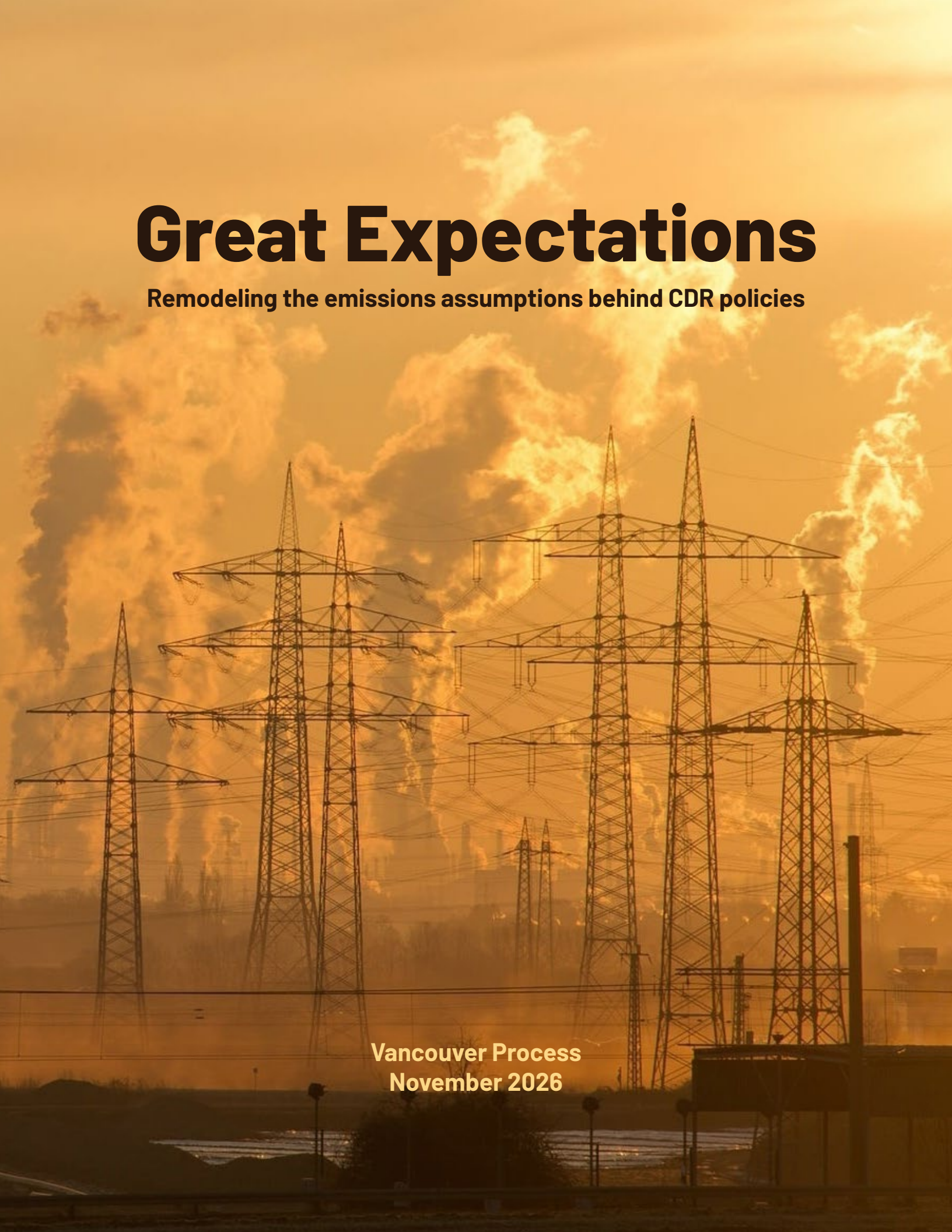


Great Expectations

Remodeling the emissions assumptions behind CDR policies

Vancouver Process
November 2026

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EXECUTIVE SUMMARY

How much carbon dioxide removal (CDR) will we need to keep our planet's ever-rising temperatures under control? Scientists have debated this question for decades. For many, the correct answer is somewhere around 10 billion tons annually by mid-century, assuming fossil fuel emissions start falling dramatically within the next few years.

But what if emissions stay elevated instead? Except for a few blips, our fossil fuel use has risen continuously since the dawn of the Industrial Age over 200 years ago. Why do scientists assume this trend will suddenly reverse?

They don't, actually, and therein lies a major problem with how we've approached the CDR challenge to date. Uncertainty about future emissions might be the single most important reason why CDR recommendations vary from one report to the next. So too is the scientifically slipshod proliferation of conclusions that have become separated from their footnotes and asterisks. Take the latest annual Emissions Gap report from the UN Environment Programme (UNEP), for example. Released in October 2026, UNEP recommended deploying 320 billion tons of CDR between now and 2100. This number quickly ricocheted through the climate policy ecosystem, welcomed as a sign of growing UN recognition of the need for CDR, but with no mention that this number assumes total GHG emissions will drop an eye-popping 69% by 2040. Indeed, UNEP's recommendation is only one among many designed primarily to align with the emissions goals of the UN's 2015 Paris Climate Agreement, rather than to provide an emissions-agnostic perspective. If emissions do indeed drop as fast as the UN is advocating, then the world won't need much CDR at all. If they don't however — and this is the direction real-world emissions are trending — we may end up needing much more CDR than we've anticipated.

The climate policy community needs a better way to compare and contrast CDR scenarios. To this end, we are pleased to put forward a first draft of such an approach in this report. To facilitate our analysis, we introduce a new comparison framework called TIER, which stands for "Temperature Impact from Emissions and Removals." TIER evaluates 121 widely varying climate scenarios, intersecting 11 possible emissions-reduction pathways with 11 possible CDR deployment pathways. From these combinations, we can more easily explore which combinations might work best for controlling temperatures, minimizing our time above 2°C, and bringing temperatures back down. TIER doesn't predetermine how far emissions will fall (if at all), how much CDR we can deploy, how much doing so might cost, or other factors that normally influence these calculations. Rather, it simply asks what temperatures will result from different combinations of emissions and CDR.

The results are revealing. For one, far higher CDR requirements than UNEP is recommending come sharply into focus. So does the importance of negative emissions. Reaching net zero will not guarantee temperature stability, nor will this achievement return our planet's temperatures to historically safer levels. But perhaps the top line conclusion is that we need to be extraordinarily ambitious with our emission reductions efforts, CDR efforts, or both; modest ambitions may get us to net zero, but half-measures will also leave us above 2°C for generations, and above 1.5°C essentially forever. If we fail to reduce our fossil fuel use to near zero, then deploying only 10 billion tons per year of CDR or 320 billion tons by 2100 will make almost no meaningful difference to global temperatures.

Climate policy is entering its most consequential phase, and the decisions we make next will impact the future of humankind for centuries to come. If we continue designing these policies around overly optimistic emissions assumptions, and thereby downplay how much CDR we will need, we will throttle the investment and policy attention CDR needs to become more capable. The longer we continue doing this, the fewer options will remain for keeping our planet livable.

GLOSSARY

Anthropogenic emissions. Emissions resulting from human activity.
Carbon dioxide removal (CDR). Deliberately removing CO2 from the atmosphere and storing it in geological formations, soils, vegetation, oceans, materials, or other reservoirs.
Carbon sinks. Natural or managed systems that absorb more carbon than they release.
Durable CDR. Carbon dioxide removal involving storage intended to last for centuries or longer.
Gross emissions. Emissions before subtracting removals.
Net emissions. Gross emissions minus removals.
Net negative. Removing more CO2 than we emit.
Net zero. Balancing CO2 emissions with equivalent removals.

ABBREVIATIONS

AR6. IPCC Sixth Assessment Report
CDR. Carbon dioxide removal
CDRMIP. Carbon Dioxide Removal Model Intercomparison Project
CMIP7. Coupled Model Intercomparison Project, Phase 7
CO2. Carbon dioxide
CO2e. Carbon dioxide equivalent
FaIR. Finite-amplitude Impulse Response climate model
GHG. Greenhouse gas
IAM. Integrated assessment model
IPCC. Intergovernmental Panel on Climate Change
NDC. Nationally determined contribution
ScenarioMIP. Scenario Model Intercomparison Project
SoCDR. State of Carbon Dioxide Removal report
TIER. Temperature Impact from Emissions and Removals
TIER-A. Applied version of TIER
UNEP. United Nations Environment Programme
UNFCCC. United Nations Framework Convention on Climate Change
WMO. World Meteorological Organization

Great Expectations

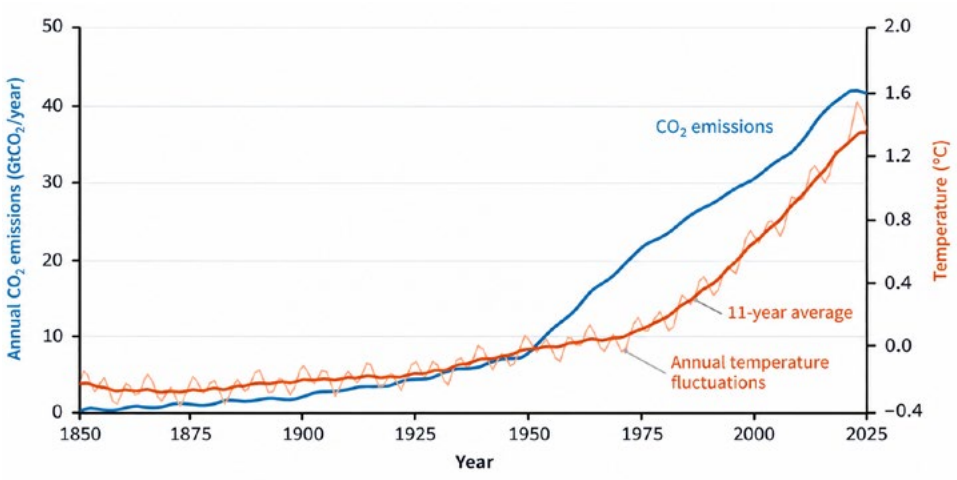
Remodeling the emissions assumptions behind CDR policies

INTRODUCTION

EMISSIONS AREN'T DECLINING

Reducing fossil fuel emissions has long been the bedrock of modern climate policy. For generations, government and business leaders have championed countless efforts to develop cleaner sources of energy, improve fuel economy, reduce consumption, and curb industrial pollution. According to this blueprint, once emissions finally fall far enough, our climate will be saved.

Figure 1. Temperature increase and human-caused CO2 emissions, 1850-2025



Source: Global Carbon Project (2026) and WMO (2026).
Note: Temperatures are in °C above preindustrial levels. CO2 emissions are annual values for CO2 only and not other GHGs, including both fossil fuel emissions (approximately 38 gigatons per year in 2025) and human-caused CO2 due to land use changes (net value of approximately 4.1 gigatons per year).

Emissions aren't declining, though. In fact, they are higher today than at any time in human history, with no long-term slowing in sight (see Figure 1).[1] Our planet's temperature continues to climb rapidly as well.

So what now? Do we need a Plan B? While we may still be on the right track, we have significant work to do, not only with regard to emissions reductions, but also carbon dioxide removals. The key to our coming course correction is this: reductions matter, but ultimately, it's the ledger balance that matters most of all.

1. Fossil fuel use produces a variety of greenhouse gases and pollutants, including carbon dioxide, methane, nitrogen oxides, sulfur dioxide, and particulate matter. This paper focuses specifically on carbon dioxide emissions and removals. As noted in Figure 2, fossil fuel use is increasing at a rate of about 1.1% annually. While policymakers often forecast decreased use in the future, industry trends are not currently pointed in that direction. With regard to temperatures, the observed 2016–2025 ten-year average was approximately 1.26°C above preindustrial levels (rounded in this report to 1.3°C), of which approximately 1.24°C was human-induced. The observed 2025 annual average was about 1.43°C (WMO 2026; Forster et al. 2026). Single-year observed temperatures can rise above the underlying warming trend due to natural climate variability, which is why progress toward the Paris Agreement's temperature goals is assessed using longer-term warming rather than individual years. Given the current rate of human-induced warming of approximately 0.27°C per decade, however, researchers expect warming to reach 1.5°C by around 2030 (Forster et al. 2026; UNEP 2026).

WHY NET ZERO (AND NET NEGATIVE)

The landmark Paris Climate Agreement, adopted in late 2015, established the first formal blueprint for how the world should draw down fossil fuel emissions to net zero — a stable plateau where we've counterbalanced our human-caused (anthropogenic) carbon dioxide emissions, mostly but not entirely by cutting emissions drastically from their current levels.[2] The Paris Agreement's end goal, though, wasn't emissions control per se but temperature control — to hold warming well below 2°C above preindustrial levels, while "pursuing efforts" to limit it to 1.5°C (which we're very close to reaching today).[3] The carbon dioxide that results from burning fossil fuels was then and still is today the major driver of global warming. Cut these emissions, and temperature increases should slow down. As a means to an end, this policy recommendation was firmly grounded in the best science of the time.

