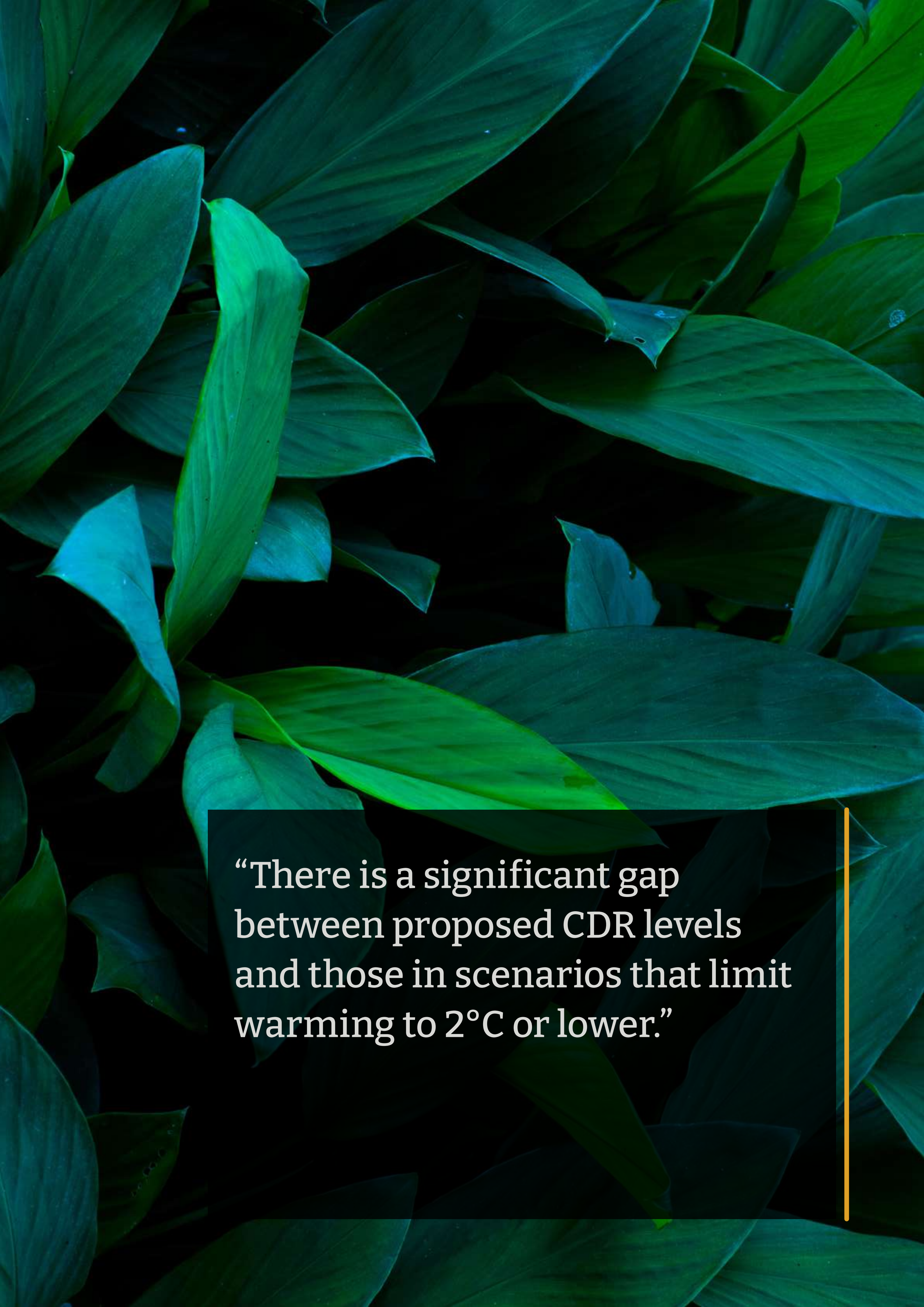

"There is a significant gap between proposed CDR levels and those in scenarios that limit warming to 2°C or lower."

Chapter 8 | The CDR gap

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We are not on track to meet the Paris temperature goal, in terms of either current or proposed Carbon Dioxide Removal (CDR). Closing the gap means expanding conventional CDR on land and rapidly scaling up novel CDR at the same time as urgently cutting emissions.

Box 8.1 Key findings

- In 2030, global scenarios that limit warming to 2°C or lower indicate additional Carbon Dioxide Removal (CDR) of 0.96 (0 to 3.4) $GtCO_2$ per year, compared with 2020. By contrast, countries have pledged an additional 0.1 to 0.65 $GtCO_2$ by 2030 in their Nationally Determined Contributions (NDCs) – a range that corresponds to unconditional and conditional NDCs. This suggests there is already an emerging CDR gap by 2030.

- In 2050, global scenarios that limit warming to 2°C or lower indicate additional CDR of 4.8 (0.58 to 13) $GtCO_2$ per year, compared with 2020. However, countries have only proposed an additional 1.5 to 2.3 $GtCO_2$ of CDR per year by 2050 in their long-term mitigation strategies. Only a minority of countries have provided transparent, quantifiable scenarios for CDR in long-term mitigation strategies so far. This implies a far more substantive CDR gap in 2050.

