



William F. Lamb,ⁱ Jan C. Minx,ⁱ Naomi E. Vaughan,ⁱⁱ Thomas Gasser,ⁱⁱⁱ Harry Smith,ⁱⁱ Rosa M. Roman-Cuesta,^{iv} Giacomo Grassi,^{iv} Julia Pongratz,^{v,vi} Stephen M. Smith,^{vii} Clemens Schwingshackl,^v Matthew J. Gidden,ⁱⁱⁱ Stephanie Roe,^{viii} Holly Buck,^{ix} Felix Schenuit,^x

ⁱ Mercator Research Institute on Global Commons and Climate Change

ⁱⁱ Tyndall Centre for Climate Change Research, University of East Anglia

ⁱⁱⁱ International Institute for Applied Systems Analysis

^{iv} Joint Research Centre of the European Commission

^v Ludwig-Maximilians-Universität München

^{vi} Max Planck Institute for Meteorology

^{vii} University of Oxford

^{viii} World Wide Fund for Nature

^{ix} University at Buffalo

^x German Institute for International and Security Affairs

Cite as: Lamb, W. F., Minx, J. C., Vaughan, N. E., Gasser, T., Smith, H., Roman-Cuesta, R. M., Grassi, G., Pongratz, J., Smith, S. M., Schwingshackl, C., Gidden, M. J., Roe, S., Schenuit, F., Buck, H. Chapter 9: The CDR gap. in **The State of Carbon Dioxide Removal 2024 – 2nd Edition** (eds. Smith, S. M. et al.). <https://www.stateofcdr.org>, doi:10.17605/OSF.IO/6V9RF (2024).



Chapter 9 | The CDR gap

Emission reductions continue to lag behind what is needed to meet the Paris temperature goal. There is an additional gap between national proposals for carbon dioxide removal (CDR) and scenarios that sustainably scale CDR to limit climate change.

Key insights

- Countries' nationally determined contributions propose an additional -0.05 to -0.53 Gt of carbon dioxide (CO_2) per year in conventional CDR (mostly afforestation/reforestation) by 2030, compared with 2020 levels of -2.1 (-1.5 to -2.7) GtCO_2 per year.
- So far, only 28 countries (counting the EU as one) have outlined their proposals for scaling CDR by 2050. If countries without proposals preserve current levels of conventional CDR, then an additional -1.9 to -2.3 GtCO_2 per year may be realized by 2050, compared with levels in 2020.
- Scenarios that limit global temperature rise to 1.5°C by dramatically reducing emissions while sustainably scaling CDR imply that an additional -1.0 to -2.9 GtCO_2 per year of CDR is needed by 2030, and an additional -2.3 to -7.4 GtCO_2 per year by 2050, compared with levels in 2020.
- There is therefore a *CDR gap* between national proposals and most scenarios consistent with the Paris temperature goal. However, the most ambitious proposals are close to the CDR levels required in a scenario where CDR requirements are minimized.
- The CDR gap is not a fixed quantity, but a range that reflects uncertainties and different judgments with respect to how society chooses to mitigate climate change. A critical uncertainty is how to consider the fact that global emissions did not decline in recent years, as was projected in scenarios. This implies that the CDR gap may be significantly larger than currently estimated.

Reductions in greenhouse gas emissions are not on track to meet the Paris temperature goal. This chapter investigates whether this is also the case for CDR. The first section describes the methods used to ascertain this and explains the concept of the CDR gap. Section 9.2 presents an estimate of the amount of CDR that is indicated in country proposals for 2030 and 2050. It goes on to compare this with the level of CDR required in scenarios that are consistent with the Paris temperature goal. The precise size of the gap between proposed CDR and Paris-consistent CDR is, however, dependent on several uncertain factors and assumptions, which are explored in Section 9.3. The final section looks at how the existing CDR gap can be closed.

9.1 The CDR gap concept

This report tracks the amount of CDR that countries are currently proposing compared with the amount required to meet the Paris temperature goal – this is the CDR gap.

The CDR gap is a measure of the difference between proposed CDR activities and the amount of CDR in scenarios that meet the Paris temperature goal. To calculate the CDR gap, this report estimates proposed CDR activities from country submissions to the UNFCCC describing how they will mitigate greenhouse gas emissions and reach net zero in the coming decades. The report then compares these proposed activities with the amounts of CDR in model scenarios that meet the Paris temperature goal while taking into account sustainability constraints. The report refers to these scenarios as *Paris-consistent scenarios*, as they limit warming to either below 1.5°C or 2°C in the 21st century (see Chapter 8 – Paris-consistent CDR scenarios).

The CDR gap concept is illustrated in Figure 9.1. The methods used to estimate the level of CDR that countries are proposing are described in Box 9.1, and how these estimates are then aligned with scenario data is described in Box 9.2. Box 9.3 highlights the key differences in this chapter compared with *The State of Carbon Dioxide Removal* 1st edition.

The CDR gap serves two functions: it highlights the amount of CDR required to reach the Paris temperature goal, and it facilitates tracking of progress towards this goal. This allows an understanding of how ambitious or sufficient national CDR proposals are; whether those national proposals can be achieved and with what costs; and whether countries overdepend on CDR in their mitigation strategies at the expense of deep emission reductions.

1. Different scenarios can be followed to reach the temperature goal of the Paris Agreement, all of which involve deep, near-term emissions reductions (which countries are far off track to achieve) complemented by carbon dioxide removal (CDR).