Today, however, we're beginning to realize that net zero won't necessarily stop global warming on its own, nor will reaching this plateau return our planet's temperatures to historically safer levels.[4] The carbon dioxide pollution that has accumulated in our atmosphere over the centuries will continue warming our planet for centuries to come. Whether these temperatures rise a little more, level off, or slowly decline depends partly on how warm our planet gets in the meantime.[5]

For this reason, we need to not only reach net zero, but move beyond it to net negative, where we start removing more human-caused carbon dioxide from the air than we emit.[6] Only net negative levels might be capable of eventually lowering temperatures and "limiting" (to the extent possible) the damage that centuries of high heat will inflict on our planet and societies.[7]

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2. Distinguishing human-caused CO2 emissions from total emissions is important here because decaying vegetation, ocean outgassing, volcanoes, plant and animal life and other sources combine to emit hundreds of billions of tons of CO2 annually. The Earth's soil, vegetation and oceans soak up most of this. This give and take between CO2 outgassing and uptake is called the carbon cycle. Into this mix, humans have been adding increasing amounts of CO2, primarily since the start of the Industrial Age, when we started burning huge amounts of fossil fuels to power modern society. The Earth's natural carbon sinks have absorbed much of our historical CO2 pollution, but climate change itself is increasingly threatening their effectiveness. Some important natural sinks, including parts of the Amazon, are already becoming net emitters of CO2. (IPCC 2021)

3. It's important to note that the Paris Agreement's 2°C goal was more political than scientific, and the agreement's 1.5°C aspirational goal (that is, the agreement noted we should "pursue efforts" to limit increases to 1.5°C) was simply a political concession to Paris delegates. A lower goal was opposed by many industrialized countries, and also by many developing countries who thought it unfair for industrialized economies to cut the rungs off the development ladder by demanding deep decarbonization measures from everyone, rather than mostly from countries like the US who caused the bulk of the CO2 problem. In recent years, more and more world leaders have stressed the need to limit global warming to 1.5°C by the end of this century.

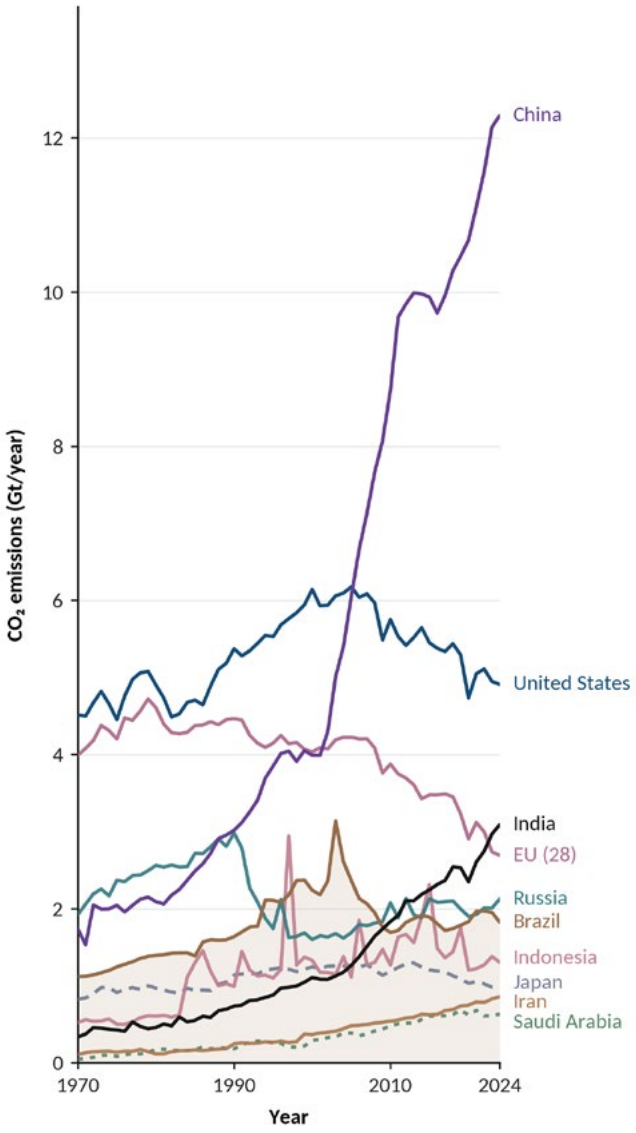
4. Sustained net-zero anthropogenic CO2 emissions will approximately stabilize CO2-induced warming, but this is not the same as saying that "net zero" however defined will stop warming, or that temperatures at net zero will remain steady for centuries. First, accounting matters. Land and oceans already absorb some of the CO2 emitted by human activity. Allen et al. (2025) warn that counting this passive uptake as a removal can make our emissions balance appear "net zero" on paper even though we haven't balanced emissions with actual removals. Genuine "geological net-zero" requires anthropogenic emissions to be balanced by additional removals plus geological-timescale storage. Second, the temperature at which emissions stop matters. In simulations with one Earth-system model (UKESM1.2), Gibbs et al. (2026) found little additional warming when CO2 emissions ceased at 1.5-2°C. But when emissions ceased after higher warming (3-5°C), temperatures increased by approximately 0.4–0.6°C over the next 150 years. A third and related point is that rising global temperatures are triggering dangerous feedback loops. For example, the permafrost regions of our planet — vast stretches of soil containing organic matter frozen over tens to hundreds of thousands of years — are beginning to thaw, releasing significant amounts of CO2 and methane. CO2 currently accounts for roughly 64% of direct greenhouse gas warming influence, while methane is responsible for about 30% of total warming observed since the preindustrial era (NOAA 2026; IPCC 2021).

5. Recent research suggests that if we wait until temperatures are well above 2°C, we could experience several more tenths of a degree of warming even after reaching net zero. (Allen et al. 2025; Gibbs et al. 2026)

6. The IPCC's Sixth Assessment Report, issued between 2021 and 2023, concluded that CDR is unavoidable for achieving net-zero CO2 emissions, and this finding is increasingly reinforced in subsequent UN assessments like UNEP's Emissions Gap Reports. Both assessments also speak about the need for net negative, although the amounts recommended are far below what may actually be needed.

7. Assuming climate restoration is possible. The science is still uncertain. There is mounting evidence, for instance, that we may not be able to return to exactly the same climate conditions as now, at least over the short term. There is also concern that remaining at elevated temperatures for too long will trigger tipping points where our climate systems fundamentally change and may never revert to "normal." (MacDougall 2013; Tokarska and Zickfeld 2015; Smith et al. 2026)

Figure 2. Annual CO2 emissions (including land use changes) by top-emitting countries in 2024



Source: Global Carbon Budget 2025 (Friedlingstein et al. 2026), processed by Our World in Data.
Notes: Fossil emissions include burning coal, oil, and gas; gas flaring; and industrial processes such as cement and steel production. Burning fossil fuels currently adds about 38.1 Gt of CO2 pollution to our atmosphere every year (about 90% of the overall total), increasing at a rate of about 1.1% annually. Land-use change emissions include deforestation, land conversion, and forest regrowth. About 4.1 Gt/y of anthropogenic CO2 comes from net land-use change; this figure has been declining by around 2% annually over the last 20 years. Taken together, these two components added 42.2 Gt of anthropogenic CO2 emissions to the Earth's atmosphere in 2025, growing at a rate of about 0.3% per year over the last decade.

In the meantime, reducing fossil fuel emissions might take a lot more time than we hoped. Many countries have managed to reduce their emissions; many others have not, though, especially those who have been unable or unwilling to reconcile the global need for emissions reductions with the national need for economic growth. In all, total emissions have continued to increase, and many analysts see a future of increasing emissions, which would be bad news for climate policies constructed on the premise that emissions will start declining soon (see Figure 2).

But what's so important about net zero and net negative anyway? Why all the fuss? Figure 3 on the next page shows the temperature impact (in °C above preindustrial levels) of net carbon dioxide levels between now and 2200. Only net is evaluated here — not emissions reductions versus CDR — because the temperature impact is the same whether we burn fewer fossil fuels (and thereby generate fewer emissions) or simply remove more of these emissions from the air.[8] We'll assume for this illustration that we take the climate challenge very seriously from this day forward and will make steady progress toward reaching net zero by either 2050, 2075 or 2100.

As is clear from this figure, reaching net zero will apply the brakes, but temperatures may still inch up over the ensuing decades. And while applying the brakes sooner rather than later will help, even reaching net zero in 2050 might still mean watching temperatures climb from 1.7°C in 2050 to 2.0°C in 2100 and 2.3°C in 2200; reaching net zero in 2100 might mean enduring 2.7°C by 2200.

None of these outcomes are victories — the prospect of stabilizing global temperatures at roughly twice today's increase should give us pause. At this level, the ongoing and compounding impacts of climate change will pose a massive challenge for societies everywhere, and the long-term trajectory for ice caps, forests, oceans, and other necessary parts of our environment will be profoundly bad (see Box 1).

8. Assuming these happen in identical amounts over the same time periods.

Box 1. What does a warmer world look like?

At the height of the last ice age, when enormous ice sheets covered much of North America and northern Europe, our planet was only about 6°C colder than preindustrial levels. What might comparable temperature changes in the opposite direction mean for life on Earth? The following descriptions refer to temperature increases above the 1850–1900 global average, the internationally accepted baseline for approximating Earth's temperature before widespread industrialization and large-scale fossil fuel consumption.

INCREASE	OUTCOME
1.5°C	**A planet under stress.** Warm-water coral reefs could decline by 70–90 percent. Severe heatwaves could regularly affect approximately 14% of the world's population. Droughts, floods, wildfires, glacier loss, and agricultural disruptions intensify. Some ecosystems begin reaching the limits of their ability to adapt.
2°C	**A planet approaching critical thresholds**. Virtually all warm-water coral reefs could disappear. Severe heatwaves regularly affect approximately 37% of humanity. Ice-free Arctic summers become increasingly common. Greenland and West Antarctic ice-sheet instability threaten coastlines for centuries to come. Food and water insecurity intensify, and the risks of irreversible climate changes mount.
3°C	**A world in crisis.** Dangerous heat and humidity spread across densely populated regions of the planet. Crop failures, water shortages, and ecosystem destruction increasingly threaten the foundations of modern economies. Up to 29% of assessed terrestrial species face a very high risk of extinction. Multiple climate tipping points could be crossed.
4°C	**An increasingly inhospitable world.** Large regions of the tropics and subtropics experience potentially lethal heat and humidity, making human habitation increasingly dependent on artificial cooling. Rainforest dieback, agricultural disruptions, and catastrophic marine ecosystem losses threaten global food security. Up to 39% of assessed terrestrial species face a very high risk of extinction.
5°C	**Hothouse Earth.** The prospect of a global mass extinction becomes increasingly real. Marine ecosystems face catastrophic losses from warming and oxygen depletion. Large-scale failures of agricultural, economic, and social systems become serious risks. The IPCC estimates that sustained warming at this level could raise global sea levels by 19–22 meters over 2,000 years.
6°C	**A planetary catastrophe.** Warming reaches a magnitude comparable to the transition out of the last ice age, but at extraordinary speed. One study estimates that at 6.2°C, the world's capacity for safe physical labor during peak heat months could fall to just 39 percent. Mass extinction, widespread displacement, and the breakdown of interconnected food, water, and economic systems threaten modern civilization.
7°C	**A fundamentally different planet.** Extreme heat and humidity threaten the habitability of entire regions. The geographic foundations of human settlement and agriculture change profoundly. Sustained warming threatens enormous and potentially irreversible losses from the world's remaining ice sheets.
8°C	**An extreme hothouse world.** Earth enters climatic territory far outside the conditions under which human civilization developed. Massive biodiversity losses and profound transformations of the oceans, ice sheets, and terrestrial ecosystems reshape the planet. Modeling suggests that sustained warming of 6–9°C could eventually trigger the loss of more than 70% of Antarctica's present ice volume. Sea levels could ultimately rise by dozens of meters. The survival of organized human civilization becomes a profound uncertainty.

It's not just how, but for how long

A world that remains at or above 2°C for 150 years would expose roughly six generations to elevated climate risks. Ice sheets would continue melting, coastlines retreating, and ecosystems deteriorating. Some of these changes could become irreversible even if we eventually succeeded in lowering global temperatures.

(Disclaimer)

These descriptions illustrate the possible consequences of global warming above preindustrial levels. They do not represent precise thresholds or timelines. Some impacts may occur at lower temperatures; others may unfold over centuries or millennia.