- This report distinguishes conventional CDR on land from novel CDR. The former includes afforestation, reforestation and forest management; the latter includes Bioenergy with Carbon Capture and Storage, Direct Air Carbon Capture and Storage, biochar, enhanced rock weathering and coastal wetland (blue carbon) management. Considering these separately is important to highlight the scale-up challenge.

- Global scenarios that limit warming to 2°C or lower scale up conventional CDR on land by a factor of 1.3 (0.95 to 2.2) by 2030 and factor of 2 (0.19 to 3.5) by 2050, compared with 2020.

- Countries plan to maintain or slightly increase current conventional CDR on land until 2030 according to their NDCs. This implies an increase by a factor of 1.1 to 1.3, compared with 2020 (for unconditional and conditional pledges, respectively). Few countries have submitted plans for scaling up conventional CDR on land by 2050, but those that have imply an increase by a factor of 2.7 to 4.2, compared with 2020.

- Global scenarios that limit warming to 2°C or lower involve scaling up novel CDR by a factor of 30 (0 to 540) by 2030 and a factor of 1,300 (260 to 4,900) by 2050, compared with 2020.

- So far, no countries have pledged to scale novel CDR by 2030 in their NDCs. Long-term mitigation strategies suggest some novel CDR deployment by 2050, increasing by a factor of about 300 compared with 2020.
- The next decade is crucial for novel CDR. Failure to create momentum in this formative phase will contribute to a widening gap by 2050 and beyond.
- Achieving the Paris temperature goal with only a small expansion of CDR is possible, but moves further out of reach every year in which greenhouse gas emissions do not fall substantially.

8.1 Components of the CDR gap

For the first time, we can compare current and proposed Carbon Dioxide Removal (CDR) with what would be required in different scenarios that meet the Paris temperature goal.

CDR is required, alongside ambitious emissions reductions, to meet the Paris temperature goal (see Chapter 1 – Introduction and Chapter 7 – Scenarios). But there are few dedicated efforts to track the development of CDR policy and deployments[226, 244], and none that estimate the size of the "CDR gap". It remains unclear to date, therefore, whether current efforts are on course to deliver enough CDR.

There are different components of the CDR gap. Here, we present a systematic comparison of *current*, *proposed* and *scenario-based* CDR to assess how on track we are to meet the Paris temperature goal. "Current CDR" refers to current levels of CDR deployment (see Box 8.2 and Chapter 6 – Deployment). "Proposed CDR" refers to future CDR levels inferred from country submissions to the United Nations Framework Convention on Climate Change (UNFCCC). These are the Nationally Determined Contribution (NDC) 2030 pledges, and scenarios in the long-term strategies through to 2050 (see Chapter 5 – Policymaking). Finally, "scenario-based CDR" refers to benchmarks of future CDR in scenarios that limit warming to 2°C or lower, drawn from the scientific literature (see Chapter 7 – Scenarios).

The aim of this chapter is to analyse the existence and size of a potential CDR gap, drawing on strands of information from across the report and building on efforts elsewhere that assess the ambitions and actions of countries in meeting the temperature goal of the Paris Agreement[227,228].

Current CDR

The assessment of current, proposed and Paris-consistent CDR requires a careful alignment of different data sources (Box 8.2) and definitions. In this assessment, we have developed a new analysis of current CDR (see Chapter 6 – Deployment). We begin with the net annual forest land sink as reported by countries in their national inventories, including harvest, regrowth and afforestation/reforestation, but excluding deforestation (taking the 2000-2020 average)[191]. Across the report, we refer to this as "conventional CDR on land", and it mainly consists of CO_2 capture and storage in forests and wood products (see Chapter 1 – Introduction for definitions of "conventional" and "novel" CDR).

An important implication of using the forest sink from national inventories is that it differs from estimates derived from global bookkeeping models developed in the scientific literature[150,229,230]. This is due to differences in how “anthropogenic” emissions and removals are defined and accounted for. National inventories for land use, land-use change and forestry (LULUCF), following the Intergovernmental Panel on Climate Change (IPCC) Guidelines[231], use an area-based approach that includes all or most of the emissions and removals occurring on land that countries consider managed. The concept of managed land used by countries may be broad, for example including parks and protected areas. Furthermore, national inventories, which are largely based on direct observations, typically include the combined impacts of both direct and indirect effects on managed land. In contrast, the bookkeeping model approach separates (1) direct emissions and removals from anthropogenic drivers (e.g. land-use change, harvest, regrowth) and (2) indirect emissions and removals due to changes in environmental conditions (e.g. fertilisation from rising atmospheric CO_2, climate change, nitrogen deposition).

