TECHNICAL NOTE

METHODOLOGY UNDERPINNING THE STATE OF CLIMATE ACTION SERIES: 2024 UPDATE

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Abstract

Limiting global temperature rise to 1.5 degrees Celsius (°C) requires transformational change across power, buildings, industry, transport, forests and land, and food and agriculture as well as the immediate scale-up of carbon removal technologies and climate finance (IPCC 2018, 2022). Updated on a near-annual basis, the *State of Climate Action* series provides an overview of the world's collective efforts to accelerate these far-reaching transitions. We first translate each sectoral transformation into a set of actionable, 1.5°C-aligned targets for 2030, 2035, and 2050, with associated indicators and datasets. Installments of the report then compare recent progress made toward (or away from) these mitigation goals with the pace of change required to achieve 2030 targets to quantify the global gap in climate action. While a similar effort is warranted to evaluate adaptation efforts, we limit this series' scope to tracking progress made in reducing greenhouse gas (GHG) emissions and removing carbon dioxide from the atmosphere.

This technical note accompanies the *State of Climate Action* series. It describes our methods for identifying sectors that must transform, translating these transformations into global mitigation targets primarily for 2030, 2035, and 2050, and selecting indicators with datasets to monitor annual change. It also outlines our approach for assessing the world's progress made toward near-term targets and categorizing recent efforts as on track, off track, well off track, heading in the wrong direction, or insufficient data. Finally, it details how we compare trends over time, as well as limitations to our methodology.

1. Selection of key sectors and critical shifts

In modelled pathways that limit global temperature rise to 1.5 degrees Celsius (°C) above preindustrial levels with no or limited overshoot,[1] greenhouse gas (GHG) emissions peak immediately or before 2025 at the latest, and then fall by a median of 43 percent by 2030 and 60 percent by 2035, relative to 2019 (IPCC 2022). By around mid-century, carbon dioxide (CO_2) emissions reach net zero in these pathways. Achieving such deep GHG emissions reductions, the Intergovernmental Panel on Climate Change (IPCC) finds, will require rapid transformations across all major sectors, including power, buildings, industry, transport, forests and land, and food and agriculture, as well as the immediate scale-up of climate finance and carbon removal technologies to compensate for the residual GHG emissions that will likely prove difficult to eliminate (IPCC 2022). Each of these transformations entails reconfiguring a GHG emissions–intensive sector, including its component infrastructure, technologies, and stakeholders, as well as interactions among these constituent parts, such that it behaves in a qualitatively different way (see Box 1 for more details on how we define transformational change). Put simply, these sectors must radically transform—they must stop releasing dangerously high levels of GHGs and instead deliver critical services to society, albeit more equitably, without spurring increases in atmospheric concentrations of GHGs.

In the *State of Climate Action* series, we translate the far-reaching transformations needed to achieve the Paris Agreement's 1.5°C global temperature limit into a more manageable set of critical shifts for each sector that, taken together, can help overcome the deep-seated carbon lock-in common to them all (Seto et al. 2016). Identifying these critical shifts for each sector, as well as key changes needed to support the scale-up of carbon removal technologies and climate finance, however, is an inherently subjective exercise, as there are many possible ways to translate a global temperature goal into a set of individual actions. So long as the overall GHG emissions budget is maintained, a range of strategies (e.g., assigning more rapid and ambitious emissions reduction targets to the power sector than to the transport sector or vice versa) can be pursued to limit global warming to 1.5°C. However, because the remaining GHG emissions budget is small, the degree of freedom to assign different weights to different sectoral transformations that must occur is relatively constrained, and IPCC (2022) makes it clear that, together, all sectors will eventually have to dramatically lower emissions to limit global warming to 1.5°C. So, if a transformation across one sector is slower than this global requirement, another needs to transition proportionately faster, or additional CO_2 must be removed from the atmosphere. Arguing that a sector needs more time for decarbonization, then, can be done only in combination with asserting that another can transition faster, if our global temperature goal is to be met.[2] A good starting point in translating these needed sectoral transformations into a set of critical shifts, then, is asking whether a sector can decarbonize by 2050. If so, how, and how quickly? If not, why not (CAT 2020b)?

To that end, we reviewed modelled pathways that limit global warming to 1.5°C with no or limited overshoot from integrated assessment models (IAMs) included in IPCC (2018) and IPCC (2022),[3] studies that rely on bottom-up modelling to identify sector-specific road maps for limiting temperature rise to 1.5°C, and bottom-up assessments of both technical and cost-effective mitigation potential, including those published in IPCC (2022). In mapping out multiple pathways that the world can take to meet this global temperature goal, these studies consider a range of factors (e.g., cost, interactions and trade-offs among mitigation actions, technical potential, environmental and social safeguards) when determining each sector's mitigation potential, as well as the specific shifts that collectively deliver that sector's contribution to limiting global temperature rise to 1.5°C. For each sector, we identified both supply- and demand-side shifts common across these studies and then assessed their potential contributions to GHG emissions reduction and avoidance, as well as carbon removal. For inclusion in the *State of Climate Action* series, we prioritized shifts that featured prominently across all or nearly all studies reviewed and that collectively represent the primary actions needed to limit global temperature rise to 1.5°C. We considered additional criteria (e.g., data availability, environmental and social safeguards) when translating these critical shifts into quantitative targets for 2030, 2035, and 2050, as noted in "Selection of targets and indicators."