Sources: IPCC (2018, 2021, 2022, 2023); Dosio et al. (2018); Sherwood and Huber (2010); Dunne et al. (2013); Steffen et al. (2018); Garbe et al. (2020); Song et al. (2021); Kemp et al. (2022); Vecellio et al. (2023).

On the other hand, reaching net negative emissions might be able to gradually bring temperatures back down. How gradually is a function of net — how much CDR we'll be able to deploy relative to how low emissions can go. If we go negative enough soon enough — say, negative 40 Gt/y by 2075 (again, with linear progress from today) — then temperatures might drop from 1.7°C in 2050 to roughly preindustrial levels by 2200.

Whatever path we choose, net negative isn't simply a nice-to-have luxury for our climate toolbox. It's a must-have if we want to avoid the prospect of climate disruption becoming the permanent and defining challenge of human existence from this day forward.

How we can do this, how quickly, for how long, and who pays aren't questions we have started thinking seriously about in international policy circles. There are communities of inventors and investors and a few bold governments and companies who have risen to the challenge over the last ten years or so, but for the most part, reducing our fossil fuel emissions has been the main focus of international policies to keep global warming under control, and there's been very little room left at the table for any other ideas and agendas.

THE NEGLECTED LEVER

Why haven't we paid more attention to CDR? There are many possibilities. One is that most CDR solutions are still experimental and not widely deployed. Because of this, forecasts about our future CDR capabilities typically come preloaded with judgments about readiness and scalability, plus likely costs, environmental impacts, resource limitations, public support, market viability, and more.

Strategic bias has also been a factor. CDR is still portrayed, although less today than in years past, as a handout to oil companies that will only delay our progress on emissions reductions. Therefore,

Figure 3. Net anthropogenic CO2 levels and temperatures, 2025-2200

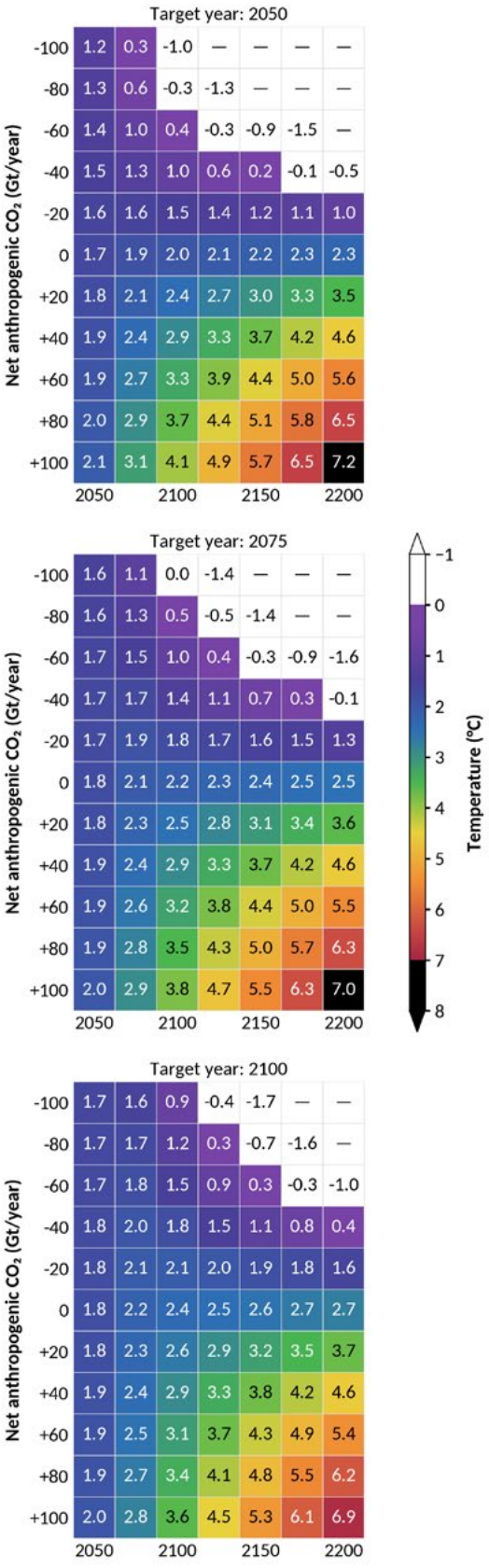


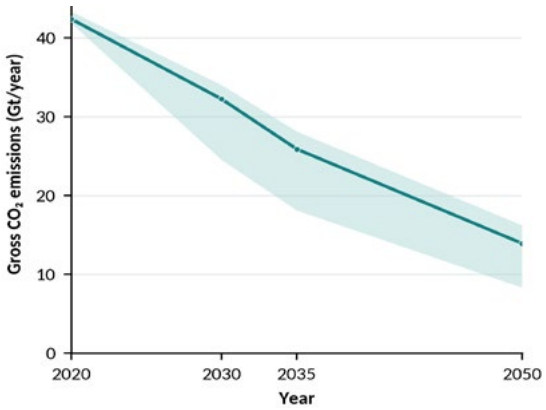
Figure 3 note: These calculations assume net anthropogenic CO2 emissions change steadily (in identical amounts over the same time, and that other emissions follow the same trajectories) from current levels to the indicated net value, reaching these in either 2050, 2075, or 2100 and maintaining them through 2200. CMIP7's Medium pathway is used for non-CO2 emissions The cells show median temperatures at 25-year intervals. Dashes indicate cells where at least 5% of the model runs gave invalid results. Negative temperature values are mathematical outcomes, not policy recommendations. See the Methods section for additional details.

our climate policies typically skew toward recommending the least amount of CDR possible while relying primarily on emissions reductions to reach net zero. For example, the Science Based Targets initiative (SBTi) — a highly influential global climate coalition that defines and validates corporate net-zero standards — requires companies to make deep emissions cuts (often around 90%) before they can count CDR toward their net-zero targets (SBTi 2026). CDR is treated as a reward for reaching our decarbonization goals rather than a tool to help us get there.

Maybe the most pervasive influence, though, has been misinterpreting the UN's prescriptive policy advice — the models the UN uses to show the world what it needs to do to reach net zero — as descriptive advice instead. For example, Figure 4a shows 401 mitigation scenarios developed by independent research teams and assessed by the IPCC. In these pathways, median gross CO2 emissions are projected to decline by 62–80% between 2020 and 2050 (Ganti et al. 2024). Similarly, Figure 4b illustrates the steep emissions decline typical of Paris-aligned pathways. These models are intended to describe what the world should do to reach net zero, but the policymaking world often uses them to predict how much CDR we will need to deploy instead. Somewhere around 10 Gt/y has been the recommendation inferred from depictions such as this — the CDR goal typically cited by policymakers — even though this calculation depends on our fossil fuel emissions dropping precipitously starting immediately (or in the case of Figure 4a, starting five years ago). Indeed, a recent forensic literature review by University of Washington researcher Rebecca Neumann suggests that interpretations (and misinterpretations) about how quickly our fossil fuel emissions will decline may be a major reason why CDR recommendations vary so widely from one set of recommendations to the next (Neumann 2026).

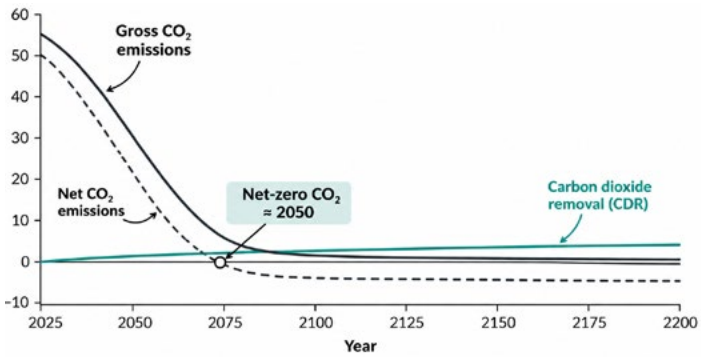
This disconnect has been obvious for years. Beck and Mahony (2018) argue that when IPCC-assessed climate pathways are constructed to meet predetermined temperature goals (like 1.5°C), these conditional scenarios can become influential policy blueprints rather than remaining neutral explorations of possible futures. The authors observe that important modeling qualifications can be lost in this process as scientific findings get translated into policy, blurring the distinction between what is possible and what is expected. Similarly, van Beek et al. (2020) note that policymakers' desire for predictions is fundamentally at odds with the explicitly non-predictive nature of the

Figure 4a. 401 IPCC mitigation scenarios



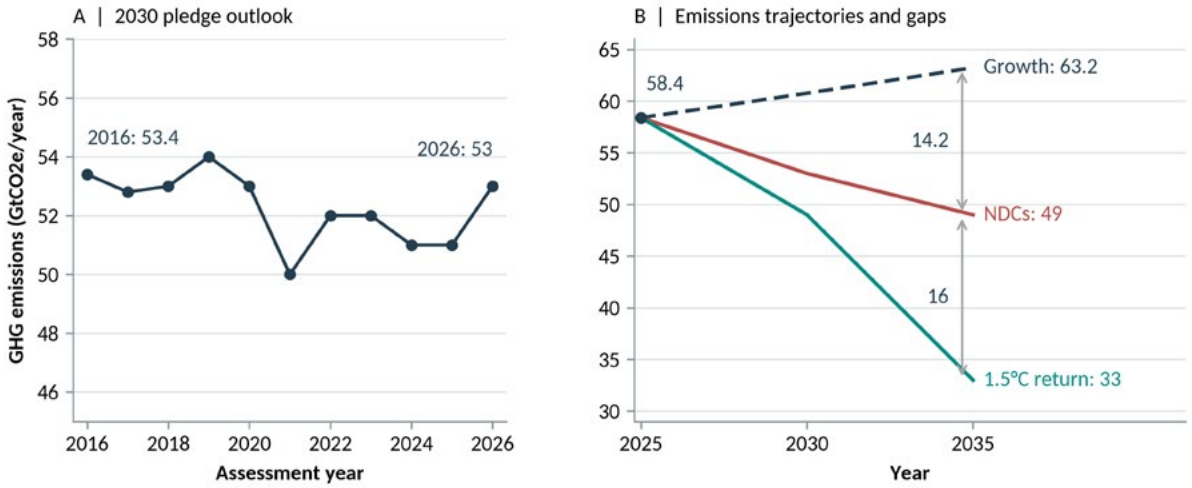
Source: Ganti et al. (2024).
Note: The solid line shows the weighted average of category medians across three IPCC pathway categories (C1–C3; see Figure 4b notes for description). The shaded area shows the range.

Figure 4b. Simplified IPCC AR6 emission pathway



Note: In international climate negotiations, UNEP Emissions Gap Reports, and national net-zero pledges, IPCC AR6 Category C1 (limit warming to 1.5°C with no or limited overshoot) and Category C2 (return warming to 1.5°C after high overshoot) pathways receive the overwhelming majority of policy attention. They are the benchmark against which national commitments (NDCs) are measured. Nearly all of these "Paris-aligned" pathways share this general shape: a sharp, immediate drop in gross CO2 emissions starting now, reaching net zero around 2050–2070, paired with moderate-to-large CDR deployment later in the century.

Figures 5a & 5b. Government GHG-reduction pledges (NDCs) vs. trajectories



Sources: UNEP Emissions Gap Reports (2016–2026), especially the 2026 edition; Global Carbon Budget 2025; IPCC AR6.
Notes: Emissions are expressed in CO2 equivalents (GtCO2e), which account for the different warming effects of greenhouse gases. CO2 represents roughly 75% of these emissions. Actual CO2 emissions, including land-use change, totaled approximately 42.2 Gt in 2025. Methane emissions are much smaller by weight but have contributed approximately 30% of historical warming. Methane traps about 80 times more heat per ton than CO2 over 20 years, although the standard emissions accounting uses a 100-year comparison.

models they use. This matters enormously when recommendations for future CDR deployment are based on emissions reductions that have yet to materialize (see Figures 5a and 5b).

This disconnect becomes all the more glaring when viewed against government commitments (their Nationally Determined Contributions, or NDCs) to rein in their GHG emissions. These NDCs have never increased high enough to make our Paris goals possible, and remain far below what might lead one to conclude that rapid fossil fuel reductions are on the horizon (see Figures 5a and 5b).

Taken together, despite our need for an effective counterbalance to continued fossil fuel use, we have not yet focused constructively on the role CDR needs to play. This isn't to say CDR is currently ready or able to contribute to our counterbalance efforts, just that we have yet to develop an objective estimate of how much CDR we might actually need (figuring out how to get there is another conversation altogether).

TOWARD MORE OBJECTIVITY

Encouraging a more clear-eyed evaluation of our possible CDR future is the purpose of this paper. We will begin by exploring the baseline idealized relationship between CO2 emissions and removals. To do this, we will first introduce a model called TIER, which stands for "Temperature Impact from Emissions and Removals." Second, we will explore a variety of emission-removal scenarios that can help shed light on how much of each we'll need in order to keep temperatures under control. And third, we will calculate the actual removal requirements for some of our more widely used CDR models, if we substitute their ideal (Paris-aligned) emissions assumptions with less favorable ones.