In this chapter – as well as in Chapter 6 (Deployment) and Chapter 7 (Scenarios) – we remove indirect effects, aligning our measurement of conventional CDR on land with the bookkeeping model approach and the definition of CDR established in Chapter 1 (Introduction). To remove indirect effects, we use the OSCAR Earth system model, following conventions established in the land-use emissions literature[150,222,230]. This conversion reduces the estimate of conventional CDR on land to 2.0 ± 0.9 $GtCO_2$ per year, down from the original estimate (including indirect effects) of 6.4 ± 2.8 $GtCO_2$ per year, as reported in national inventories (Chapter 6 – Deployment). This is smaller than the comparable average estimate derived from bookkeeping models of 3.1 ± 0.9 $GtCO_2$[232], likely owing to those models' inclusion of more detailed processes (notably of shifting cultivation) that simulate larger overall gross emissions and removals. The removal of indirect effects has implications for the other sources of data in the analysis, which we discuss in subsequent sections. Conventional CDR on land is uncertain to a high degree (approximately ±50%), although five-year averages have been relatively stable since 2000.

Anthropogenic activity on land drives emissions from deforestation, as well as removals. In this analysis, we isolate only the removals. Eliminating global deforestation is a critical condition for achieving the Paris temperature goal, but it is not discussed here[233].
To the estimate of conventional CDR on land we add the gross annual storage from “novel CDR” projects. These include Bioenergy with Carbon Capture and Storage (BECCS), Direct Air Carbon Capture and Storage (DACCS), biochar, enhanced rock weathering and coastal wetland (blue carbon) management. Only a small component of total current CDR is from such novel CDR methods (0.002 $GtCO_2$ per year).

The resulting estimate of total current CDR is 2.0 $GtCO_2$ per year, of which 99% is conventional CDR on land. For comparison, total net greenhouse gas (GHG) emissions as a result of human activity – including removals as well as emissions from deforestation in the land sector – were 59 $GtCO_2e$ in 2019[1].

Proposed CDR

Based on the available information, national policymaking on CDR is in its infancy, and few countries have proposed a significant scaling of CDR in documents submitted to the UNFCCC. This finding is based on a qualitative analysis of policy activity in leading countries (see Chapter 5 – Policymaking) and a quantitative assessment of NDCs and long-term mitigation strategies (see Box 8.2).

The NDCs indicate that countries plan to slightly increase current levels of conventional CDR on land up to 2030. Unconditional pledges in the NDCs amount to approximately 2.1 $GtCO_2$ per year in 2030, while conditional pledges amount to 2.6 $GtCO_2$ per year (see Box 8.2 for the differences between conditional and unconditional pledges). Many countries pledge to reduce deforestation emissions, but only a few pledge to increase forest sinks. Together with a few countries that project a decline in their sinks, an overall small net increased in conventional CDR on land is implied by the NDCs. No countries pledge a significant upscaling of novel CDR methods in their NDCs.

Nonetheless, a lack of transparency hinders assessment: many countries indicate that the LULUCF sector is a component of their pledge, but few provide sufficient information to fully quantify this contribution, particularly in terms of the forest sink, potentially leading to an underestimate[153, 234]. To date, no countries have included novel CDR in their NDCs, even if some mention – but do not quantify – methods such as coastal wetland management or components of CDR such as Carbon Capture and Storage in their qualitative description of planned mitigation efforts. The relative lack of attention given by policymakers to novel CDR is further evidenced by the limited number of BECCS, DACCS and biochar projects in the pipeline. Currently announced projects will amount to just a small addition of 0.009 $GtCO_2$ per year in 2025, on top of existing capacity (see Chapter 6 – Deployment).

Out to 2050, the long-term mitigation strategies indicate that governments are starting to consider a wider portfolio of methods beyond conventional CDR on land. Unfortunately, only a limited number of countries have published long-term mitigation strategies (unlike NDCs, countries are not obligated to publish such strategies under the Paris Agreement; see Box 8.2). Further, the strategies and scenarios in these documents are not formal policy commitments by countries but, rather, illustrate how governments may choose to mitigate emissions in the longer term and, in particular, how net-zero emissions could be reached. Many of those submitted contain ambiguities and lack transparency. As a result, the long-term mitigation strategies are a pragmatic, but very imperfect, starting point for an assessment of proposed removals up to 2050.

Of the 53 long-term mitigation strategies submitted by the end of September 2022, only 22 outline mitigation scenarios with quantifiable CDR levels in 2050. Taking the highest combined estimate of CDR from these scenarios, removals total about 2.9 $GtCO_2$ per year in 2050, of which the majority (78%) is conventional CDR on land. The lowest estimate is 2.1 $GtCO_2$ per year, of which 70% is conventional CDR on land. The range reflects the differing scenarios outlined by governments, which have different balances of emission reductions versus CDR deployments.

Box 8.2 Sources used to estimate the CDR gap and their uncertainties

Current Carbon Dioxide Removal (CDR) in this assessment is based on the forest land sink in national greenhouse gas inventories, taking the 2000-2020 average of ~2.0 $GtCO_2$ per year compiled in Grassi et al.[191]. This is combined with a database of existing Bioenergy with Carbon Capture and Storage, Direct Air Carbon Capture and Storage, biochar, enhanced rock weathering and coastal wetland (blue carbon) management projects (see Chapter 6 – Deployment for further details). There are large uncertainties in land-based removals due to data limitations in inventories and complex impacts of both human and natural drivers. Further, there are uncertainties in the number of known novel CDR projects (limited data is available for projects in China, for instance) and their verified levels of storage.