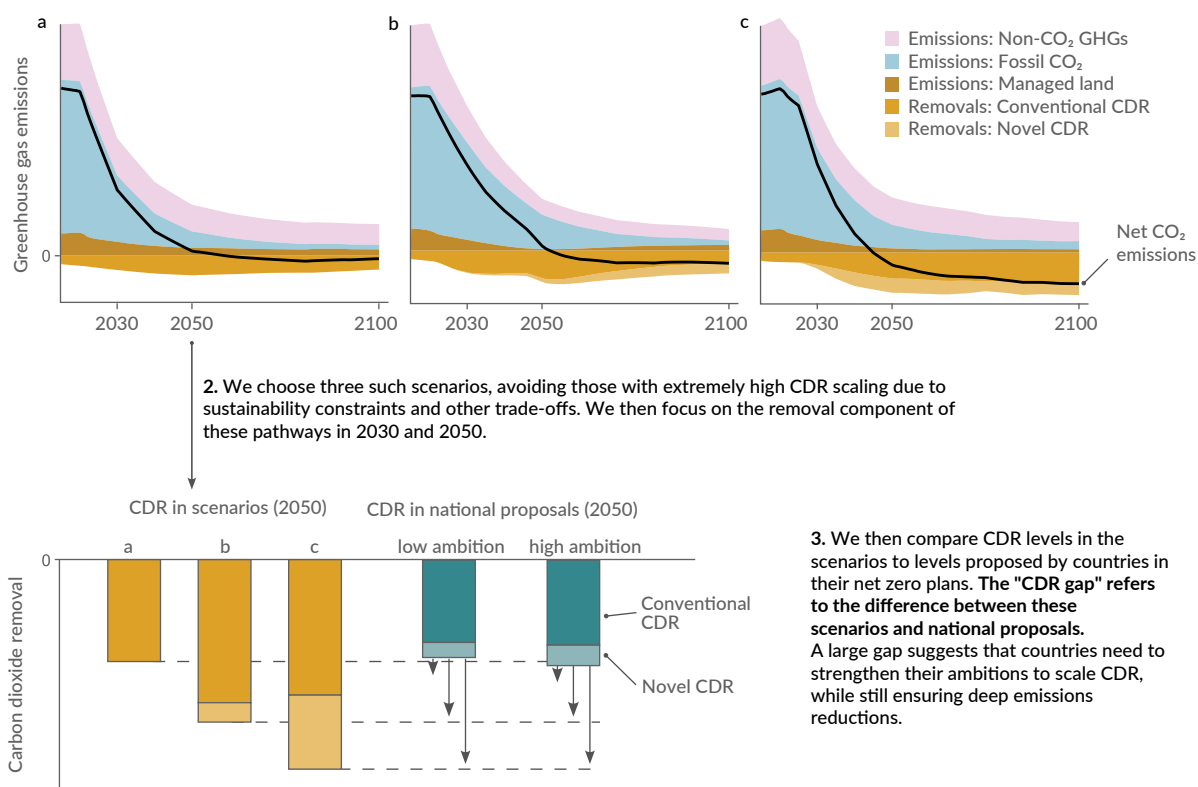


Figure 9.1 The carbon dioxide removal (CDR) gap concept. GHG = greenhouse gas.

Key considerations when calculating and interpreting the CDR gap

Quantifying the CDR gap involves making normative judgments about the appropriate pathway to take to mitigate climate change – notably, about how that pathway balances efforts to reduce emissions with efforts to scale up CDR. In other words, one could choose scenarios where CDR is scaled to very high levels and thereby discover a large gap when comparing these scenarios with national proposals. Conversely, one could choose scenarios with low levels of CDR and discover a smaller gap. This report addresses this, in part, by selecting three contrasting *focus scenarios* for the CDR gap analysis. Each of these scenarios represents a different pathway to reach the Paris temperature goal, with different levels and types of CDR scaling (Figure 9.1).

Scaling up CDR to very high levels would likely bring negative environmental, social and other sustainability impacts. A higher dependence on CDR in the future could also displace emission reduction efforts in the near term. A key factor in selecting the Paris-consistent focus scenarios was therefore to ensure that they sustainably scale CDR, according to the criteria established and discussed in Chapter 8 (Paris-consistent CDR scenarios). The chosen scenarios also prioritize deep and rapid emission reductions in the near term. It should be emphasized that the CDR gap is not a fixed quantity, but a range that reflects uncertainties and different judgments with respect to how society chooses to mitigate climate change.

In essence, this report compares national proposals against a set of scenarios that exhibit:

- Remaining cumulative carbon dioxide (CO₂) emission budgets that provide a 50% chance of limiting global temperature rise to 1.5°C by 2100 with no or limited temperature overshoot
- Relatively conservative levels of CDR
- High ambition in near-term emission reductions

Although this report's analysis specifically treats CDR separately from net emissions, this does not imply that the scaling of CDR methods will take place independently from other sector-based mitigation strategies. For instance, there are strong potential synergies and trade-offs between land-based CDR options, agricultural transitions and dietary shifts.⁴¹² Similarly, scaling up novel CDR methods such as direct air carbon capture with storage dovetails with strategies to achieve a deep decarbonization of the industry and aviation sectors.⁴¹³

Closing the CDR gap without reducing emissions will not achieve the Paris temperature goal. As such, the CDR gap, viewed in isolation, should not be misused or misinterpreted to delay emission reductions or downplay the need for such reductions. As illustrated in the three focus scenarios used in this analysis, there is a range of ways to reduce emissions; some pathways require more effort, more innovation or more societal change to reduce emissions, which can in turn lower the need for CDR. This interconnection between CDR and emission reductions at global, regional and sectoral levels is important to consider.

Types of CDR included in the gap analysis

The CDR gap analysis is oriented around the two categories of removals used throughout the report: conventional CDR and novel CDR (see Chapter 1 – Introduction, for definitions).

Conventional CDR. This refers to removals achieved through afforestation/reforestation and forest restoration, as well as other enhancements to the land sink via management of soils and vegetation (e.g. soil carbon sequestration in croplands and grasslands, agroforestry). A considerable amount of conventional CDR already occurs today, mostly through afforestation/reforestation, as documented in Chapter 7 (Current levels of CDR).

Novel CDR. This refers to methods such as direct air carbon capture with storage, bioenergy with carbon capture and storage, and biochar, which are in an early stage of development.

Both of these categories of CDR are found in the focus scenarios and in national proposals for scaling CDR. However, specific methods of CDR are represented to varying degrees. For example, afforestation/reforestation, bioenergy with carbon capture and storage, and direct air carbon capture with storage are commonly represented in the focus scenarios; in national proposals, afforestation/reforestation, forest management and soil carbon sequestration are more prevalent.¹⁵⁵

Box 9.1 Methods for estimating proposed CDR

Data sources. This analysis draws on documents submitted by countries to the UNFCCC. This includes nationally determined contributions, long-term strategies, and further national documents such as biennial update reports, national communications and forest reference emission levels. Documents up to COP28 (November 2023) were included in the analysis.

Levels of proposed CDR are often not transparently reported in the UNFCCC documents.^{154,155,414,415} In countries' proposals for reaching 2030 targets, novel CDR methods tend not to be included, but conventional CDR often is. However, for 2050 targets, many countries do include both types of CDR in their long-term strategies to reach net zero.

Analysis of 2030 targets. Information was compiled for 111 of 198 countries. Countries with high emissions were prioritized, while city states, small islands and arid countries with limited land-use emissions or removals were excluded. Two types of 2030 target exist, both of which are presented in the gap analysis: "conditional" targets, which would be fulfilled only with the support of other UNFCCC parties, and "unconditional" targets, for which no such conditions are described.