HAS THIS QUESTION ALREADY BEEN MODELED?

There is already substantial literature examining the relationships between emissions reductions, carbon dioxide removal, global temperatures, and the possibility of reversing climate change. Much of this work has been conducted through integrated assessment models (IAMs), which combine

assumptions about economic growth, energy systems, technology development, land use, government policies, and other factors to estimate future emissions and climate outcomes. Other studies employ complex Earth-system models and much simpler climate models to examine how the atmosphere, oceans, and terrestrial ecosystems respond to different emissions and removal scenarios (IPCC 2022; Ganti et al. 2024).

For example, the Coupled Model Intercomparison Project (CMIP), now entering its seventh phase, represents one of the most comprehensive efforts to compare possible climate futures. Its latest Scenario Model Intercomparison Project (ScenarioMIP) includes pathways ranging from continued high emissions to aggressive mitigation, delayed reductions, and sustained net-negative emissions. Some experiments extend centuries beyond 2100 and investigate the reversibility of global warming (van Vuuren et al. 2026). The Carbon Dioxide Removal Model Intercomparison Project (CDRMIP) has also explored climate reversibility, the response of natural carbon sinks to atmospheric CO2 removal, and the effectiveness and environmental consequences of different removal methods (Keller et al. 2018).

Other studies have concentrated more specifically on CDR deployment. The third edition of the State of CDR Report (hereafter referred to as SoCDR) evaluates the scale, timing, and composition of CDR across several modeled mitigation pathways, including scenarios representing existing national commitments, immediate ambitious mitigation, and delayed climate action (Gidden et al. 2026). Ganti et al. (2024) examine the relative contributions of emissions reductions and CDR in achieving climate objectives, while Bindl et al. (2025) investigate the consequences of planning for CDR deployment levels that subsequently prove difficult or impossible to achieve. More recently, Schwinger et al. (2026) have examined methodological challenges in evaluating the atmospheric effectiveness of CDR and separating removal activities from the broader socioeconomic scenarios in which they are embedded. These studies provide much of the scientific foundation for the present analysis.

This report builds on these studies but approaches the question of CDR differently. Rather than relying on baked-in assumptions about emissions trajectories, technology limits, Paris targets, and so on, the TIER framework used in this report calculates relationships. What happens when CO2 emissions are x and CO2 removals are y? Without prejudging the inputs or predetermining the outputs, we can develop a more mathematical assessment of what our CDR needs might actually be. This is not to diminish the importance of IAM-style assessments — only to emphasize that simply in terms of raw numbers, emissions versus removal, we have yet to develop an unweighted approximation of these values. TIER can help model this relationship.

TIER can be configured in a number of different ways to look at temperature impacts across time and regions, explore peak warming impacts and years above 2°C, explore different emission and removal pathways against each other, and more, allowing policymakers to easily compare the impacts of various pathway combinations. Table 1 compares the TIER framework with other studies or frameworks.

We hope the resulting analysis can address two complementary questions. First, what temperature outcomes follow from different combinations of emissions reductions and CDR deployment? And second, what combinations of emissions reductions and removals might be required to achieve our desired climate outcomes, such as limiting warming to 2°C, stabilizing temperatures after an overshoot, or eventually returning temperatures to preindustrial levels? These questions are well established in climate research, but TIER brings them together in a consistent framework that makes the trade-offs easier to visualize — and in doing so, might make it possible to explore climate futures that current scenarios haven't yet revealed.

Table 1. Comparison of TIER with existing climate and CDR modeling frameworks

STUDY OR FRAMEWORK	PRINCIPAL FOCUS	METHODOLOGICAL APPROACH	TIER'S APPROACH
Climate Action Tracker (CAT)	How current government policies and climate pledges affect future warming	Combines national emissions projections into four global policy scenarios and estimates temperatures using MAGICC7	TIER is a comparative framework that independently varies two key climate mitigation actions: emissions reductions and carbon dioxide removal. It evaluates 121 combinations of annual emissions and removal trajectories on a consistent scale, examining their temperature consequences through 2200. Unlike frameworks that assess existing policies or adopt integrated socioeconomic pathways, TIER explores a wide range of possible futures, including persistent or rising emissions and CDR deployment well beyond current expectations. Its purpose is not to predict which pathways are most likely, assess their economic or technological feasibility, or evaluate the secondary impacts of individual CDR methods. Rather, it isolates the temperature consequences of different combinations of emissions and removals to help identify the scale and timing of mitigation that may be needed under different circumstances.
En-ROADS	How different climate policies and technologies interact to affect warming	Interactive climate simulator with adjustable inputs for emissions reductions, energy systems, and CDR	
CMIP7 ScenarioMIP (2026)	Climate outcomes under different possible emissions futures, including overshoot and reversal	Coordinated scenarios drawing on IAM projections and Earth-system modeling	
CDRMIP (2018–present)	Climate reversibility, carbon-cycle responses, and effectiveness of CDR	Controlled Earth-system experiments, including idealized CO2 removal and climate-reversal experiments	
SoCDR, third edition (2026)	CDR requirements, deployment pathways, and feasibility under different mitigation ambitions	Multi-model assessment of scenarios, including Paris-consistent pathways	
Ganti et al. (2024)	Contributions of gross emissions reductions and CDR to climate objectives	Analysis of mitigation pathways assessed in the IPCC literature	
Bindl et al. (2025)	Risks of planning for CDR deployment levels that differ from what becomes feasible	Integrated assessment and decision analysis under uncertain CDR availability	
Schwinger et al. (2026)	Atmospheric effectiveness of CDR and the construction of scenarios without CDR	Earth-system modeling framework comparing scenarios with and without removal activities	

Sources: Climate Action Tracker (2026); Climate Interactive/En-ROADS (2026); van Vuuren et al. (2026); CDRMIP; SoCDR (2026); Ganti et al. (2024); Bindl et al. (2025); Schwinger et al. (2026). The comparisons are our summary.

METHODS

CDR SCOPE AND ACCOUNTING

TIER treats emissions reductions and CDR deployment as independent inputs. Its removal trajectories include both conventional land-based CDR and novel approaches, following the broad accounting used in the latest SoCDR.[9] While our strong preference is to consider the baseline for our current CDR progress as close to zero — we have delivered only 1.7 megatons of durable CDR to date, which is a rounding error compared to the gigaton levels of CDR we need[10] — SoCDR estimates our current levels as approximately 2.2 gigatons per year instead (Gt/y). These represent existing conventional removals, primarily associated with forests and land management. They are climati-

9. Coordinated by the University of Oxford, SoCDR — now in its 3rd edition — has quickly emerged as the most accessible and authoritative summary reference on CDR progress. Hundreds of authors are involved in analyzing issues ranging from technology to finance to policy developments.

10. See CDR.fyi reports for the latest figures.

cally relevant but difficult to verify, prone to reversal, and not necessarily additive — these removals aren't all happening deliberately as a result of our CDR efforts. Nevertheless, excluding them would make TIER's numerical targets difficult to reconcile with commonly cited CDR goals and calculations, so TIER will also use 2.2 Gt/y as our baseline CDR level, without agreeing that doing so is scientifically justified; it's a necessary statistical concession.

CLIMATE MODEL AND SCENARIO INPUTS

TIER uses the FaIR 2.2.5 climate model (Leach et al. 2021; Smith et al. 2024) to evaluate 121 combinations of eleven gross anthropogenic CO2 emission pathways (E0–E10) and eleven CO2 removal pathways (R0–R10). Each combination was run from 1750 through 2200 using 841 constrained climate-parameter configurations, with internal stochastic variability disabled to isolate the modeled forced response. Before calculating, we evaluated our implementation against historical temperature observations and atmospheric greenhouse gas concentrations using the calibrated climate configurations from FaIR's FASTMIP v1.6.0 calibration dataset (Smith 2026) and were able to reproduce FaIR's published 2004–2023 warming averages for all configurations to within 0.00001°C (Smith 2026).[11] No artificial temperature offset has therefore been applied to TIER calculations. The model inputs, code, outputs and reproduction instructions are provided separately in a data file available online.

AVOIDING DOUBLE COUNTING

SoCDR estimates that humans are currently generating about 2.2 Gt/y of conventional CDR (we disagree, but again, will go along with this calculation to facilitate model comparison). But because this 2.2 Gt/y is baked into SoCDR's carbon removal estimates — as well as the estimates of many other models — and because we're trying to disaggregate emissions and removals for the TIER model, we add the 2.2 Gt/y back onto the emissions ledger, then subtract the same 2.2 Gt/y on the removals side. This keeps our starting net emissions at 42.2 Gt/y without counting removals twice. Therefore, we will define gross anthropogenic CO2 emission for our analysis as net levels plus 2.2 Gt/y, or 42.2 plus 2.2, or 44.4 Gt/y.[12]

RADIATIVE FORCING

Methane, nitrous oxide, aerosol precursors and other greenhouse gases are not included in E or R, only CO2. However, these GHGs will play important and changing roles as temperatures and net emissions change. TIER therefore assigns unique starting points for the FaIR model to use depending on E level (see Table 2). These starting points come from the CMIP7 ScenarioMIP version 1.1.1, covering nine pollutants. Other forcing inputs include the supplied solar, volcanic, land-use and irrigation series. Beyond 2100, non-CO2 emissions are extended using our own scenario assumptions.

UNCERTAINTY

The temperature estimates in this report are not certainties. For each TIER scenario, FaIR runs 841 different calculations, each using slightly different assumptions about how our climate responds to changes in atmospheric CO2 and other emissions. The median is the middle result. The 5th and 95th percentiles represent the lower and upper ends of the middle 90% of these results. The median is generally more representative of FaIR's estimates than either extreme, but none of these numbers is guaranteed to be correct.

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11. The calibration underestimates atmospheric nitrous oxide but we have not adjusted the results to compensate

12. This is not an independently measured gross-emissions estimate, just our accounting-adjusted reference. For additional discussion about the 2.2 Gt/y estimate, see Edwards et al. (2026).

NO OTHER INFLUENCES

We will assume for this analysis that CDR is the only tool available to us for keeping temperatures under control — we won't use any geoengineering tools like solar radiation management.[13] This assumption isn't realistic, of course, because these tools may well end up being deployed if our planet's temperatures start rising too quickly, but holding external influences constant is a necessary condition for our analysis. We will also assume that our CDR solutions will work at scale and will be affordable, and sustainable, setting aside our prejudgments. And finally, we will assume that our climate won't experience tipping points during periods of increasing temperatures, which would introduce an unknown change, and that temperature reductions would actually occur as modeled (here again, confidence on both of these points is not warranted, but it is necessary for this analysis).[14]

Table 2. Mapping emissions-reduction scales to non-CO2 inputs

TIER E SCALE	SCENARIOMIP CATEGORY USED AS QUALITATIVE ANALOGUE	QUALITATIVE NON-CO2 EMISSIONS ASSUMPTIONS (NOT NUMERICAL E OR R DEFINITIONS)
0–2	High (H)	Rising CH4 and N2O; partial aerosol decline
3	65% H / 35% M	Intermediate H–M inputs
4	25% H / 75% M	Near-Medium with stronger growth
5	Medium (M)	CH4 stable to moderately rising; N2O rising; substantial aerosol-pollution decline
6	65% M / 35% ML	Intermediate M–ML inputs
7	25% ML / 75% L	Intermediate ML–L inputs
8	Low (L)	Strong CH4/N2O mitigation; declining aerosols
9	Very Low (VL)	Rapid greenhouse-gas mitigation; strong aerosol reductions
10	Very Low (VL)	Same VL non-CO2 emissions assumptions as E9; E10 differs in its CO2 pathway alone.

Source: The seven emission reduction pathways identified in CMIP7 are H (High), HL (High to Low), M (Medium), ML (Medium to Low), L (Low), LN (Low to Net Negative), and VL (Very Low), from the official ScenarioMIP v1.1.1 (Kikstra et al. 2026). The percentage blends and assignments of E levels to those markers are TIER design choices, not official CMIP7 E levels.