Proposed CDR levels are based on countries' Nationally Determined Contributions (NDCs) and long-term mitigation strategies, both of which are submitted by countries to the United Nations Framework Convention on Climate Change under the Paris Agreement. Private sector announcements are not included here, although early indications suggest they may be substantial (see Chapter 3 – Innovation).

A large amount of literature is dedicated to analysing the NDCs and their implications for the land use, land-use change and forestry flux in 2030, which requires a number of assumptions to be made[152,153,234,235]. Since this chapter focuses on the forest land sink only, we take the 2011-2020 average forest sink from Grassi et al. (2022)[191] as the baseline for removals in the NDCs. We then document where countries commit to additional specific removals or changes to the forest sink in their NDCs, using all documents available by June 2022 following the method of Grassi et al. (2017)[153]. "Conditional" pledges are the sum of pledges that would be fulfilled on the condition that stated actions are taken by other countries (e.g. some countries base their pledges on the condition that they are provided with climate finance or assistance). "Unconditional" pledges refer to those that would be taken regardless of action in other countries.

Proposed CDR in 2050 is quantified using the scenarios in the long-term mitigation strategies (also known as the Long-term Low Emissions Development Strategies, or LT-LEDS). We build on recent efforts to summarise the 2050 CDR levels described in these documents[149,236], finding that as of September 2022 such information exists for most European Union countries, the Russian Federation and the United States, but few others. We extract levels of CDR by 2050 from the underlying scenarios in the long-term mitigation strategies, where available, excluding all "business as usual" or "no policy" scenarios in order to have a comparable set that incorporates climate action. Some large emitters such as China, India and Indonesia have submitted a long-term mitigation strategy but do not provide sufficient information to quantify CDR efforts, while many others have yet to submit one.

In their scenarios, most countries describe the net flux of emissions and removals, rather than removals only. For simplicity, we assume that no deforestation occurs in 2050 under these scenarios and therefore count these net fluxes as removals. This is supported by the fact that countries with high current levels of deforestation, such as Brazil, the Democratic Republic of the Congo, and Indonesia, do not have a quantified long-term mitigation strategy, while other countries with lower current levels of deforestation that do have a quantified scenario, such as Cambodia and Colombia, aim to achieve zero deforestation in their long-term strategies. Of course, this likely underestimates total removals from these countries in 2050, as a certain baseline of emissions on land will always occur, but here we opt for a transparent and simple approach to render the long-term mitigation strategy data comparable with proposed and scenario-based CDR.

The NDCs and long-term strategies are oriented around national inventories and hence include indirect anthropogenic effects, such as CO_2 fertilisation. We therefore remove indirect effects in the NDCs and long-term strategies to render them comparable with the estimates of current and scenario-based CDR. We do this by distinguishing (1) maintained current sinks and (2) newly proposed sinks in the NDC pledge or long-term strategy scenario. These can be distinguished from the document texts or by cross-referencing them with current national inventories. For (1), we apply the ratio of direct to direct and indirect removals (2.0/6.4), as identified in Chapter 6 (Deployment). For (2), we preserve the original value, as newly proposed afforestation or regeneration implies largely direct removals. For example, the Russian Federation's long-term strategy proposes to expand the current flux of ~650 $MtCO_2$ per year to 1,200 $MtCO_2$ per year; we assume a direct current sink of ~200 $MtCO_2$ per year (650 × (2.0/6.4)), plus an additional 550 $MtCO_2$ per year of direct removals, for a total of 750 $MtCO_2$ per year. We apply a global ratio of direct to direct and indirect removals, which may obscure differing contributions of indirect effects by region or biome (an important issue for future research).

Scenario-based CDR levels are based on scenarios drawn from the integrated assessment model (IAM) literature. These scenarios depict alternative future pathways of how the global energy and land-use system can evolve to limit global temperature rise to 1.5°C and 2°C. We use the Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC AR6) IAM scenario database, scenario categories C1-C31. These categories have varying probabilities of limiting temperature rise, as well as different levels of peak warming (see Table 7.1 in Chapter 7 – Scenarios). Not all the scenarios are necessarily consistent with the goal of the Paris Agreement. Collectively, we refer to all C1-C3 scenarios as "2°C or lower" scenarios.

Scenarios that limit warming to 1.5°C or 2°C

The amounts of CDR required to limit warming to 2°C or lower are represented here using integrated assessment model scenarios (see Box 8.2 and Chapter 7 – Scenarios). A consistent characteristic of these scenarios is that they all feature multiple gigatonnes of carbon removals annually. However, the amount of CDR in scenarios varies considerably, shaped by a number of factors (see Chapter 7 – Scenarios, Section 7.3).