The analysis of conventional CDR focused on how countries reported contributions to their targets from the land use, land-use change and forestry (LULUCF) sector. Countries were grouped into three categories:

1. *Countries that provide a headline mitigation target with no specified contributions from the LULUCF sector: The analysis assumes that these countries preserve their 2011–2020 average levels of removals in the LULUCF sector.*
2. *Countries that specify the contribution of the LULUCF sector to their overall mitigation target but do not distinguish between removals and reductions in emissions relating to deforestation or land-use change: The analysis assumes that these countries preserve their 2011–2020 average proportions of removals to emissions in any changes they propose to their net LULUCF flux.*
3. *Countries that specify the contribution of the LULUCF sector as well as specific removal commitments: For these countries, the proposed removal figures were recorded. Where necessary, these figures were normalized against the country's 2011–2020 average (e.g. where commitments were given in terms of growth projections).*

For all countries, a consistent baseline of historic LULUCF emissions and removals was used, as provided by Grassi et al., 2022.³²²

Analysis of 2050 targets. Data were drawn from information compiled by Smith et al., 2022,¹⁵⁵ and Smith et al., 2024,³⁵¹ covering all 70 countries that have published long-term strategies. National documents are not available for all EU countries; therefore, EU-level totals were used instead, sourced from modelling studies by the European Commission.⁴¹⁶

A subset of countries was identified whose long-term strategies contain scenarios that transparently describe levels of conventional or novel CDR

by 2050. Countries often present a variety of scenario pathways in their long-term strategies. The national scenarios containing the least CDR are combined in the gap analysis as the “low” estimate of proposed CDR. The national scenarios with the most CDR are combined as the “high” estimate.

A key assumption was made in interpreting any overall LULUCF flux levels described in these documents. These are assumed to consist entirely of removals through conventional CDR (i.e. they are assumed to contain zero emissions from deforestation or land-use changes).

Box 9.2 Aligning proposed CDR with scenario data

As this analysis draws on national submissions to the UNFCCC to identify levels of proposed CDR, these levels align closely with inventory-based reporting conventions. Importantly, these conventions differ from those used for estimating the land-use fluxes in IPCC scenarios, which are based on the global bookkeeping model approach (see Chapter 7 – Current levels of CDR, Box 7.2).

The main difference is that inventory-based reporting typically includes CDR driven by indirect anthropogenic effects, such as rising CO₂ levels, nitrogen deposition and other climatic effects. Inventories also report a larger area of managed land than bookkeeping models. A portion of inventory-based removal estimates therefore falls outside this report’s definition of CDR, as the removals are not directly human caused and, crucially, depend on the future trajectory of global emissions and environmental change.³³⁶

These indirect anthropogenic effects have been excluded from the proposed CDR levels for 2030 and 2050. To do so, the same conceptual approach as in Grassi et al., 2021, and the Global Carbon Budget has been followed,^{417,418} as described in the Chapter 9 Technical Appendix.

Box 9.3 Points of departure from The State of Carbon Dioxide Removal 1st edition

First, the most significant change in the methodology compared with *The State of Carbon Dioxide Removal* 1st edition is extending the data set for countries’ removal proposals in two ways: (1) to include all nationally determined contributions and long-term strategies published up to COP28 (November 2023) and (2) to analyse additional types of document. In a number of important cases, removal proposals are not described in nationally determined contributions but are elaborated in national communications (China, Japan), biennial update reports (Peru), long-term strategies (Chile, US), or national projections or assessments (Brazil, India).

Second, given the large volume of information missing from the long-term strategies, the gap analysis now assumes that all countries without national

proposals for CDR preserve their current levels of conventional CDR up to 2050. Critical examples of this are highlighted in the results (Section 9.2), and the missing information is discussed as an uncertainty in Section 9.3.

Third, while the gap analysis uses the same three focus scenarios as in the first edition, the background range of scenarios used to contextualize the results has been adjusted. This approach follows from changes to the methodology, as described in Chapter 8 (Paris-consistent CDR scenarios), where sustainability and other screening criteria have been applied to narrow the range of scenarios depicted in this report. The three focus scenarios have also been renamed to better communicate their features:

- Focus on Demand Reduction → 1.5°C with no novel CDR
- Focus on Renewables → 1.5°C with higher conventional CDR
- Focus on CDR → 1.5°C with higher novel CDR

9.2 The size of the CDR gap

Proposed CDR falls short of what is required in all but the most ambitious scenarios that meet the Paris temperature goal.

In this section, the estimated amount of CDR present in country proposals is described. This level is then compared with levels in scenarios that are consistent with the Paris temperature goal to inform the CDR gap assessment.

Proposed levels of CDR in 2030

If all nationally determined contributions (NDCs) were implemented, including those conditional on financial and other support, conventional CDR would slightly increase by 2030: it would provide an additional -0.53 GtCO_2 per year, from a baseline of -2.1 (-1.5 to -2.7) GtCO_2 per year in 2011–2020. If only unconditional NDCs were implemented, conventional CDR would barely change: it would provide only an additional -0.05 GtCO_2 per year by 2030 compared with 2020 levels.

These values are lower than those presented in the first edition of this report, which described an increase of -0.10 to -0.65 GtCO_2 per year by 2030. This reduction is due to the data set having been expanded to consider more national documents (see Box 9.3).

The additional -0.53 Gt per year of CDR under conditional NDCs is made up as follows:

- 55 countries describe specific changes in conventional CDR by 2030, which total -0.22 GtCO_2 per year.
- 31 countries do not state specific changes in CDR but describe how their overall land use, land-use change and forestry (LULUCF) fluxes will develop by 2030. The CDR levels inferred from this data account for -0.33 GtCO_2 per year.
- 25 countries provide no estimate of how the LULUCF sector will develop; it is therefore assumed that these countries will preserve their current level of removals.

Most of the change in removals under conditional NDCs is therefore not directly proposed

by countries but has been inferred from their description of how overall LULUCF fluxes will develop by 2030.

While some countries mention novel CDR in their NDCs and national documents, none so far provide sufficient information to infer the contribution of these removals by 2030. This is mainly because countries offer only qualitative targets or group these methods within broader categories, such as fossil-based carbon capture and storage or biomass-based energy systems. The gap assessment therefore assumes no additional novel CDR is proposed by 2030.

Proposed levels of CDR in 2050

If countries implement the proposals in their long-term strategies that expand CDR the least, total CDR would increase by -1.9 GtCO_2 per year by 2050 from a baseline of -2.1 GtCO_2 per year in 2011–2020. The set of proposals with the highest amount of CDR would add -2.3 GtCO_2 per year compared with 2011–2020 levels.

In both cases, slightly less than half (-0.7 GtCO_2 per year to -0.9 GtCO_2 per year) of the proposed growth in CDR would be delivered through novel methods.

The range of the total proposed removals in 2050 is narrower than in the first edition of this report, which described an additional -1.5 to -2.3 GtCO_2 per year by 2050. This is primarily due to refinements in the methodology (see Box 9.1) rather than newly submitted or updated long-term strategies.