RESULTS & DISCUSSION

THE TIER FRAMEWORK

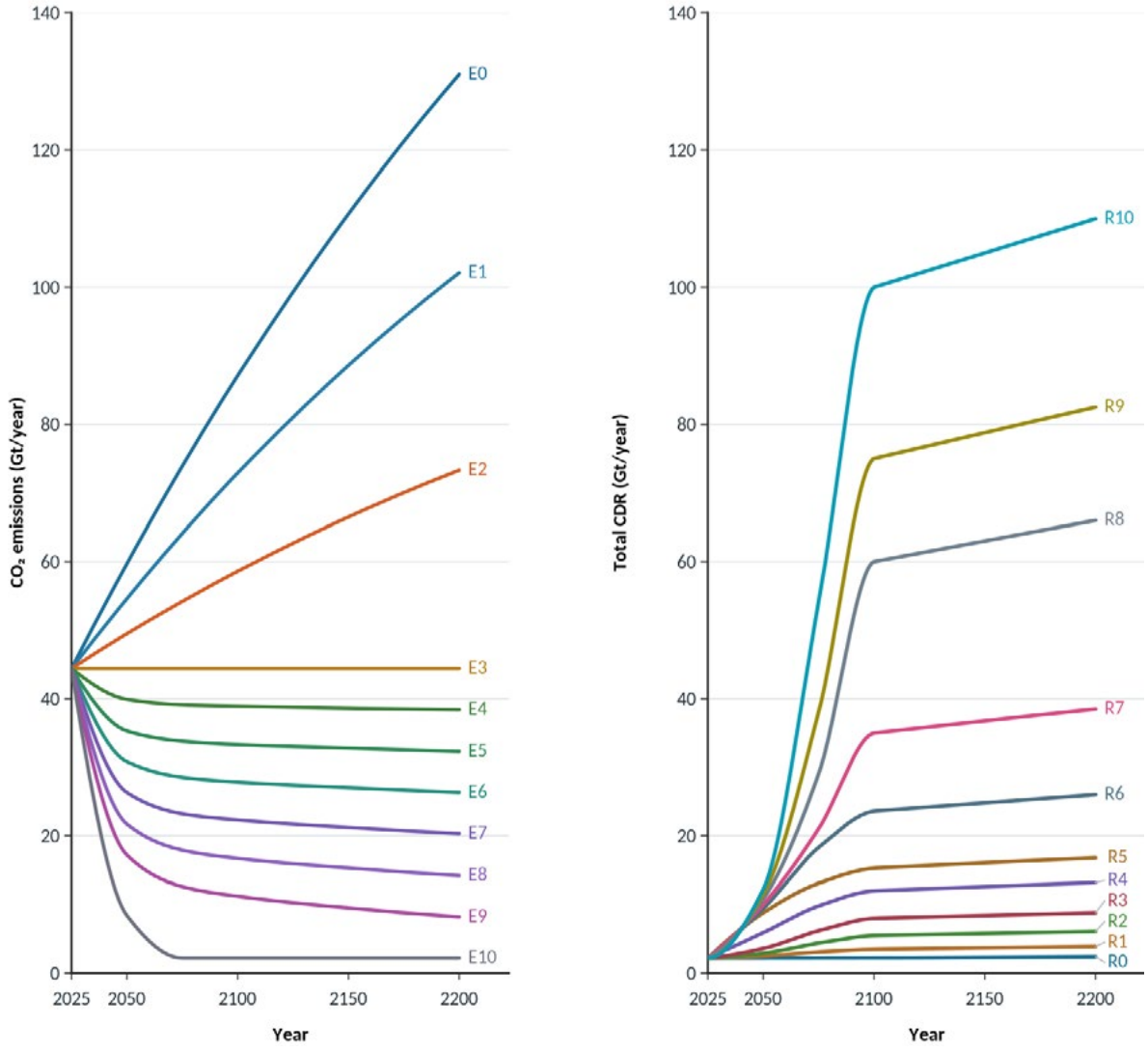
TIER (Temperature Impact from Emissions and Removals) is an emissions-removals scenario framework that compares outcomes from many different combinations of idealized CO2 emissions reduction and removal pathways. Each unique TIER pathway combination is identified via two suffix labels — E and R — where E represents the emissions reduction pathway, and R represents the removal pathway (or in other words, how much CDR we will deploy). Both E and R pathways are ranked on a scale from 0-10, where lower numbers indicate lower ambition, and higher numbers indicate higher ambition. In written form, for example, TIER 1/5 would represent a model with low emission reduction ambition and modest CDR ambition.

13. Temperatures may indeed increase to the point where we need to seriously consider deploying a variety of geoengineering solutions while we develop our CDR capacity and reduce emissions. While these solutions currently lack broad public support, and have not been tested at scale to determine their effectiveness or unintended consequences, we do have real-world evidence of their potential. For example, we know volcanic eruptions inject sulfur dioxide gas high into the atmosphere where it acts like a mirror that keeps our planet cooler. The 1883 Krakatoa eruption lowered global temperatures by around 0.5°C for several years. And humans have already mimicked this effect, albeit inadvertently. The sulfur dioxide cargo ships emitted for decades brightened marine clouds; following the implementation of strict new international shipping fuel rules in 2020, this accidental cooling effect diminished, contributing to a subsequent spike in global temperatures.

14. FaIR is a reduced-complexity climate model that captures many important climate relationships but does not resolve the full range of processes represented in more sophisticated Earth-system models.

Figure 6 and its data tables (Tables 3 and 4) on the following page describe the TIER emission reduction and carbon dioxide removal scales. The emission scales E are idealized, constructed to represent a wide range of discrete pathways.[15] The same is true of TIER's removal scales R, which have S-shapes typical in technology adoption settings (except for R0) and are widely distributed, but aren't necessarily patterned after existing models. A baseline of 2.2 Gt/y of CDR is assumed for our calculations, representing current levels of nature-based removals (as explained in the Methods section). An applied version of TIER will be discussed later which evaluates more familiar emission and removal pathways. For comparison purposes, the three median removal pathways used by SoCDR are plotted in Figure 7 (Delayed Ambition, Highest Ambition, and Targets & Pledges) alongside the lower ambition TIER pathways (R1 through R6).[16]

Figure 6. TIER pathways, 2025–2200



15. See Tables 3 and 4 on the opposite page for pathway checkpoints by 25 year intervals. Annual emissions and removal levels between checkpoints are calculated using shape-preserving piecewise cubic interpolation. The intent of this distribution is to explore a wide range of plausible and consistent pathways that don't intersect in order to maximize the clarity of our matrix comparisons.

16. SoCDR models are evaluated later in this report.

Table 3. TIER emission reduction (E) pathways, 2025–2200 (CO2 levels in gross Gt/y)

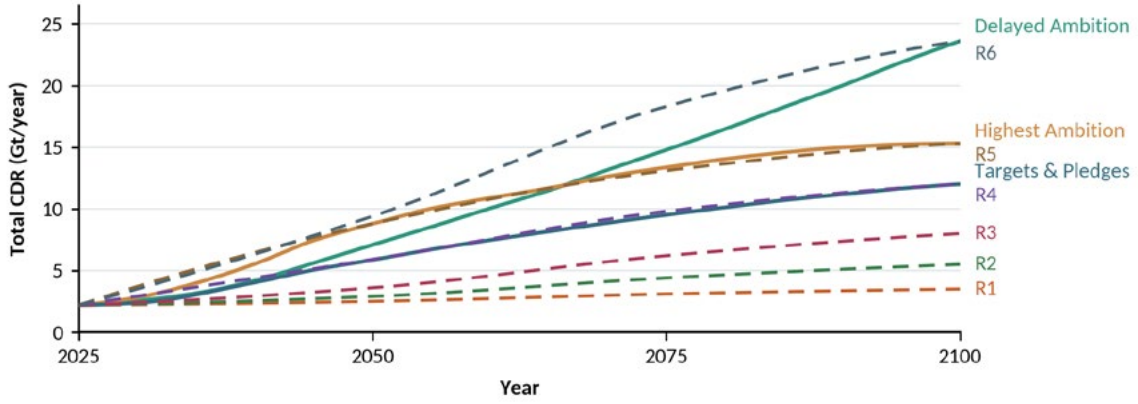
LEVEL	2025	2050	2075	2100	2150	2200	DESCRIPTION
E0	44.4	59.7	73.9	87.1	110.7	131.0	Continued strong growth
E1	44.4	54.6	64.1	72.9	88.6	102.1	Substantial emissions growth
E2	44.4	49.5	54.2	58.6	66.5	73.3	Moderate sustained growth
E3	44.4	44.4	44.4	44.4	44.4	44.4	Constant baseline emissions
E4	44.4	39.9	39.1	38.9	38.6	38.4	Very limited reductions
E5	44.4	35.3	33.8	33.3	32.8	32.3	Slow reductions; persistent residuals
E6	44.4	30.8	28.5	27.8	27.0	26.3	Moderate emissions reductions
E7	44.4	26.3	23.2	22.3	21.2	20.3	Stronger reductions
E8	44.4	21.7	17.9	16.7	15.3	14.2	Deep emissions reductions
E9	44.4	17.2	12.6	11.2	9.5	8.2	Very deep emissions reductions
E10	44.4	8.4	2.2	2.2	2.2	2.2	Anthropogenic CO2 emissions eliminated by 2075 (except for land use)

Table 4. TIER carbon dioxide removal (R) pathways, 2025–2200 (in Gt/y)

LEVEL	2025	2050	2075	2100	2150	2200	DESCRIPTION
R0	2.2	2.2	2.2	2.2	2.3	2.4	Existing conventional CDR; 10% rise after 2100
R1	2.2	2.5	3.1	3.5	3.7	3.9	Minimal additional deployment
R2	2.2	2.9	4.4	5.5	5.8	6.1	Low deployment
R3	2.2	3.6	6.2	8.0	8.4	8.8	Low–moderate deployment
R4	2.2	5.9	9.8	12.0	12.6	13.2	SoCDR Targets & Pledges benchmark
R5	2.2	8.8	13.1	15.3	16.1	16.8	SoCDR Highest Ambition benchmark
R6	2.2	9.4	18.3	23.6	24.8	26.0	SoCDR Delayed Ambition benchmark (approximate)
R7	2.2	10.0	21.0	35.0	36.8	38.5	Experimental: elevated deployment
R8	2.2	10.8	29.0	60.0	63.0	66.0	Experimental: extensive deployment
R9	2.2	11.5	38.0	75.0	78.8	82.5	Experimental: extreme deployment
R10	2.2	12.2	54.0	100.0	105.0	110.0	Experimental: maximum deployment

Note: All R pathways rise 10% from 2100 to 2200.

Figure 7. TIER R1-R6 pathways versus SoCDR pathways, 2025–2100



Source: TIER-defined E/R pathways and SoCDR (2026).

NET ZERO VARIANT

Figure 8 shows the shape and progression of the net zero curve across the 121 different combinations of TIER's 11 emissions pathways and 11 CDR pathways. If E and R changed equally at the same time, net zero would cut a diagonal across our matrix from top left to bottom right. But since emissions will likely decline gradually over time, and CDR will likely follow more of an S-shaped increase (or a combination of S-shaped increases depending on whether we deploy one technology or many), our net zero line evolves less predictably.

From this depiction, note how only dramatic emissions reductions combined with equally dramatic CDR will allow us to reach net zero by 2050 (following TIER's prescribed E and R pathways). By 2075, a few more combinations are possible, and a few more again by 2100. Beyond 2100, however, the curve barely moves (the visual difference is negligible), which is to say that we will never reach net zero in the coming decades without very high E, or with more modest E and very high R.

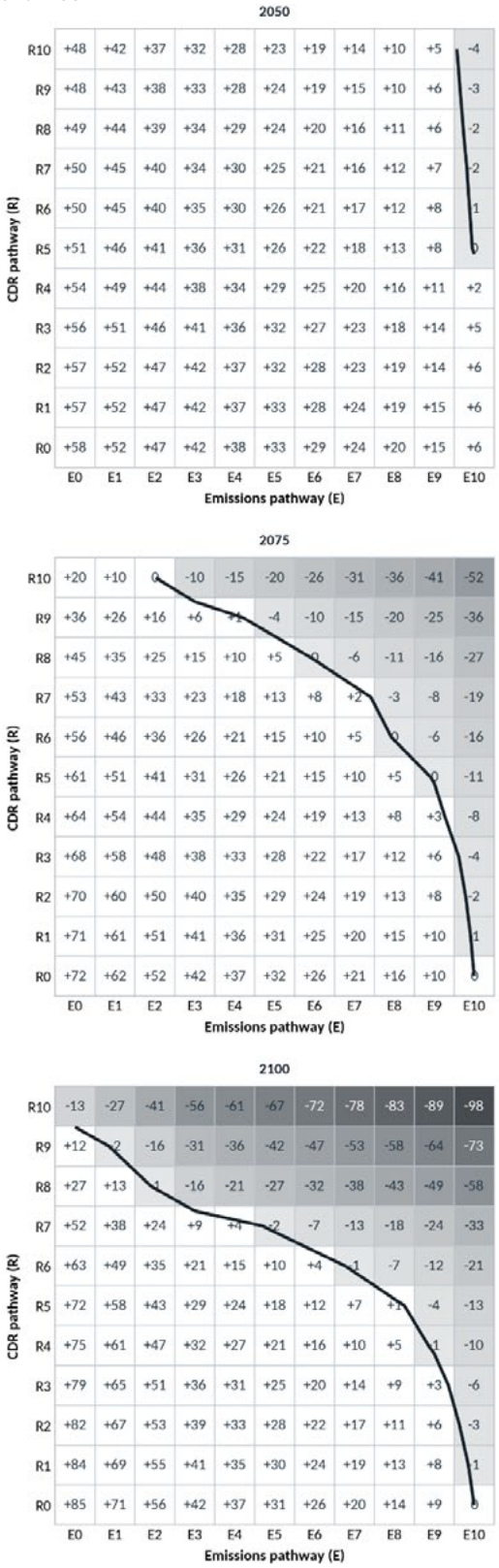
This isn't a surprise, of course, but we often speak about reaching net zero as a function of very high E and only low-to-modest R. Other combinations are possible, but none that combine only modest E and R ambitions. We will need significant progress on either or both scales. For example, a noteworthy but modest 10% drop in emissions over the next 25 years (to about E4) will need to be paired with highly ambitious removals of 35-60 Gt/y (R7-R8) in order to reach net zero by 2100.