Table 8.1 depicts the additional CDR by 2030 and 2050 projected across all the scenarios considered. In the second half of the century, conventional CDR on land tends to saturate or even decline, while most of the growth then occurs through novel CDR methods such as BECCS and DACCS (see Figure 7.1 and Table 7.2 in Chapter 7 – Scenarios).

Table 8.1. *Additional Carbon Dioxide Removal (CDR) in scenarios from 2020 to 2030 and 2050. 2°C or lower scenarios are reported as the median and 5-95th percentiles. In the lower range of some of these scenarios, conventional CDR on land actually decreases compared with 2020, explaining the negative numbers. The additional conventional CDR on land in the long-term mitigation strategies(*) is based on the difference between the land use, land-use change and forestry flux in country scenarios versus their latest national inventories in 2020, converted to remove indirect effects.*

Scenarios	Additional conventional CDR on land from 2020 (GtCO2 per year)		Additional novel CDR from 2020 (GtCO2 per year)		Additional CDR (total) from 2020 (GtCO2 per year)	
	2030	2050	2030	2050	2030	2050
2°C or lower scenarios	0.8 [-0.11 - 3]	2.5 [-1.8 - 6.2]	0.059 [0 - 1.1]	2.7 [0.52 - 9.7]	0.96 [0 - 3.4]	4.8 [-0.58 - 13]
Focus on Demand Reduction	1	2.3	0	0	1	2.3
Focus on Renewables	2.7	4.1	0.14	0.91	2.9	5.1
Focus on Carbon Removal	0.66	4.0	0.95	3.5	1.6	7.4
Nationally Determined Contributions (NDCs)	[0.1 - 0.65]	NA	0	NA	[0.1 - 0.65]	NA
Long-term mitigation strategies	NA	[0.9 - 1.7]*	NA	-0.6	NA	[1.5 - 2.3]*

In addition to the full set of scenarios, we highlight **three illustrative scenarios**, which depict different ways to meet the Paris temperature goal (see Chapter 7 – Scenarios). These scenarios do not cover the whole range of possible scenario futures, but they illustrate that key mitigation choices deeply influence how much CDR will be required by mid-century.

- *Focus on Demand Reduction* – Global energy demand is rapidly reduced through improvements in the efficiency of end-use devices and service delivery. This scenario limits warming to 1.5°C with a large contribution from conventional CDR on land (4.8 $GtCO_2$ in 2050) but no additional CDR deployments from novel CDR.

- *Focus on Renewables* – This scenario limits warming to 1.5°C by implementing a rapid supply-side transformation, based on the deployment of increasingly cost-competitive renewable energy technologies. It also envisions a large contribution from conventional CDR on land (6.7 $GtCO_2$ in 2050), but this is complemented by removals from BECCS (0.91 $GtCO_2$ in 2050).

- *Focus on Carbon Removal* – This scenario holds warming to 1.5°C but envisions a slower transformation of the energy supply system with an incomplete phase out of fossil fuels. This scenario also has a large contribution from conventional CDR on land (6.3 $GtCO_2$ in 2050), but significantly more CDR from BECCS and DACCS than in the other illustrative scenarios (3.5 $GtCO_2$ in 2050). This scenario does not feature extreme scaling behaviour for novel CDR but is close to the median of C1 scenarios

All three illustrative scenarios involve immediate, rapid and sustained emission reductions, reaching a peak in global net GHG emissions in 2020 or shortly after, placing them on a path to net-zero CO_2 emissions between 2050 and 2065 (see Figure 7.2 in Chapter 7 – Scenarios). *Focus on Demand Reduction* reduces gross GHG emissions by 48% between 2020 and 2030, whereas *Focus on Renewables* and *Focus on Carbon Removal* reduce them by 31% and 33%, respectively.

8.2 The CDR gap: Conventional CDR on land

Almost all scenarios that limit warming to 2°C or lower expand conventional CDR on land. Yet even maintaining current conventional CDR on land requires dedicated policies and management.

Figure 8.1 brings together estimates of current and proposed levels of CDR and compares these with 2°C or lower scenarios. In this comparison, we observe that current levels of CDR (2.0 $GtCO_2$ per year) need to be at least maintained in the coming decades: all scenarios that reach the Paris Agreement goal require a baseline level of removals to counterbalance expected residual emissions. Maintaining current levels of CDR – which, as it stands, are almost entirely attributable to conventional CDR on land – is a precondition for limiting warming to 2°C or lower. Yet the majority of scenarios do not just maintain current conventional CDR on land but expand it in the coming decades (Table 8.1).

Insofar as we can infer from the NDCs, countries indeed plan to slightly increase current conventional CDR on land. However, these increases fall short of those projected in the scenarios. Proposed CDR from conditional NDCs reaches 2.6 $GtCO_2$ per year in 2030, with 0.65 $GtCO_2$ of additional CDR entirely from conventional CDR on land (the NDCs do not include any novel CDR). In comparison, the further expansions in conventional CDR on land in our three focus scenarios by 2030 are quantified at an additional 0.66 $GtCO_2$ per year (*Focus on Carbon Removal*), 1.0 $GtCO_2$ per year (*Focus on Demand Reduction*) and 2.7 $GtCO_2$ per year (*Focus on Renewables*). These all give rise to a potential near-term ambition gap. Our focus scenarios characterise the range that most scenarios in the IPCC WG3 database span, but we note the existence of scenarios with even higher deployments of conventional CDR on land by 2030.