Only a small minority of countries provide sufficient information in their long-term strategies to infer CDR proposals by 2050, however. Of the 70 countries that had submitted a long-term strategy by COP28 (November 2023), only 28 included quantifiable levels of removals (including the EU, analysed as one country). For all other countries, it has been assumed that they are able to sustain their current levels of conventional CDR. Thus, 28 countries account for all the proposed changes in total CDR by 2050.

CDR in scenarios that sustainably scale CDR to meet the Paris temperature goal

As discussed in Chapter 8 (Paris-consistent CDR scenarios), scenarios that meet the Paris temperature goal dramatically reduce emissions in the coming decades. At the same time, these scenarios scale up CDR to gigatons of annual removals by 2050. However, there is considerable variation in the degree to which different models and types of scenarios scale up CDR. These differences are driven by several factors, including the application of sustainability constraints (e.g. on global biomass use), the speed and depth of near-term emission reductions (e.g. immediate versus delayed policy action), or the quantity of residual emissions at the point of net zero (e.g. depending on the availability of mitigation technologies or the implementation of demand-side measures).

Chapter 8 describes a set of *Paris-relevant scenarios*. This set consists of scenarios that limit global temperature rise to 1.5°C with 50% probability, scenarios that initially exceed a temperature rise of 1.5°C but then return to that level by the end of the century, and scenarios that limit temperature rise to 2°C with 67% probability. These scenarios are referred to by the IPCC as C1, C2 and C3 scenarios, respectively.

Chapter 8 also describes a subset of the Paris-relevant scenarios that are more likely to scale CDR sustainably. The Paris Agreement states that climate change mitigation must be done “in the context of sustainable development and efforts to eradicate poverty”. Therefore, CDR pathways that align with social and environmental sustainability principles are more policy relevant. This subset of scenarios is known as *Paris-consistent scenarios* in this report.

In the Paris-consistent scenarios, the increase in total deployment of CDR by 2030 and 2050 is as follows:

- By 2030: total CDR deployment increases to -4.0 (-3.9 to -4.4) GtCO₂ per year, from a baseline of -2.1 GtCO₂ per year in 2011–2020. Within these near-term increases in removals, only a minority (0.12 (0.05 to 0.3) GtCO₂ per year) is delivered through novel CDR.
- By 2050: total deployment of CDR increases to -7.8 (-6.6 to -8.9) GtCO₂ per year, of which -5.7 (-5.2 to -5.9) GtCO₂ per year is conventional CDR and -1.9 (-1.0 to -3.7) GtCO₂ per year is novel CDR.

Alongside this scaling of CDR, the evaluated scenarios simultaneously reduce greenhouse gas emissions by 25 (21 – 28) GtCO₂e by 2030 and 41 (39 – 43) GtCO₂e by 2050. This represents a significant break with the status quo observed to date of annual increases in global emissions.

As in *The State of Carbon Dioxide Removal* 1st edition, this chapter evaluates the CDR gap against a specific set of *focus scenarios* that follow specific storylines to limit warming to 1.5°C with no or limited overshoot (known as category C1 in the IPCC Sixth Assessment Report). The deployment of CDR within these scenarios is as follows:

- **1.5°C with no novel CDR.** Global energy demand is rapidly reduced through improvements in the efficiency of end-use devices and service delivery. This scenario has a large contribution from conventional CDR (an increase of -2.3 GtCO₂ per year by 2050 compared with 2020) but purposefully does not deploy novel CDR.
- **1.5°C with higher conventional CDR.** A rapid supply-side transformation is implemented through the deployment of increasingly cost-competitive renewable energy technologies. This scenario also has a large contribution from conventional CDR (an increase of -4.1 GtCO₂ per year in 2050 compared with 2020). This is complemented by the scale-up of novel CDR (-0.9 GtCO₂ per year in 2050).
- **1.5°C with higher novel CDR.** A slower transformation of the energy supply system takes place, with an incomplete phase-out of fossil fuels in the 21st century. This scenario also has a large contribution from conventional CDR (an increase of -4 GtCO₂ per year in 2050 compared with 2020). This is combined with significantly more novel CDR than in the other focus scenarios (-3.5 GtCO₂ per year in 2050).

Within the range of sustainable scenarios evaluated in this report, *1.5°C with no novel CDR* sits just lower than the 25th percentile for total removals in 2050 (see Figure 9.2). The

1.5°C with higher conventional CDR scenario is close to the median, and *1.5°C with higher novel CDR* sits at the 75th percentile.

In addition to scaling CDR, the three focus scenarios dramatically reduce gross greenhouse gas emissions by 2030 compared with 2020 levels: by –51% in *1.5°C with no novel CDR*; by –39% in *1.5°C with higher conventional CDR*; and by –40% in *1.5°C with higher novel CDR*.

The CDR gap

The increase of CDR proposed by countries in 2030 falls short of the CDR levels required in every focus scenario, as well as levels across the broader range of sustainable scenarios. The minimum relative gap (i.e. looking only at changes from current levels, as reflected in Table 9.1) is estimated at approximately 0.5 GtCO₂ per year in 2030. This is the difference between the level proposed in conditional (i.e. best case) NDCs, which would increase CDR by –0.53 GtCO₂ per year, and the level in *1.5°C with no novel CDR*, which would increase CDR by –1 GtCO₂ per year. For the other focus scenarios, which have higher rates of CDR scaling in the short term, the gap increases to beyond 1 GtCO₂ per year.

From the limited amount of information that can be derived from countries' long-term strategies – and assuming all other countries sustain current levels of removals – the minimum gap is estimated at close to zero in 2050. This is the difference between the combined total from long-term strategy scenarios with the highest amount of CDR, which would increase CDR by –2.3 GtCO₂ per year, and the level in *1.5°C with no novel CDR*, which would also increase CDR by –2.3 GtCO₂ per year. When compared with other focus scenarios, which have higher rates of CDR scaling in the medium term, the gap widens significantly to multiple gigatons of removals per year. In absolute terms, the CDR gap is 0.9 to 2.8 GtCO₂ per year in 2030 (conditional NDCs) and 0.4 to 5.4 GtCO₂ per year in 2050 (high long-term strategies estimate), as shown in Figure 9.2.

The gap in conventional CDR

Proposals by countries to expand conventional CDR fall short of the CDR levels required in every focus scenario. Between –1.2 to –1.4 GtCO₂ per year of additional conventional CDR is implied in the long-term strategies by 2050. This falls short of levels in the *1.5°C with no novel CDR* scenario by at least 1.1 GtCO₂ per year and falls short of levels in the other focus scenarios by about 3 GtCO₂ per year.

The gap analysis in this report assumes that countries without a quantifiable long-term strategy preserve their existing levels of conventional CDR. These “absent” countries include Brazil, China, the Democratic Republic of Congo, and India. These are among the countries with the most significant current forest fluxes (Chapter 7 – Current levels of CDR), although they currently have minimal removals due to direct human activity, according to the adjusted inventory accounts (see Box 9.1 and Chapter 9 Technical Appendix). As most countries with quantifiable long-term strategies foresee preserving or increasing their current levels of conventional CDR, it may be that the gap starts to decrease as more countries publish long-term strategies.