This is just the net zero math, however, not the temperature math. What will our future temperatures look like for these different pathway combinations?

TEMPERATURE VARIANTS

The next TIER matrix illustrates how our emission reduction and removal pathways might combine to keep temperatures below 2°C. As we noted with the net zero comparison, the future favors high-ambition E and R pathways, not modest combinations of both. Consider the TIER 8/4 pathway, for example, where we've managed to cut emissions roughly in half by 2050 (to 21.7 Gt/y) and to 16.7 Gt/y by 2100; the R4 pathway requires 12 Gt/y of CDR deployment by 2100. This combination of ambitious emissions reduction with more modest but still ambitious CDR results in a median tempera-

Figure 8: Net anthropogenic CO2 flows in 2050, 2075, and 2100



Note: Net zero regions shaded. Line represents approximate net zero combinations of E and R.

ture increase of about 1.9°C above preindustrial levels in 2100, even though net CO2 levels are still hovering above net zero at around 5 Gt/y.[17]

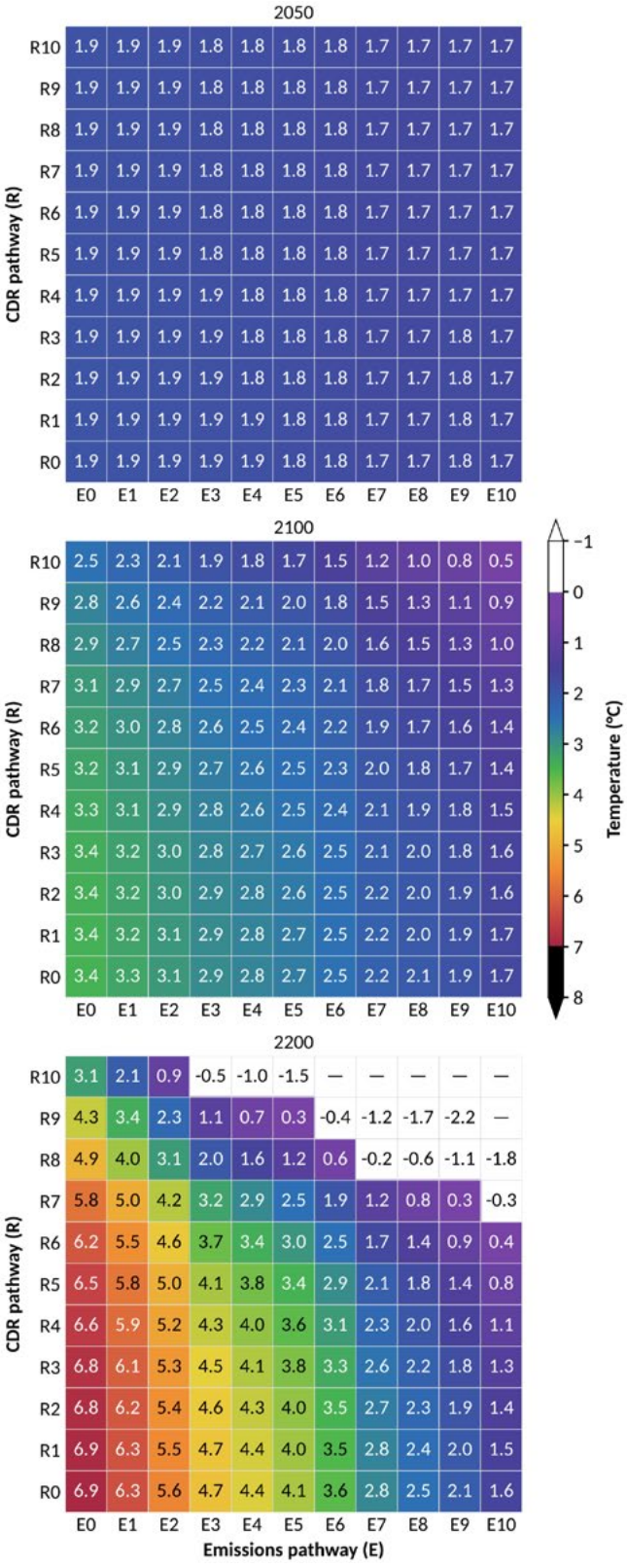
Conversely, the TIER 4/8 pathway we mentioned previously — where our emissions are ticking down slowly over the course of this century — might require R10 levels of removals in 2100 (100 Gt/y) to bring median warming below 2°C, even though emissions at this point are net negative. The combination of slowly reducing emissions and slowly developing CDR capacity will have conspired to allow temperatures to increase so much that only extreme levels of CDR will keep us below 2°C.

To this point — as we'll discuss more in the time variant section — speed matters. Failing to reduce emissions or deploy CDR in a timely manner will have implications for temperatures, as well as for our pathway options.

PEAK TEMPERATURE VARIANTS

Peak temperatures are another helpful visualization we can generate using TIER. In this representation (see Figure 10 on the following page), we aren't only interested in what temperatures we will experience at different times, but how high temperatures will reach in the interim. If our goal is to always stay below 2°C, then a matrix of peak temperatures between now and 2200 makes clear which pathways, if any, might make this possible. For pathway E5 (where we reduce our current CO2 emissions 20% to 35.3 Gt/y by 2050) and below, for example, no amount of CDR deployment less than 100 Gt/y by 2100 will suffice. Even at E6 (a roughly 30% cut by 2050) we may need to deploy R9 levels of CDR (about 75 Gt/y) to stay below 2°C.

Figure 9. TIER median temperature projections, 2050, 2100, and 2200



Note: Dashes indicate cells where at least 5% of model runs gave invalid results. Negative temperature values are mathematical outcomes, not policy recommendations.

17. The IPCC describes an approximately linear relationship between cumulative net CO2 emissions and global warming. Its central estimate is that for each 1,000 Gt of CO2 of additional cumulative emissions, approximately 0.45°C of additional warming will occur (with a range of 0.27–0.63°C). If the E8/R4 net emissions remained at +4.7 Gt/y, their approximate additional contribution to warming would be about 0.02°C over 10 years, 0.11°C over 50 years, and 0.21°C over 100 years (without also considering other influences like changes in methane or radiative forcing). Consequently, the total global temperature could temporarily stabilize at this level — or even decline — despite slightly positive net CO2 emissions. (IPCC 2021)

YEARS ABOVE 1.5°C AND 2°C VARIANTS

A variation on our peak temperature calculation is years above 1.5°C and 2°C (see Figure 11). Which pathway combinations give us the best chance of limiting long-duration overshoot and the damage it will cause? As the 1.5°C matrix shows, even the most aggressive emission reductions and removal pathways might result in decades of future temperatures above this level; less ambitious pathways might stay above 1.5°C essentially forever (barring some other influence).

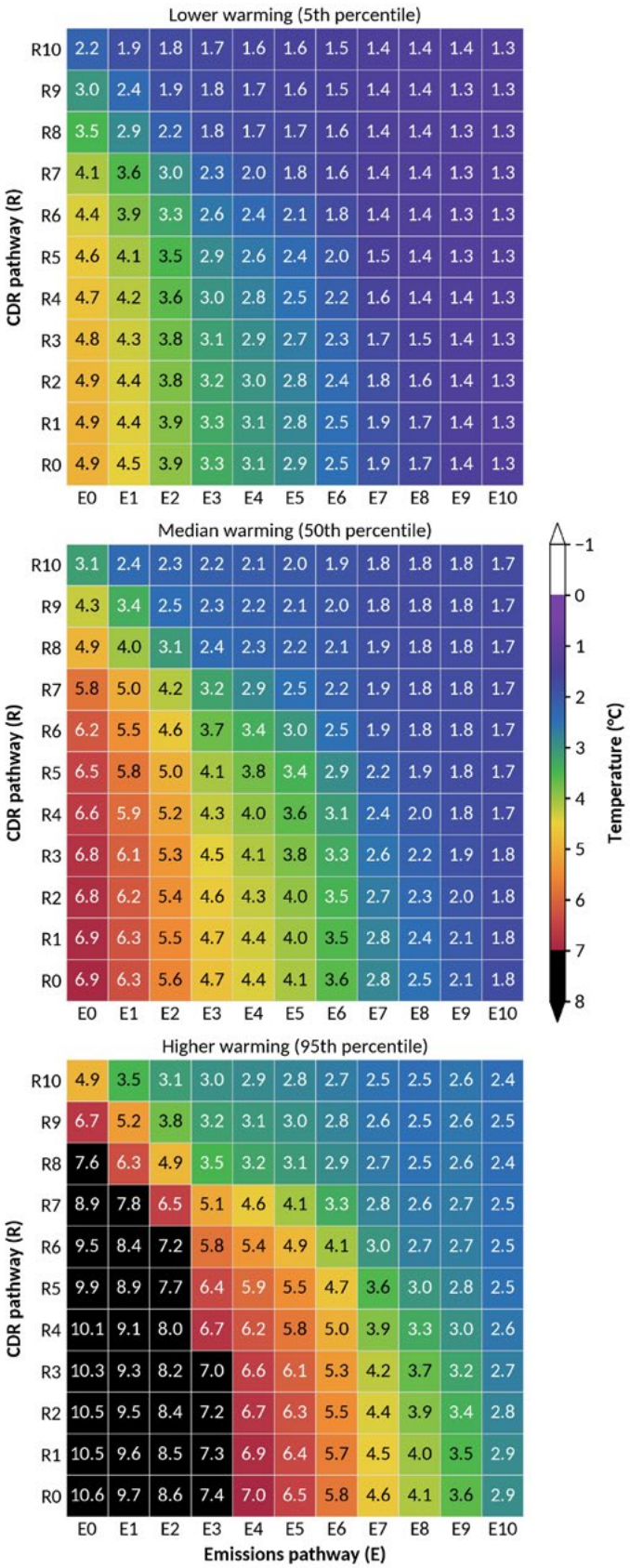
The news is slightly better regarding years above 2°C, but only for pathways with ambitious emissions reductions. Still, even though highly successful emissions reduction programs might be able to avoid 2°C, minimizing years above 1.5°C requires significant CDR.[18]

OTHER TIME VARIANTS

We can also use TIER to explore a variety of time-related outcomes. For example, TIER can be calculated in three dimensions (with time in years along the z-axis), creating detailed surface maps of pathway combinations. Or we can calculate static two-dimensional representations of temperatures at specific points in time (as we've done so far), or even calculate TIER combinations with implementation delays.