Further, there is a clear signal in the long-term strategies that forest sinks are a key component of net zero targets. Among those countries with quantifiable scenarios, most plan to at least maintain current forest sinks, while there are several prominent examples of ambition to expand these removals, such as scenarios from the United States (an increase from 0.8 $GtCO_2$ per year in 2020 to 1.3 $GtCO_2$ per year in 2050) and the Russian Federation (an increase from 0.7 $GtCO_2$ per year in 2020 to 1.2 $GtCO_2$ per year in 2050). However, these country estimates include indirect effects; when indirect effects are removed and country scenarios are aggregated, newly proposed conventional CDR on land is much smaller, at 0.9-1.7 $GtCO_2$ per year. This compares to expansion in our three focus scenarios quantified at 3.9 $GtCO_2$ per year (*Focus on Carbon Removal*), 2.3 $GtCO_2$ per year (*Focus on Demand Reduction*) and 4.1 $GtCO_2$ per year (*Focus on Renewables*). Nonetheless, a number of countries with large land areas and potentially significant ambitions regarding other CDR methods are absent from this 2050 data, including Brazil, China and India, whose inclusion would very likely significantly increase proposed CDR levels for 2050.

Countries will need to implement land-use policies and forest management practices just to maintain current conventional CDR on land. These removals are sustained in managed forests by balancing growth and harvest, shifting carbon stocks to long-lasting wood products, and promoting afforestation and reforestation. Forest fires, pests and other disturbances will increasingly threaten conventional CDR on land owing to global warming, requiring further interventions (e.g. thinning, prescribed fires) to preserve these removals[237]. Very high uncertainties in current (and hence future) levels of conventional CDR on land mean that it may not be precisely known if these removals are on track to match requirements in the scenarios.

Further, countries may have to deal with a weakening of indirect effects, such as CO_2 fertilisation, as atmospheric CO_2 levels stabilise. In Paris-relevant scenarios, indirect effects could be halved by 2050[150]. It is unclear whether such a weakening is accounted for in national long-term strategies. If not, countries may find that they cannot reach net zero under their current plans for scaling conventional CDR on land. On the other hand, if countries do not reduce emissions in line with the Paris temperature goal, indirect effects would be preserved to some extent, but forest sinks would instead be threatened by climate impacts. The future robustness of forest sinks is therefore far from guaranteed.

8.3 The CDR gap: Novel CDR

Almost all scenarios that limit warming to below 2°C require novel CDR to be scaled up, but countries currently have few firm plans to do this.

Almost all scenarios that limit warming to below 2°C do not just increase conventional CDR on land but also scale up novel CDR rapidly in the coming decades. In the case of *Focus on Renewables* and *Focus on Carbon Removal*, novel CDR is already implemented by 2030, amounting to 0.14 and 0.95 $GtCO_2$ per year, respectively. Across all below 2°C scenarios, there is a median of 0.059 (0 to 1.1) $GtCO_2$ per year of novel CDR by 2030. While these numbers may appear small, they mean growing novel CDR deployment by a factor of 30 (0 to 540), within seven years.

Although many pathways that limit warming to below 2°C highlight stark demands for novel CDR even in the short- to mid-term, countries so far only have limited plans to scale it up (Chapter 5 – Policymaking), and the NDCs do not include any such plans. However, the innovation literature highlights that the early years of technology development (the "formative phase") are consequential in determining how fast and to what level novel CDR can be scaled in the longer term[238]. The extent of early deployment of novel CDR over the next decade is therefore crucial, as a failure to create momentum in this formative phase will contribute to a widening gap by 2050 and beyond.

Looking to 2050, the most ambitious scenarios in the long-term mitigation strategies describe total novel CDR removals of 0.6 $GtCO_2$ per year, mainly driven by the United States (0.5 $GtCO_2$ per year). Again, this falls short of scale-up rates in the scenarios, which range from novel CDR levels of 0.91 (*Focus on Renewables*) to 3.5 $GtCO_2$ per year (*Focus on Carbon Removal*), or 450 to 1,750 times larger than current levels. Across the entire sample of below 2°C scenarios, many scale up CDR even more by 2050 – with a median of 1,300 times (260 to 4,900) greater than today's level.

Only 22 countries have so far submitted quantifiable long-term strategies. While it is possible that the shortfall of novel CDR could be made up by new countries submitting long-term mitigation strategies with underlying scenarios, so far most country scenarios have a far greater focus on conventional CDR on land than on novel CDR. If we include indirect effects (as is standard practice in reporting by countries), then just 16-21% of removals in the long-term strategies come from novel CDR. This suggests that a serious "CDR ambition gap" is emerging: few countries have developed transparent plans to scale novel CDR, leaving a significant shortfall between proposed and scenario-based CDR by 2050.