The gap in novel CDR

Countries have not transparently communicated their expectations for scaling novel CDR by 2030 but do foresee deployments in their long-term strategies of between -0.7 and -0.96 GtCO₂ per year by 2050. There is no gap between these proposals and the *1.5°C with no novel CDR* scenario (which, as per its title, does not deploy novel CDR). However, the lower end of proposals fall short of novel CDR levels in the *1.5°C with higher conventional CDR* scenario (which has an additional -0.91 GtCO₂ per year in 2050) and the *1.5°C with higher novel CDR* scenario (which has an additional -3.5 GtCO₂ per year in 2050).

As with conventional CDR, the absence of published, quantifiable proposals for scaling novel CDR is consequential for this analysis. In particular, data are currently missing for a number of countries known to be developing road maps and policies towards deploying novel CDR, such as China, Norway and Saudi Arabia.

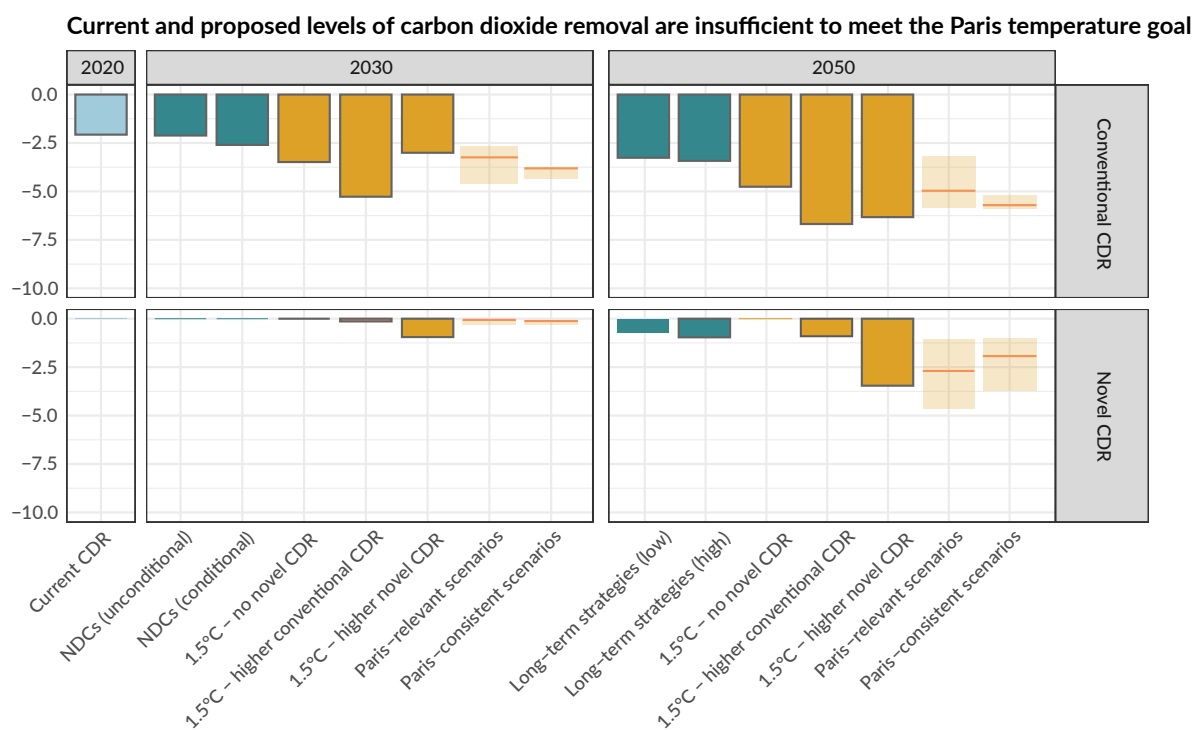
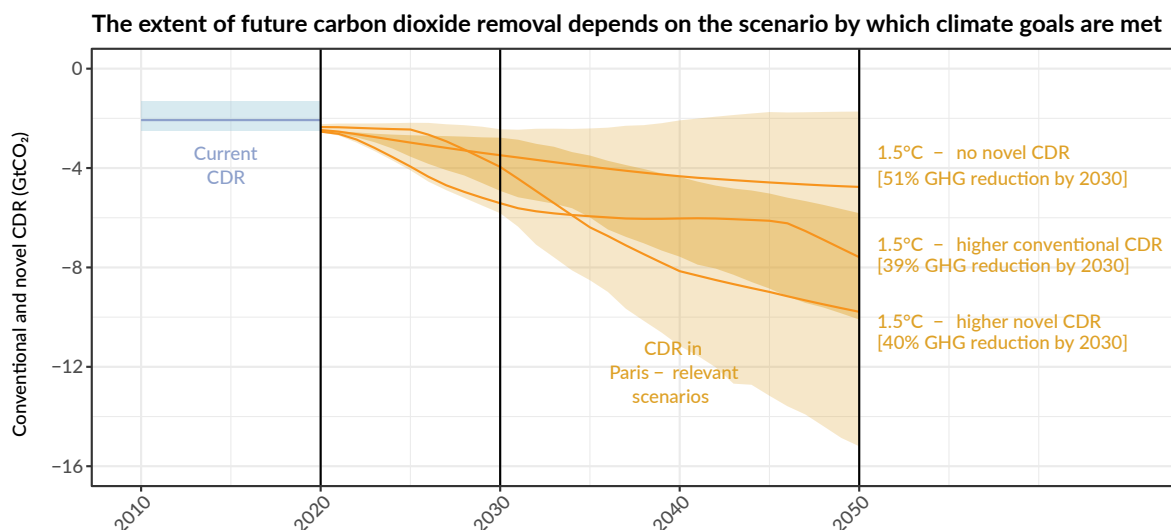


Figure 9.2 The carbon dioxide removal (CDR) gap. Top: current levels of CDR and levels in scenarios up to 2100. The shaded areas depict the 5th to 95th and the 25th to 75th percentiles of all Paris-relevant scenarios (categories C1–C3). The lines depict CDR levels in three Paris-consistent focus scenarios that limit warming to 1.5°C, alongside the gross greenhouse gas (GHG) emission reductions (compared with 2020 levels) required by 2030 for each. Bottom: levels of current, proposed and scenario-based CDR, split by conventional CDR and novel CDR in 2020, 2030 and 2050. Green bars depict proposed CDR levels in the nationally determined contributions (NDCs; which also include other official submissions to the UNFCCC) and the long-term strategies. Gold bars depict CDR levels in the three focus scenarios, as well as the medians and ranges (25th to 75th percentiles) of the wider set of Paris-relevant and Paris-consistent scenarios.