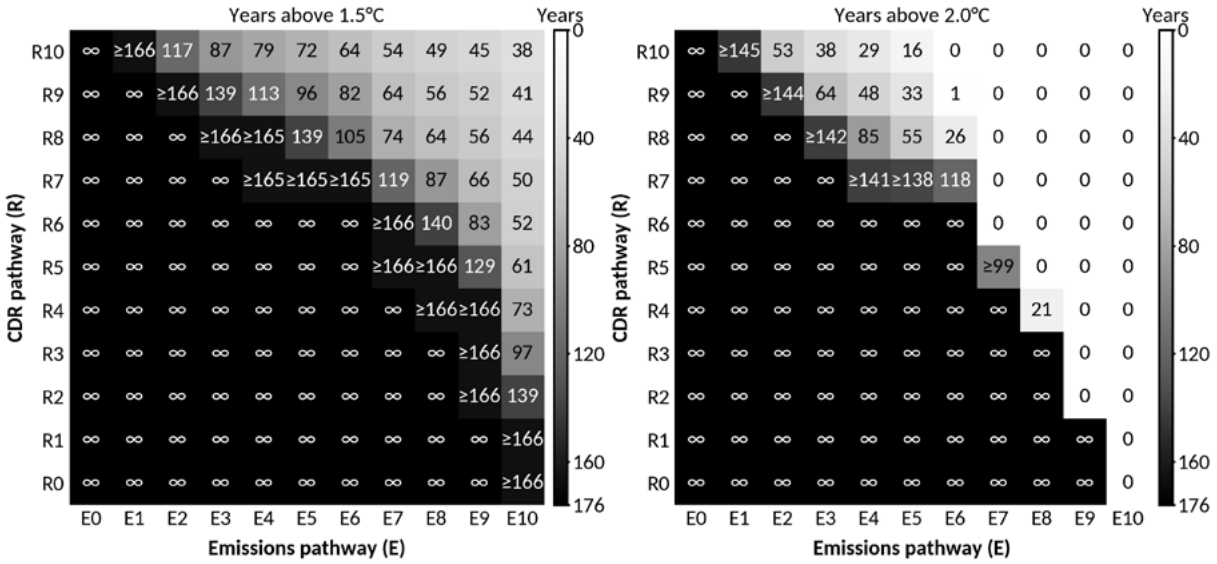
Consider the TIER 7/6 pathway, for example, which allows us to hold temperatures to 1.9°C in 2100 with R6 levels of CDR — relatively modest compared to higher R pathways. TIER 7/6 might even lower temperatures to 1.7°C in 2200. But what happens to these ambitions if we delay them by 10 or 20 years? Figure 12 shows the consequences. TIER 7(20)/6 represents a 20-year delay in E, TIER 7/6(20) represents a 20-year delay in R, and so on. As you can see, delaying both E and R by 20 years results in temperatures that are 0.26°C higher in 2100 and 0.31°C higher in 2200, pushing us over 2°C in both cases. An otherwise promising pathway ends up being inadequate.

Figure 10. Peak temperatures by 2200



18. Again, assuming we don't also deploy geoengineering measures to help keep our planet cool.

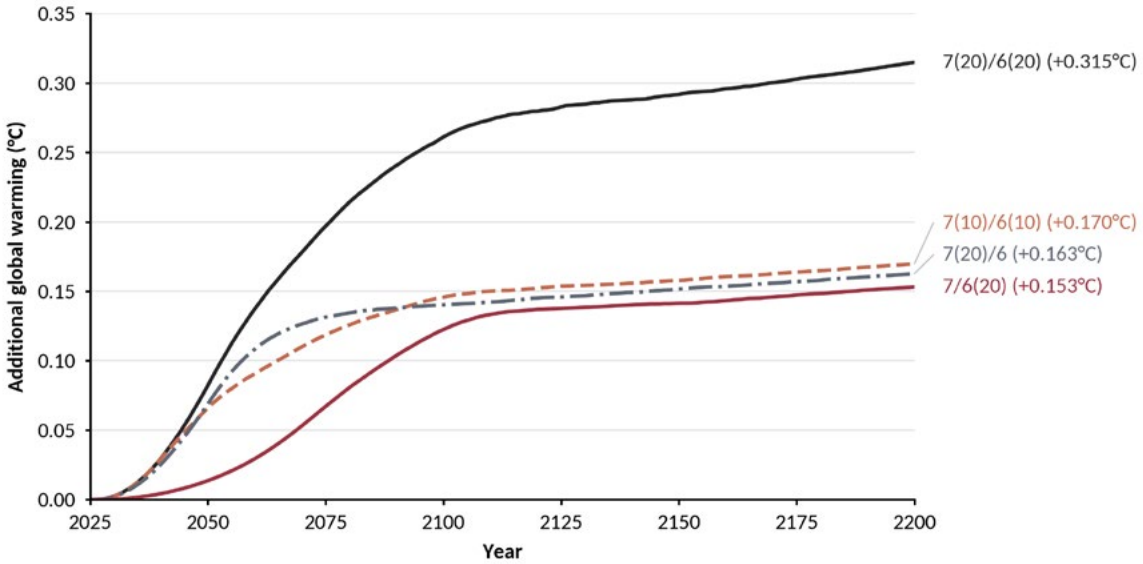
Figure 11. Years above 1.5°C and 2°C at various TIER levels



Note: The infinity symbol (∞) indicates pathways where warming is not expected to fall below the threshold without further intervention. Values preceded by ≥ indicate that temperatures remain above the threshold in 2200 but could decline afterward. These projections are conditional. TIER's calculations end in 2200, so indefinite warming is inferred rather than directly modeled.

Figures 13a and 13b (and their data tables, Tables 5 and 6) on the next page illustrate the generalized outcome of emission reduction and CDR implementation delays of 10 and 20 years. The temperature shifts are subtle but significant for our 2°C goals, with both delays closing off pathways that might otherwise be more achievable (at least relatively speaking).[19]

Figure 12. Temperature consequences of delayed ambition



Note: Assume we follow a TIER 4/4 pathway during the delay period — modestly ambitious — before finally getting on the 7/6 pathway.

19. These exact conclusions are obviously an artifact of our pathway shapes. Still, it stands to reason that delays will have an impact on temperatures and our choices for addressing them.

Figure 13a. Temperatures in 2100 with 10- and 20-year delays in CO2 emissions reduction

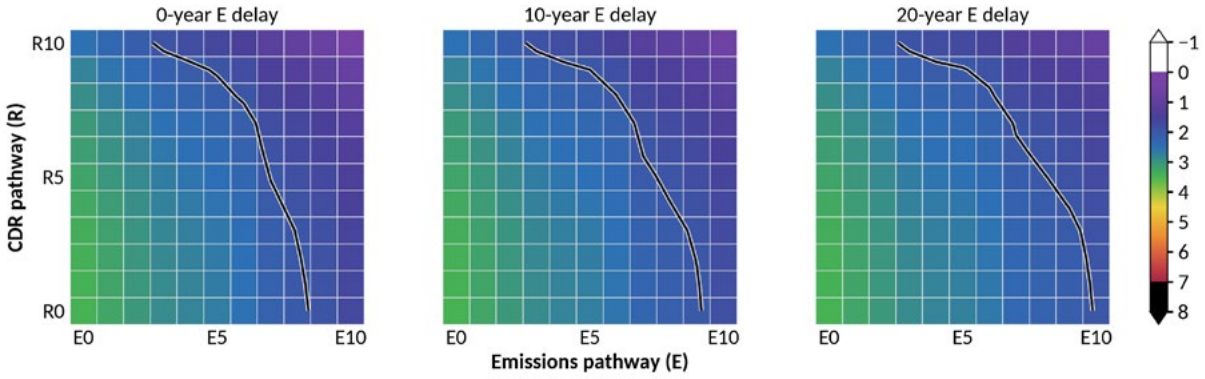


Table 5. Temperatures in 2100 with 10- and 20-year delays in CO2 emissions reduction

E DELAY	MEDIAN TEMPERATURE IN 2100	TEMPERATURE RANGE (5TH–95TH PERCENTILE)	ADDITIONAL WARMING FROM DELAY	RANGE OF ADDITIONAL WARMING	PATHWAYS BELOW 2°C IN 2100
0 years	2.34°C	1.08–3.79°C	—	—	43
10 years	2.38°C	1.20–3.81°C	+0.03°C	0–0.17°C	36
20 years	2.42°C	1.29–3.82°C	+0.06°C	0–0.32°C	32

Figure 13b. Temperatures in 2100 with 10- and 20-year delays in CDR deployment

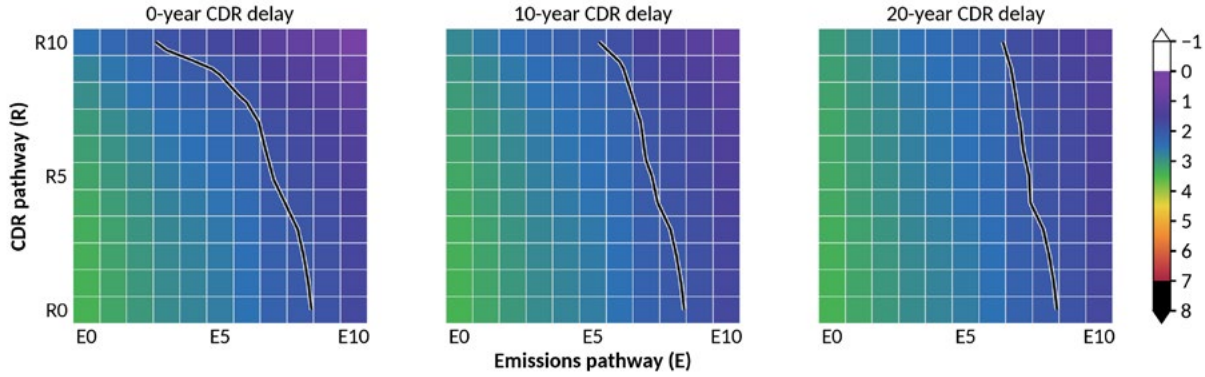


Table 6. Temperatures in 2100 with 10- and 20-year delays in CDR deployment

CDR DELAY	MEDIAN TEMPERATURE IN 2100	TEMPERATURE RANGE (5TH–95TH PERCENTILE)	ADDITIONAL WARMING FROM DELAY	RANGE OF ADDITIONAL WARMING	PATHWAYS BELOW 2°C IN 2100
0 years	2.34°C	1.08–3.79°C	—	—	43
10 years	2.43°C	1.25–3.85°C	+0.04°C	0–0.36°C	36
20 years	2.49°C	1.35–3.90°C	+0.07°C	0–0.62°C	33

OTHER PATHWAY-SPECIFIC VARIANTS

We can also use TIER to analyze specific pathways in more detail. For example, suppose our gross anthropogenic CO2 levels remain constant (level E3 in TIER). What would our CDR deployment requirements look like over time in this case, and what would be the temperature consequences of various deployment levels?

Figure 14 illustrates these outcomes. It's readily apparent that at E3, no amount of CDR deployment (among the options considered) will hold peak temperatures to 2°C, and R9-10 would be required to return temperatures to their current level or below by 2200 (75-100 Gt/y).

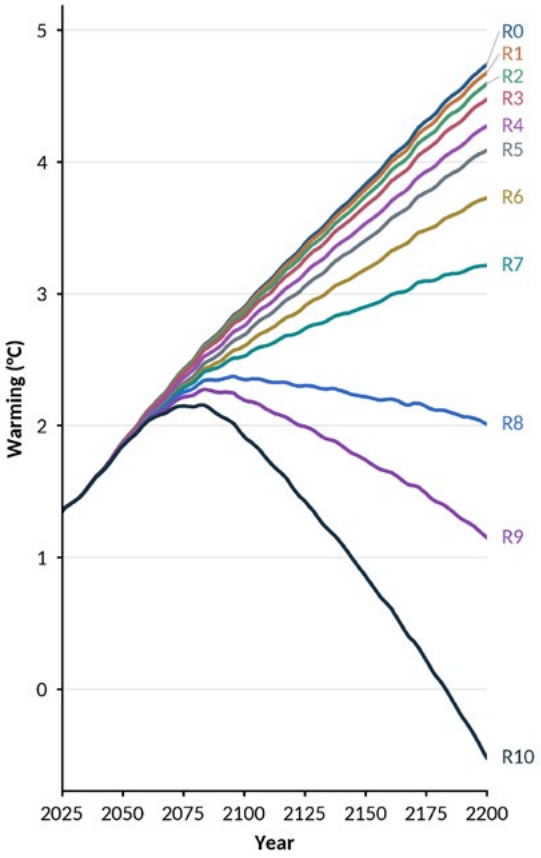
Pathway-specific analyses like these can help us test-drive our solutions to make sure they're fit for task, as well as make course adjustments over time as needed.

APPLIED VARIANTS

We can also develop applied variations of TIER, where we map established emission pathways against established CDR deployment pathways. These comparisons, which we'll refer to as TIER-A frameworks, can help us explore how established CDR models might perform using less favorable emission reduction assumptions.

Figures 17 and 18 on the following page, for example, show how SoCDR's main CO2 removal pathways (Figure 15, below) would fare across CMIP7's seven emission reduction pathways (Figure 16).

Figure 14. The impact of constant gross CO2 emissions on CDR needs and temperatures, 2025-2200



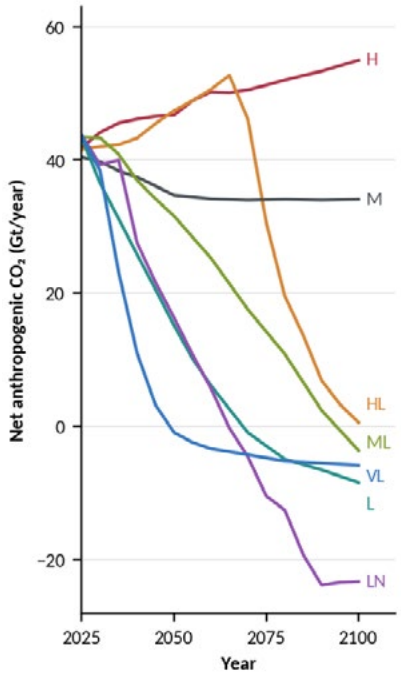
Note: For the R10 pathway, continuing with CDR after returning temperatures to preindustrial levels is just a mathematical representation, not a policy recommendation.

