 2030 we could see 30.5-208.5 $MtCO_2$ per year of BECCS deployment, 7-297.5 $MtCO_2$ per year of DACCS deployment, 1.8-65 $MtCO_2$ per year of biochar deployment and 0.036-0.061 $MtCO_2$ per year from all other methods (see Figure 6.4). Based on a longer available historical dataset and knowledge of the demand dynamics behind HWPs, we expect HWPs will at most continue to exhibit linear growth moving forward. While the exponential extrapolations used for novel CDR projects may seem large, it is important to note that despite persistently linear forecasts, solar and wind energy deployment have exhibited exponential trends over the past decade[211], and similar dynamics for CDR methods cannot be ruled out. For this to occur, however, substantial acceleration in innovation pace and scope would need to take place (see Chapter 3 – Innovation).

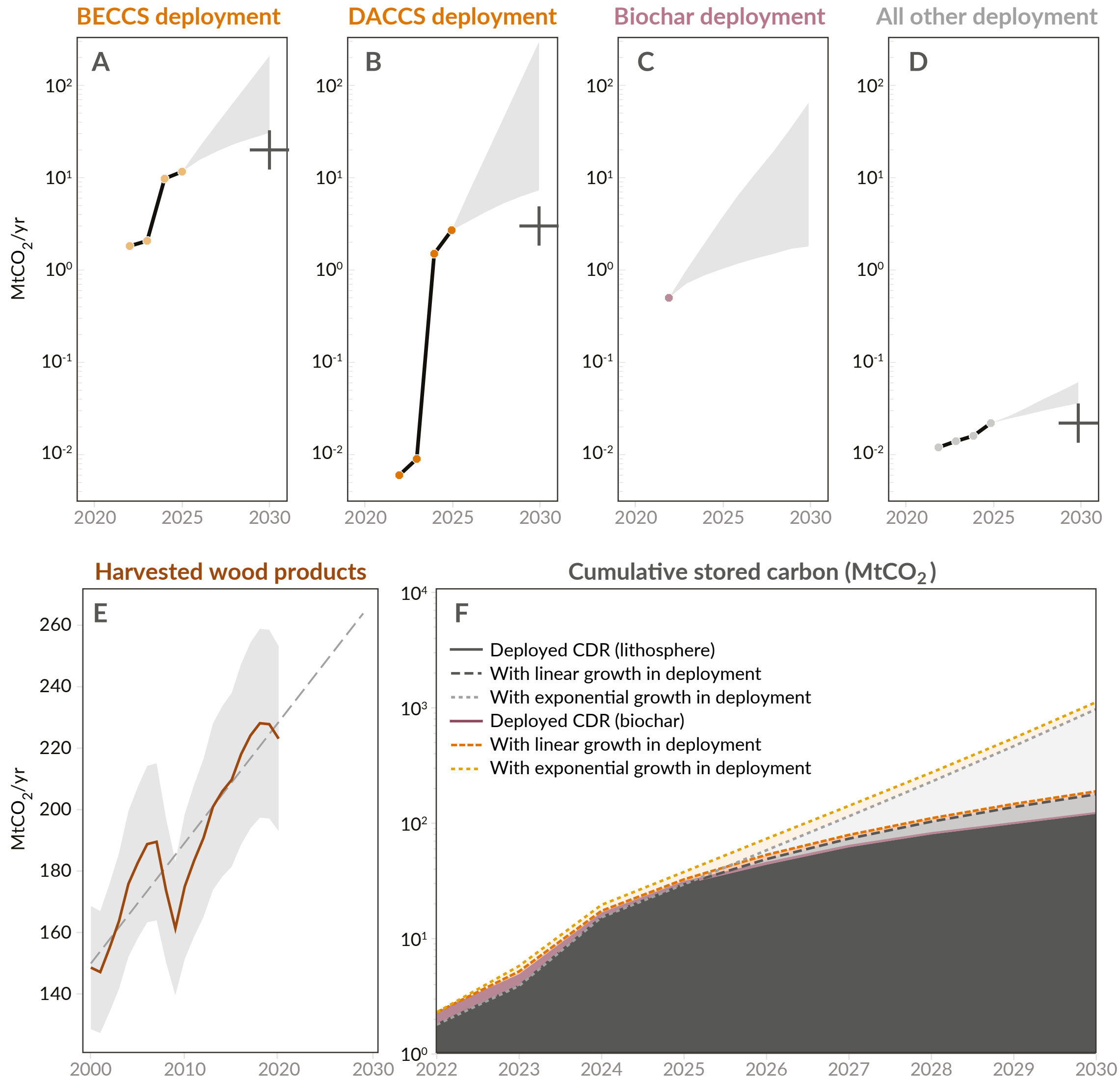

Figure 6.4. *(A-D) Deployment of various methods for generating carbon sinks, measured in $MtCO_2$ per year. Grey projections indicate a lower (linear) and upper (exponential) extrapolation of 2020-2025 deployment data. The grey crosses indicate 2030 deployment if only currently in-development projects are completed. (E) Harvested wood product production, measured in $MtCO_2$ per year, with a linear projection to 2030, with 9-95% uncertainty in grey. (F) Cumulative stored carbon by storage reservoir/pool, given observed deployment, continued linear deployment and continued exponential deployment, measured in $MtCO_2$. Definitions: Bioenergy with Carbon Capture and Storage (BECCS); Carbon Dioxide Removal (CDR); Direct Air Carbon Capture and Storage (DACCS).*

6.4 Looking ahead

Improving estimates of CDR deployment requires issues around measurement, data and reporting to be resolved.

Developing an accurate estimate of CDR deployment is necessary if we want to achieve the goals of the Paris Agreement, as without an accurate deployment baseline it is challenging to determine if we are generating sufficient volumes of CDR (see Chapter 8 – The CDR gap). There are three main barriers that need to be overcome to ensure we can maintain an accurate CDR deployment estimate going forward. Firstly, agreement will need to be reached on how to accurately measure CDR from conventional CDR methods on land and CDR achieved through other managed land based activities. Second, a central repository for CDR project data will need to be built. Thirdly, CDR project reporting will need to be standardised (see Chapter 9 – Future assessments).