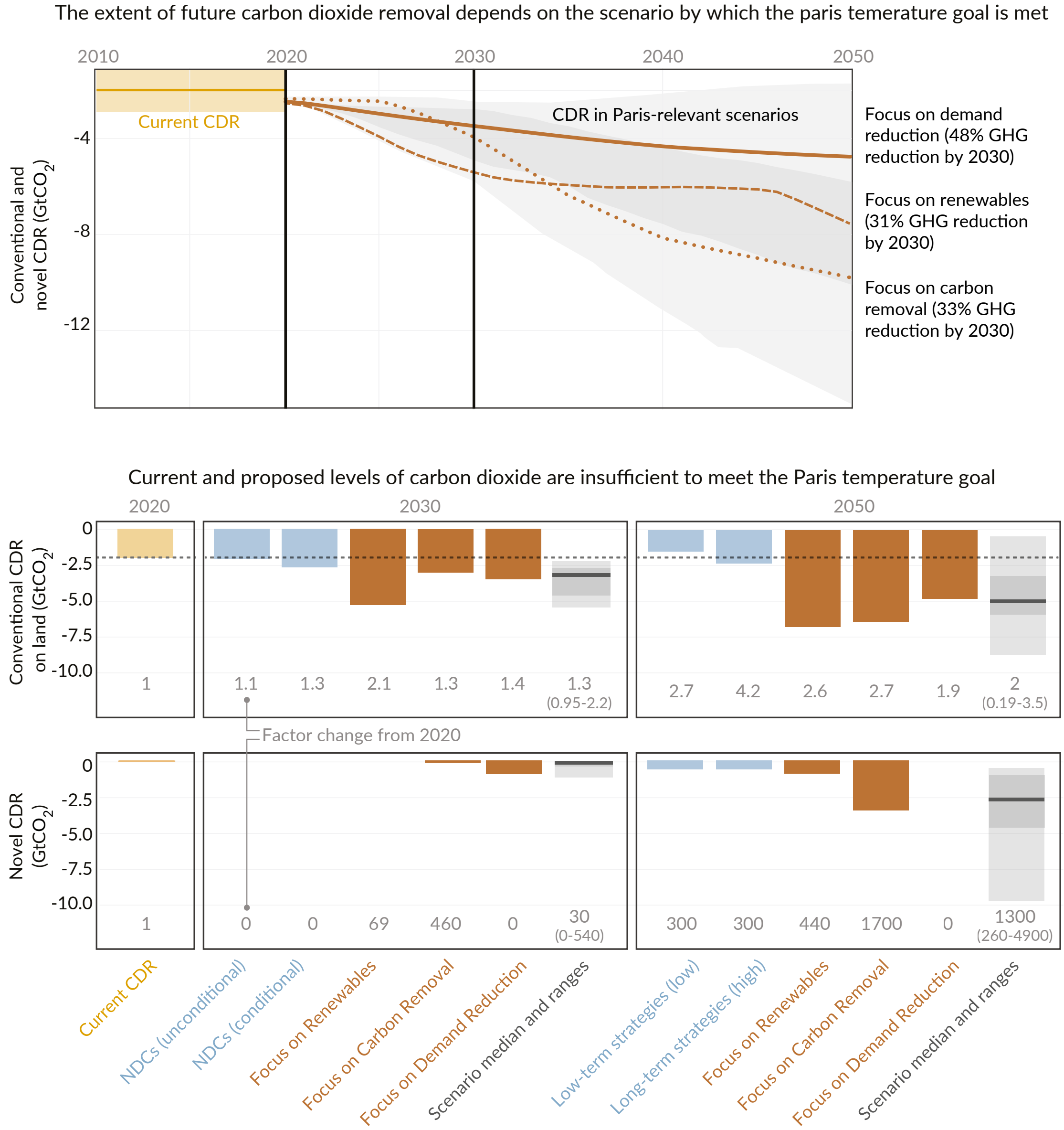

Figure 8.1. *The CDR gap. Carbon Dioxide Removal (CDR) includes conventional CDR on land (the managed forest land sink) plus novel CDR (gross removals from Bioenergy with Carbon Capture and Storage, Direct Air Carbon Capture and Storage, biochar, enhanced rock weathering and coastal wetland (blue carbon) management). Conventional CDR on land estimates exclude sinks that are treated as "natural" or "indirectly human induced" in the global carbon budgeting literature. In the upper panel, the blue line depicts total current CDR and the shaded blue area indicates the uncertainty. The orange shaded area depicts the 5th to 95th and 25th to 75th percentile of Intergovernmental Panel on Climate Change C1-C3 scenarios that limit warming to below 2°C. The orange lines depict three Focus Pathways that limit warming to 1.5°C, based on varying assumptions of action and technology diffusion. The emission reductions described for each scenario in the top panel refer to gross greenhouse gas (GHG) emissions. The lower panels show the contributions of conventional CDR on land and novel CDR in the Focus scenarios, as well as the overall scenario median and ranges (as in the top panel), versus estimates of current and proposed CDR from Nationally Determined Contributions (NDCs) and long-term mitigation strategies. It also depicts the relative scale-up of each category compared with levels in 2020. In the case of conventional CDR on land in the*

long-term strategies, this refers to the difference between the land use, land-use change and forestry flux in country scenarios versus those countries' latest national inventories in 2020. In the case of the scenario ranges, the median and 5th to 95th factor change is shown.