	Additional total CDR compared with 2011-2020 (GtCO ₂ per year)		Additional conventional CDR compared with 2011-2020 (GtCO ₂ per year)		Additional novel CDR compared with 2011-2020 (GtCO ₂ per year)		Gross GHG emission reductions compared with 2011-2020 (%)	
	2030	2050	2030	2050	2030	2050	2030	2050
Paris-consistent scenarios	-1.6 [-1.4 to -1.9]	-5.3 [-4.1 to -6.4]	-1.3 [-1.3 to -1.9]	-3.2 [-2.7 to -3.4]	-0.1 [-0.1 to -0.3]	-1.9 [-1 to -3.7]	46 [39 to 53]	76 [73 to 79]
1.5°C with no novel CDR	-1	-2.3	-1	-2.3	0	0	51	78
1.5°C with higher conventional CDR	-2.9	-5.1	-2.7	-4.1	-0.14	-0.91	39	80
1.5°C with higher novel CDR	-1.6	-7.4	-0.66	-4.0	-0.95	-3.5	40	77
Nationally determined contributions ^a	-0.05 to -0.53	NA	-0.05 to -0.53	NA	0	NA	NA	NA
Long-term strategies ^b	NA	-1.9 to -2.3	NA	-1.2 to -1.4	NA	-0.7 to -0.96	NA	NA

^a As described in Box 9.1, the nationally determined contribution analysis includes additional national documents, such as national communications and biennial update reports.

^b Proposed CDR derived from the long-term strategies is incomplete, owing to the limited number of countries with these documents; all countries without quantifiable strategies are therefore assumed to retain current (2020) levels of conventional CDR.

Table 9.1 Numbers behind the carbon dioxide removal (CDR) gap, reported as additional CDR compared with 2011–2020. GHG = greenhouse gas; NA = not available.

9.3 Uncertainties

The precise size of the gap between current CDR and Paris-consistent CDR is dependent on a number of uncertain factors and assumptions.

This section discusses the CDR gap analysis in the context of ambiguities in national proposals for CDR, questions around the credibility of these proposals, current trends in conventional CDR, and uncertainties in the scenario evidence. These aspects of uncertainty suggest concrete areas of future research that could further strengthen the CDR gap evaluation (see Box 9.4).

Ambiguities in national proposals for CDR

Many countries do not clearly state their plans for scaling CDR. This applies to NDCs, long-term strategies and other national documents submitted under the UNFCCC. Of these,

the long-term strategies may be the most consequential as they refer to mid-century plans, when CDR scaling becomes more urgent. The absence of clear plans adds different layers of ambiguity, which limit the CDR gap assessment.

The gap analysis assumes that countries without long-term strategies and quantifiable scenarios are able to sustain existing levels of conventional CDR. This broadly aligns with the expectations established by countries with published strategies.¹⁴³ However, as discussed in this section, it will not be an easy task even to sustain current removals.

The gap analysis finds many instances where countries do not report gross emissions and removals separately in their proposals. Many countries instead employ sectoral accounting, which follows the logic of national greenhouse gas inventories by reporting both emissions and removals within the sectors in which they occur. In the case of the LULUCF sector, the analysis assumes zero deforestation in the long-term strategies, and thus counts all net fluxes as removals. In other cases, for instance where bioenergy with carbon capture and storage is included in net reduction scenarios for the energy sector (e.g. Indonesia, Thailand), the implied removals cannot be assessed. Standardizing reporting practices across countries to avoid these issues is therefore a priority, particularly for emerging novel methods.

Emissions from international aviation and shipping are commonly excluded from the scope of national climate targets. Some countries, such as the UK, integrate these emissions into the scope of net zero targets.⁴¹⁹ Integration does not necessarily mean unilateral action, but it is a recognition that decarbonizing aviation and shipping globally will require new fuel and carbon management infrastructure within national borders, including novel CDR. Additionally, integration implies that further CDR would be required to offset residual emissions from these sectors (e.g. the International Energy Agency estimates approximately 210 MtCO₂ of emissions in 2050 for domestic and international aviation in its net zero scenarios). Nonetheless, these sectors are excluded from the CDR gap assessment, owing to the lack of scenarios from the International Civil Aviation Organization and the International Maritime Organization that transparently report gross reductions, residual emissions or implied removals.

Credibility of national proposals for CDR

What role do the NDCs, long-term strategies and other documents under the UNFCCC play in national policymaking? In other words, how credible are they as signals that countries will implement policies and ultimately scale their proposed levels of CDR?

On the one hand, these documents are key elements of the multilateral climate governance architecture. The “nationally determined” nature of the ratcheting-up mechanism was the main enabler for the adoption of the Paris Agreement. On the other hand, the extent to which these documents are embedded in national climate policymaking and reflect the state of policy planning and decision-making varies considerably. In some cases, UNFCCC processes and deadlines can have a structuring effect on national climate policymaking; in others, NDCs and long-term strategies can be a subordinate element, primarily used and written for foreign audiences and detached from national climate policies and politics. The long-term strategies in particular are primarily modelling or projection exercises with multiple scenarios rather than plans, and relevant actors may be unfamiliar with these

strategies.

However, analysis of the material and data provided by countries can still provide insight into national policy developments. While the figures derived from the analysis should not be over-interpreted in their detail, the assessment of these documents provides credible ballpark numbers that help identify gaps in climate policy. See Box 9.4 for how the credibility of these plans could be further evaluated.

Current trends in conventional CDR

Recent trends in conventional CDR can give further insight into the credibility of future proposals. Figure 9.3 depicts trends in conventional CDR for the world and the top 15 countries for recent removals (averaged over 2011–2020) as calculated in this chapter (see Box 9.1). These trends are contrasted with the most ambitious proposals from the long-term strategies. These proposals total an additional -1.4 GtCO_2 per year in 2050 on top of the 2011–2020 baseline, assuming that countries without proposals maintain current (2011–2020) levels of removals.

Consistent with Chapter 7 (Current levels of CDR), this shows that global removals have been relatively stable over the past two decades and are currently not on track to increase by 2030 or 2050. Further, many countries are not on track to sustain current conventional CDR or to meet long-term proposals. Notable examples where removals have been decreasing over the past decades include Canada, Chile, the EU27, Mali and the Republic of Korea. In the US, removals have been relatively stable but are not on track to meet 2050 targets. China, on the other hand, has seen a large and sustained increase in removals over the past two decades.