Figure 15. SoCDR CDR pathways and all 23 individual global IAM projections, 2025-2100



Source: SoCDR (2026)
Notes: The figure on the left is the median total CDR prescribed for the three main SoCDR pathways at different points in time (assuming 2.2 Gt/y in 2025). Lines between years are representative only and should not be interpreted as indicating CDR deployment levels. The right figure shows the 23 available projections included in these three main pathways (eight Targets & Pledges, seven Highest Ambition, and eight Delayed Ambition), with the black ticks indicating median values (which are plotted in the left figure).

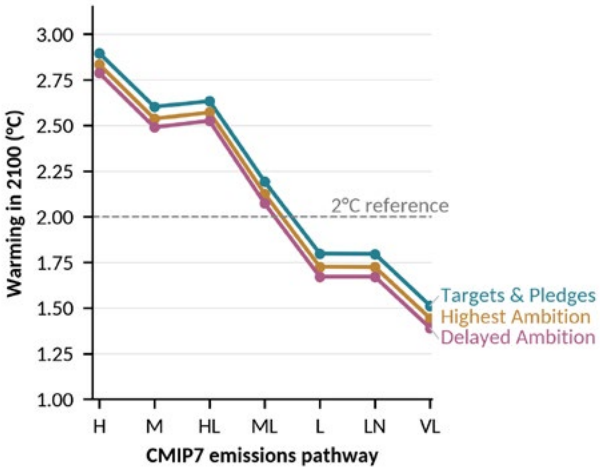
Figure 16. CMIP7 emission reduction pathways



CMIP7 SCENARIO	DESCRIPTION
High (H)	A policy failure pathway where climate targets are rolled back and emissions grow significantly.
High-to-Low (HL)	High initial emissions that peak around mid-century before being cut sharply to hit net-zero by 2100.
Medium (M)	The baseline reference track, which assumes the continuation of current global policies.
Medium-to-Low (ML)	Characterized by delayed global mitigation efforts followed by stronger emission reductions later in the century.
Low (L)	An aggressive mitigation pathway designed to successfully stabilize global warming below the 2°C threshold.
Low Net-Negative (LN)	A trajectory featuring a temporary temperature overshoot followed by massive-scale atmospheric carbon dioxide removal.
Very Low (VL)	The most ambitious Paris Agreement-consistent pathway, requiring rapid, immediate global decarbonization.

Source: IIASA ScenarioMIP-CMIP7 global ensemble, pre-release v0.1 (September 2026), seven marker-IAM pathways converted to Gt/y.
Note: These curves show net anthropogenic CO2 emissions, including CDR already counted in the CMIP7 pathways. For the TIER-A comparison, we added back each pathway's reported CDR before substituting the SoCDR removal path.

Figure 17. Warming by 2100 for three median SoCDR models across seven different CMIP7 pathways



Sources: SoCDR (2026) and 841-member FaIR 2.2.5 ensemble.
Notes: The lines connect distinct scenario categories, and are not intended to represent a continuous emissions scale.

As we can see from Figure 17 (left), the CDR deployment levels modeled by SoCDR — which are adapted from Paris-aligned Integrated Assessment Models used by the UNFCCC and IPCC — are sufficient to hold median warming below 2°C when paired with ambitious emissions reductions. Substituting a range of other plausible emission futures like CMIP7's High and Medium trajectories, however, results in temperature outcomes well above 2°C. Figure 18 on the following page describes the range of outcomes inside these models.

This is an important caveat for all our widely-referenced models, whose modest CDR requirements are also often based on Paris-consistent decarbonization pathways. Modest CDR recommendations don't hold up under less favorable emissions assumptions. Indeed, we can

reverse-engineer these models to see how much CDR would actually be required if their underlying emissions assumptions are less generous. Figure 19 on the following page does this for SoCDR's median Targets & Pledges model, exploring how much more CDR this model might require in order to keep temperatures below 2°C by 2100. As the figure shows, using CMIP7's Medium emissions pathway, the model's CDR requirements for 2100 rise from 12 Gt/y to a median of about 56 Gt/y — a substantially different target.

RESEARCHER VARIANTS

For researchers who want to construct their own emissions reduction and removal pathways, this approach also offers the research community the opportunity to compare and contrast different models. To maintain consistency, researchers should still use a 0-10 scale on both axes. Different frameworks can be identified by researcher name and year — for example, TIER-Smith(2026).

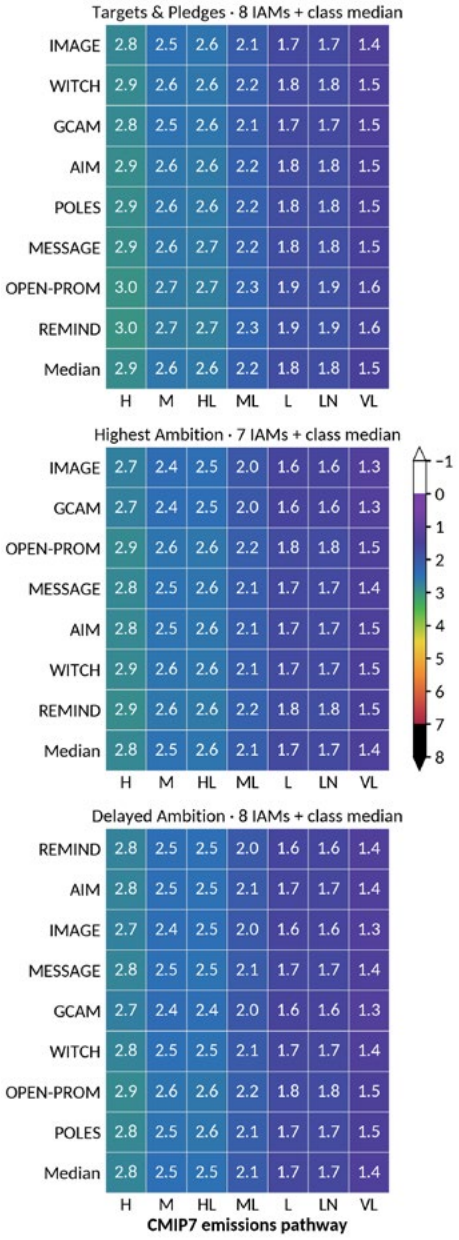
WHY THIS INQUIRY MATTERS

Asking whether our current CDR estimates accurately reflect reality is critically important, because a more realistic assessment may not just be slightly different from these estimates, but markedly different. Expanding our CDR capacity from 10 Gt/y to 12 Gt/y doesn't require a lot of new thinking; expanding from 10 Gt/y to 56 Gt/y or even higher, however, is an extraordinary jump, far beyond what our current basket of CDR solutions is capable of achieving (Hampson 2026).

Financing at this higher level of deployment may be nearly impossible as well. Our current solutions might cost over $1 trillion annually at 10 Gt/y of deployment (Pett-Ridge et al. 2023). A rapidly warming world beset by environmental crises, declining global GDP, and escalating adaptation spending will be ill-prepared to spend this kind of money, let alone $5.6 trillion annually for 56 Gt/y of CDR.[20] Therefore, emissions reduction efforts are vital, but so too are efforts to figure out how to scale CDR to much higher levels than we're currently envisioning, and at much lower cost, whether this means improving the efficiency and effectiveness of current solutions, inventing new ones, or some combination of both.

And what should our CDR goal actually be? Across the 32 TIER combinations that keep median peak warming below 2°C through 2200, the middle CDR level in 2100 is about 35 Gt/y, not the much more commonly referenced 10 Gt/y goal.[21] While

Figure 18. Warming by 2100 for all 23 SoCDR model-scenario combinations across seven different CMIP7 pathways



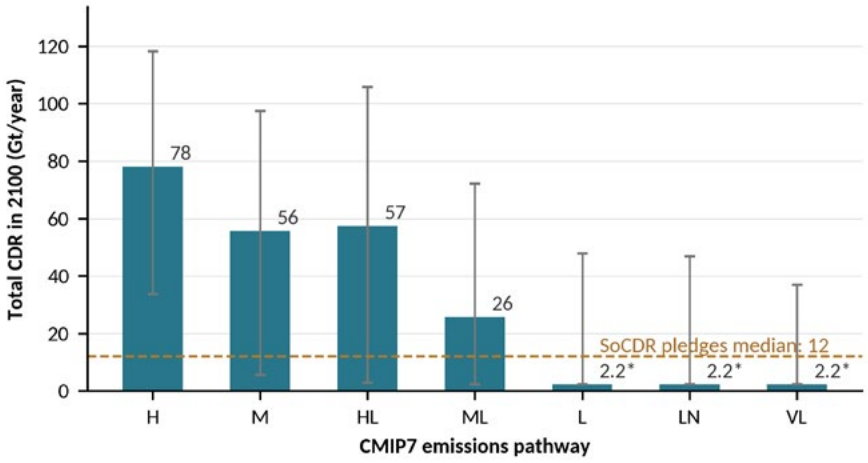
Sources: SoCDR (2026), IIASA ScenarioMIP v0.1 net CO2 and embedded total CDR, v1.1.1 non-CO2 emissions where available
Notes: Each scenario substitutes SoCDR CDR after adding back CMIP7's reported CDR (net CO2 = CMIP7 net + CMIP7 CDR – SoCDR CDR). Within each CMIP7 emissions pathway, non-CO2 emissions are held fixed as we change the SoCDR removal level. Figures show median 2100 warming from 841 calibrated FaIR 2.2.5 configurations for each comparison (not adjusted MAGICC temperatures). Land-use and CDR-category definitions are not fully harmonized. See Methods section for discussion.

20. Assuming we can remove CO2 at $100/ton. This is a highly aspirational cost estimate at the moment, however; even if we were capable of deploying this much CDR capacity today, the cost of 56 Gt/y of CDR would be much higher.

21. Excluding the seven pathways where extreme CO2 drawdown causes modeling errors lowers this figure to approximately 24 Gt/y.

there are several high-E, low-R pathways for staying below 2°C in 2100, these will not provide lasting relief or repair. High-E pathways alone, with no CDR, will never drive temperatures below 1.5°C, and deploying only limited amounts of CDR will keep temperatures elevated for many generations. Only high-R pathways — high CDR — hold out the possibility of limiting the amount of time our planet stays above 1.5°C or 2°C, and the possibility of eventually restoring our temperatures to safer levels.

Figure 19. SoCDR Targets & Pledges CDR needed to reach about 2°C in 2100 across seven CMIP7 emissions pathways



Sources: SoCDR (2026) and 841-member FaIR 2.2.5 ensemble.
Notes: For these calculations, we preserved the general shape of the Targets & Pledges pathway, and estimated how much more CDR each model run would need to reach 2°C in 2100. Emissions and non-CO2 forcing assumptions were held fixed. The blue column represents the 50th percentile amount of CDR needed. Whiskers show the 5th–95th percentile amounts. The asterisk indicates cases where the median CDR requirement is at the 2.2 Gt/y baseline.

CONCLUSION

What combination of emission reduction and removal measures do we need to keep our planet's temperatures below 2°C in the coming decades and centuries? Reaching net zero and then net negative as soon as possible is increasingly important for our future.[22] Getting there from here, however, will require an extraordinary commitment to emissions reductions, carbon dioxide removals, or both. The responsible policy approach is to limit net emissions, and net can be affected by both reductions and removals. Concerns that focusing on CDR will only drain our resources and attention away from emissions reduction efforts are well-meaning but ultimately self-defeating because reaching net zero is unlikely to stop further warming by itself, nor will it lower our planet's temperatures to historically safer levels. We need CDR, and will likely need more than we realize if emissions don't drop as far and fast as policymakers hope.

Will we succeed? Surely eventually, once we recognize the true dimensions of the challenge at hand and develop the technical solutions and political courage to move forward. But "eventually" is a loaded word. Until then, emissions may get worse before they get better. The key question for policymakers today is this: If our fossil fuel use doesn't start declining soon, and significantly, should we continue our generations-long effort to reduce emissions to the exclusion of all other mitigation strategies, or should we also start developing, in earnest, viable countermeasures to help keep our planet cool — at a minimum, through CDR?

This question should be rhetorical, but somehow it is not. Our CDR ambition is lacking, and estimates regarding our future CDR needs are far too low. The sooner we correct these shortfalls, the safer our future world can become.

22. Again, assuming we have no other tools at our disposal to help keep the Earth from overheating (which isn't necessarily true, but it's the premise of this analysis).

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