8.4 A low-CDR world

A few scenarios meet the Paris temperature goal with only a small expansion of CDR, but they require aggressive reductions in GHG emissions, which we are not on track to achieve.

There are some scenarios that project comparatively modest increases in current conventional CDR on land, while avoiding novel CDR altogether. These scenarios lie at the lowest end of total CDR requirements across the 21st century and include the *Focus on Demand Reduction* illustrative scenario, which slightly more than doubles current conventional CDR on land to 4.8 GtCO_2 per year by 2050. A comparison of current and proposed CDR with these scenarios would suggest that the overall CDR gap is manageable, so long as efforts to expand current conventional CDR on land to meet these levels are successful. However, a key feature of these low-CDR scenarios is that they involve highly ambitious and rapid emission reductions. *Focus on Demand Reduction* requires an immediate implementation of climate policies leading to a global emissions peak in 2020, followed by a rapid pathway to net-zero CO_2 emissions by 2059[239]. Total gross GHG emissions between 2020 and 2030 are reduced by 48% (30GtCO_2eq) in this scenario.

To what extent is such a pathway still within reach? According to the latest assessment of the "emissions gap", current policy scenarios project emissions of 58 GtCO_2 in 2030, while unconditional and conditional NDC scenarios project emissions of 55 and 52 GtCO_2, respectively[240]. In other words, global GHG emissions are set to remain approximately stable between now and 2030 if the unconditional NDCs are implemented or to slightly decrease if conditional NDCs are implemented. Furthermore, as of 2021, global GHG emissions have begun to grow again[240,241]. This suggests that key milestones for planning ambitious mitigation pathways, implementing policies and reducing emissions are not being met, pushing a low-CDR worldfurther out of reach.

8.5 Closing the CDR gap

Closing the CDR gap requires us to rapidly reduce emissions, expand conventional CDR on land rapidly scale up novel CDR. If novel CDR is not supported now, during the formative phase of technology development, countries risk a widening CDR gap by 2050. For every year that GHG emissions do not fall substantially, our dependence on CDR increases.

The scenario literature unequivocally highlights that reducing GHG emissions to a small fraction of today's levels is the foundation for limiting global temperature rise to 2°C or below. The faster this happens, the better the chance we have of scaling up CDR sustainably: lower cumulative and residual emissions will ultimately reduce the amount of CDR we require to reach net-zero GHG emissions and to achieve the Paris temperature goal (Chapter 7 – Scenarios).

For every year in which GHG emissions do not fall substantially, our dependence on

CDR increases and a low-CDR world is pushed further out of reach. Key milestones for implementing policies, peaking emissions and ultimately achieving the required emission reduction rates are being missed. As such, it is critical to redouble mitigation efforts but also to explore opportunities for integrated, cross-sector policies that can support both emission reductions and CDR upscaling. For instance, a food system transition to lower meat diets would lower "hard-to-abate" emissions in the agriculture sector that otherwise must be compensated for by CDR, while potentially freeing up space for forest sink removals[242,243]. Developing novel CDR is an important climate measure, given our increasing dependence on such technologies. The lack of comprehensive information, plans and priorities on novel CDR from countries is especially problematic given the long time horizon needed to safely scale up these methods (see Chapter 3 – Innovation). Scenarios already implement substantial novel CDR levels by 2050, reflecting matured BECCS, DACCS, biochar and enhanced rock weathering industries with technologies ready for widespread adoption. Achieving short- to medium-term milestones along the long road to these levels is therefore key, highlighting the need for increased research, investment and policy support for novel CDR.

Pathways that limit warming to 1.5°C or 2°C start scaling novel CDR before 2030. While levels of novel CDR may appear small, they imply substantial increases in deployments. Just 0.1 $GtCO_2$ removed by novel CDR in 2030 implies an increase in current levels by a factor of 50 by the end of the decade. Furthermore, the literature on technology upscaling has shown that the early, formative phases of technology development will strongly determine what contribution novel CDR can make to climate mitigation by mid-century[238]. If novel CDR does not receive support during this formative phase, ensuring that these technologies are ready to deliver significant removals in a few decades, countries risk a widening CDR gap by 2050. Ultimately, this report highlights three key criteria for closing the CDR gap. First, current conventional CDR on land needs to be expanded, likely requiring additional policies and the active management of forest sinks to protect removals from future climate impacts. Second, novel CDR needs to be developed and scaled to meet future possible needs, which will require active support and investment from countries. Third, and above all, our dependence on CDR needs to be limited by implementing stringent emission reductions as soon as possible.