These examples underline that even simply preserving existing land-based sinks – as assumed in this analysis – will be a considerable challenge. The recent decline of the European forest sink has been linked to decreased afforestation (i.e. land conversion to forest), increased mortality (i.e. from drought, storms, fire and disease) and, in particular, to increased harvest.^{420,421} Without a significant reversal of current management practices, the EU27 will not meet its 2030 targets in the LULUCF sector. The increasingly adverse effects of climate change, including precipitation changes, heat and wildfire events, and the spread of pests such as bark beetles will further increase pressure on forest carbon sinks and likely expand the CDR gap.

Many countries are not on track to sustain conventional CDR, nor to meet long-term proposals

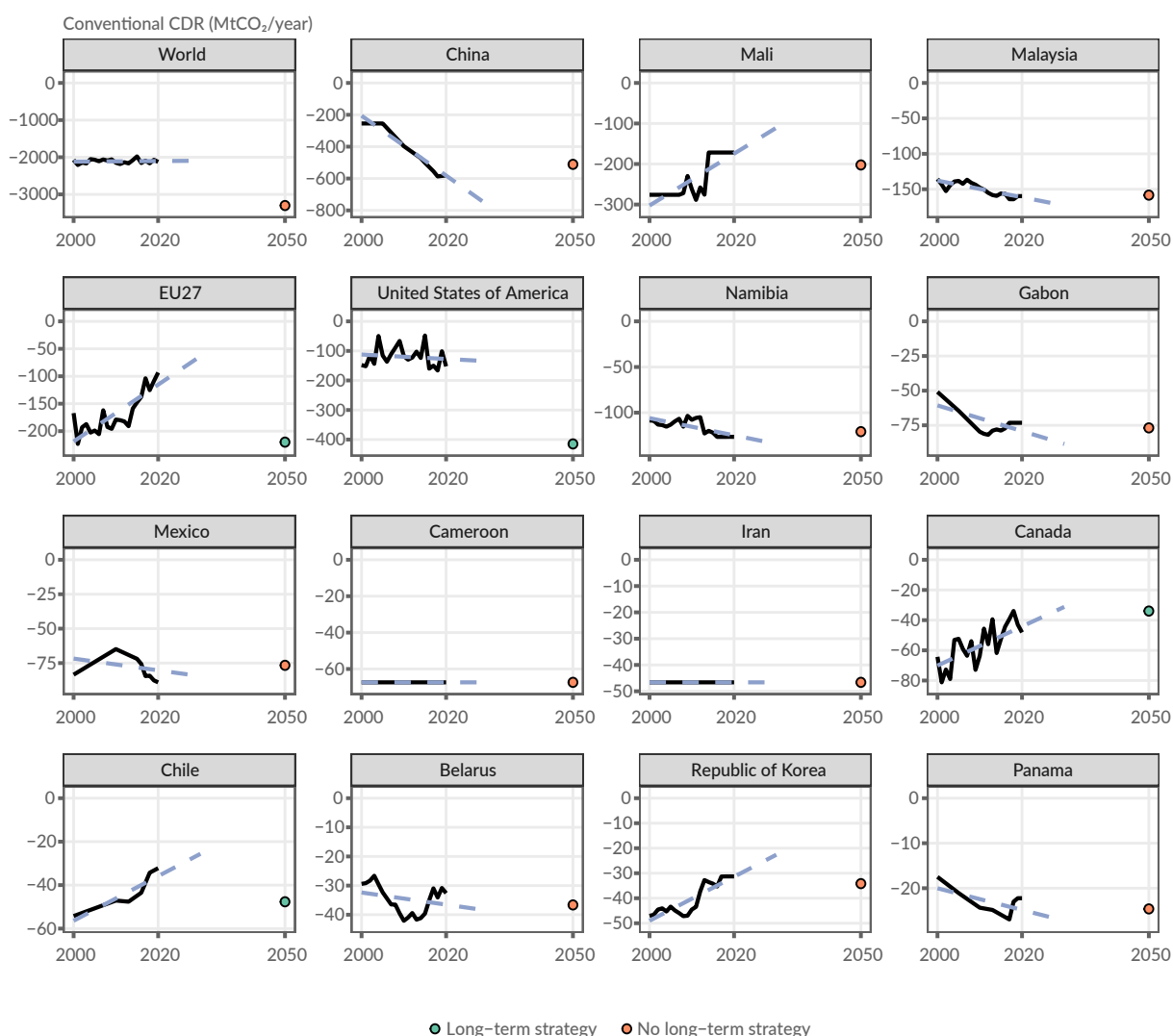


Figure 9.3 Historic conventional carbon dioxide removal (CDR, black line) versus future proposals in the long-term strategies for the world and for selected countries. Historic conventional CDR is calculated as the sum of forest land fluxes in national inventories, excluding emissions from organic soils and harvested wood products, minus the 20-year average of natural land sinks estimated by dynamic global vegetation models for that country. Dashed lines show the linear trend up to 2030. The 15 countries with the highest decadal average removals (2011–2020) have been selected, alongside the world average. Where a country has no quantifiable long-term strategy, a target level is projected for 2050 equal to average removals from 2011 to 2020. Uncertainties in both absolute levels and trends are high, and results differ from Chapter 7 (Current levels of CDR) owing to the inventory approach used here. Data sources: National inventories from Grassi et al., 2022³²² dynamic global vegetation models from Friedlingstein et al., 2023.⁴¹⁸

Uncertainties in scenario evidence

The CDR gap analysis uses model scenarios to benchmark national proposals. These scenarios are subject to a number of uncertainties. A fundamental issue is that many scenarios published during the IPCC Sixth Assessment Report cycle are now relatively dated, describing pathways where emissions already peaked in the early 2020s. As a result, they do not take into account that emissions have not only failed to decrease in the past years, but have actually increased, and further eaten into the remaining carbon budget. Figure 9.4 illustrates this problem and how an *additional mitigation burden* can be quantified to estimate the effort required to get back on track to a given scenario pathway. The estimate for the 1.5°C with no novel CDR scenario is that between 0.7 and 1.5 GtCO₂ per year of additional mitigation is already required to compensate for the missed emission reductions between 2020 and 2022. Since this additional mitigation could consist of either deeper reductions or the scale-up of CDR, the implication is that the CDR gap is already wider by up to 1.5 GtCO₂ than is depicted in the prior section.

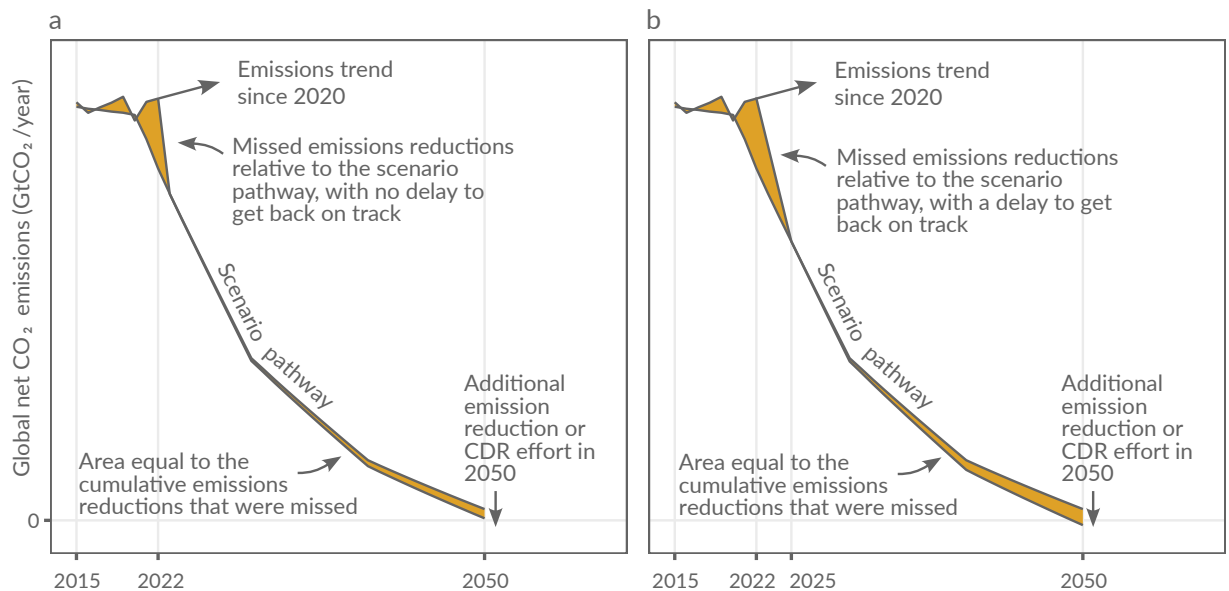


Figure 9.4 Assessment methods for calculating the additional mitigation burden due to failed historic emission reductions relative to scenario pathways. In each panel, the amount of cumulative emissions in the top triangle (missed emission reductions) is equal to the compensated mitigation in the lower triangle. The lower triangle allows an estimate of additional mitigation at any point in time up to net zero and is calculated for each focus scenario in Table 9.2. In panel b, emissions are estimated to rejoin the scenario pathway in 2025.

Scenario	Additional mitigation required due to missed emission reductions in 2020–2022 (GtCO ₂ per year)			
	Without delay (Figure 9.4a)		With delay (Figure 9.4b)	
	2030	2050	2030	2050
1.5°C with no novel CDR	0.2	0.7	0.4	1.5
1.5°C with higher conventional CDR	0.1	0.3	0.1	0.4
1.5°C with higher novel CDR	0.2	0.6	0.4	1.4

Table 9.2 Assessment of additional mitigation needed due to failed historic emission reductions relative to the scenario pathway. CDR = carbon dioxide removal.

In addition to being out of date, scenarios do not explicitly deal with the considerable uncertainties in the climate system. Specifically, they do not take into account that estimates of climate sensitivity – the temperature response to an increase in atmospheric CO₂ concentrations – range substantially. A doubling of CO₂ concentration compared with pre-industrial levels, for example, could lead to between 1.4°C and 2.2°C of warming.⁴²² Accordingly, CDR requirements could be considerably larger or smaller, depending on how the climate sensitivity plays out, pointing to a potential need for a contingency CDR capacity in case of “bad climate outcomes”.

Box 9.4 Limitations and knowledge gaps

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

- *Evaluating the credibility of country proposals:* What is the likelihood that countries will implement their declared policies and, ultimately, scale their proposed levels of CDR? Answering this question may involve assessing the legal basis of CDR proposals in their respective national jurisdictions,⁴²³ tracking relevant policies as they manifest in different countries, and evaluating near-term deployments by companies (as in Chapter 3 – Demonstration and upscaling). A comparative analysis and tracking of national CDR efforts alongside emission reductions may bring further insight on the credibility of proposals, given that there is a well-developed literature on the latter.
- *Evaluating trends in current conventional CDR:* Are countries on track to preserve current conventional CDR? Answering this question will require detailed regional studies to track trends and drivers of forest fluxes, including newly planted areas, harvest levels, and losses due to drought, wildfires, pests and disease.
- *Evaluating new scenario evidence:* How does the CDR gap compare to the most up-to-date scenarios? Here, there is an important role for integrating scenarios with up-to-date historical emission estimates, as well as for scenarios that depict different levels and strategies for sustainably scaling CDR.

9.4 Closing the CDR gap

The CDR gap can be closed by dramatically reducing emissions, increasing current conventional CDR carefully through sustainable practices, and rapidly scaling novel CDR.

The analysis presented in this chapter shows that for the majority of scenarios that limit global temperature rise to 1.5°C, with no or limited overshoot, there remains a CDR gap. This gap indicates that countries need to strengthen their ambitions if the Paris temperature goal is to be met. This conclusion is consistent with assessments focusing on overall net emission reductions.^{133,423–425} While it is critical for countries to prioritize near-term policies that reduce fossil fuel emissions and limit deforestation, this section focuses on the specific challenges of closing the CDR gap.

For conventional CDR, sustainably preserving and scaling these removals will require active policies to limit the impact of natural disturbances, promote sustainable land practices and prevent illegal harvests. European and boreal forests are already trending towards lower levels of removals, raising concerns that existing proposals are too optimistic.^{420,421} Nonetheless, global potentials for sustainably restoring forests and delivering land-based CDR are large.⁴²⁶

Further, land management practices that would scale conventional CDR can be integrated with sustainable development and biodiversity objectives, such as those set out in the Sustainable Development Goals and the Global Biodiversity Framework.⁴²⁷ Monitoring, reporting and verification will be a critical component of enhanced policy action for conventional CDR (see Chapter 10 – Monitoring, reporting and verification), as any such action should be additional, quantifiable, and in line with other social and environmental objectives.

Novel CDR presents a different set of challenges, as these methods are in an early stage of development and are not as well integrated into national policy planning. Without significant policy action in the near term to support novel CDR methods through their formative phases, it is difficult to conceive of them being able to provide gigatons of removals in the second half of the 21st century. Monitoring, reporting and verification approaches are also lagging for these methods, alongside a general lack of guidance on how to include them in national proposals under the UNFCCC. Importantly, enhanced emission reductions would reduce society's dependence on these methods and hedge against uncertainties in how fast they can scale.

Overall, this report's analysis of the CDR gap shows that, in addition to insufficient policy and action to reduce emissions, governments are planning for insufficient scaling of CDR in the coming decades. A twofold strategy that limits society's dependence on CDR through rapid and deep emission reductions while supporting and scaling CDR implementation is not a contradiction, but a necessary pathway towards successful climate policy.



THE STATE OF
**Carbon
Dioxide
Removal**