BOX 1 | What is transformational change?

Calls for transformational change have gained traction throughout the global climate change community,[a] reflecting an emerging consensus that current efforts have failed to spur GHG emissions reductions at the speed and scale required to avoid intensifying and, oftentimes, irreversible climate change impacts. But while most scientists and policymakers broadly agree that transformation refers to a fundamental, systemic change, there is no widely accepted definition of this term (which is sometimes used interchangeably with *transition* and *systems change*), nor is there a shared understanding of how such a process unfolds in practice.[b] This lack of conceptual clarity risks rendering these powerful terms vague buzzwords that can be co-opted to describe any change, making it difficult to distinguish business-as-usual (BAU) action from transformation.[c]

To avoid diluting these terms' utility in communicating the enormous effort needed to limit global temperature rise to 1.5°C, the *State of Climate Action* series draws on commonalities across well-cited definitions in global environmental change research to conceptualize transformation as the reconfiguration of a system (note that sectors themselves are systems), including its component parts and the interactions among these elements, such that it leads to the formation of a new system that behaves in a qualitatively different way (Table B1.1). Given the commonalities across definitions, we use *transition* and *systems change* interchangeably with *transformation*. These terms essentially describe a change from one system to another—for example, a shift from a deforested pasture for beef cattle to a restored, healthy forest that sequesters CO_2 or from a transportation network dominated by fossil fuel–powered cars to one that supports more sustainable forms of mobility like walking, bicycling, or electrified public transit. Such systems change entails "breaking down the resilience of the old and building the resilience of the new."[d]

TABLE B1.1 | Definitions related to transformation, transition, and systems change commonly cited in the global environmental change research

CONCEPTS	DEFINITIONS	QUOTED SOURCES
Transformability	"The capacity to create a fundamentally new system when ecological, economic, or social (including political) conditions make the existing system untenable."	Walker et al. 2004
	"Transformability means defining and creating novel system configurations by introducing new components and ways of governing [social-ecological systems], thereby changing the state variables, and often the scales of key cycles, that define the system. Transformations fundamentally change the structures and processes that alternate feedback loops in [social-ecological systems]."	Olsson et al. 2006
	"The capacity to transform the stability landscape itself in order to become a different kind of system, to create a fundamentally new system when ecological, economic, or social structures make the existing system untenable . . . .Deliberate transformation involves breaking down the resilience of the old and building the resilience of the new."[g]	Folke et al. 2010

Transformation	"In the context of ecosystem stewardship, transformations involve forward-looking decisions to convert a system trapped in an undesirable state to a fundamentally different, potentially more beneficial system, whose properties reflect different social-ecological controls."	Chapin et al. 2010
	"A fundamental reorganization of the [social-ecological system] so that the system functions in a qualitatively different way than it did before."	Biggs et al. 2010
	"A change in the fundamental attributes of natural and human systems."	IPCC 2022
Transition	"Transitions (changes from one stable regime to another) are conceptualized. . .as occurring when landscape pressures destabilize prevailing regimes, providing breakthrough opportunities for promising niches. This implies a nonlinear process of change in which, after passing critical thresholds, elements of a previously dominant regime recombine with successful niches into a new dynamically stable configuration."	Westley et al. 2011
	"A transition is a radical, structural change of a societal (sub)system that is the result of a coevolution of economic, cultural, technological, ecological and institutional developments at different scale levels."	Rotmans and Loorbach 2009
	"The process of changing from one state or condition to another in a given period of time. Transition can occur in individuals, firms, cities, regions and nations, and can be based on incremental or transformative change."	IPCC 2022
Sociotechnical transition	"Transitions entail major changes in the 'socio-technical systems' that provide societal functions such as mobility, heat, housing, and sustenance. These systems consist of an interdependent and co-evolving mix of technologies, supply chains, infrastructures, markets, regulations, user practices, and cultural meaning."	Geels et al. 2017b
	"We define such transitions as shifts from one sociotechnical system to another. . . .We consider transitions as having the following characteristics: Transitions are co-evolution processes that require multiple changes in socio-technical systems. . .are multi-actor processes, which entail interactions between social groups. . .are radical shifts from one system to another . . .are long-term processes. . .[and] are macroscopic."	Grin et al. 2010
Large systems change	"By large systems change (LSC), we mean change with two characteristics. One we refer to as breadth: change that engages a very large number of individuals, organizations and geographies across a wide range of systems. . .The second characteristic we refer to as depth: LSC is not simply adding more of what exists or making rearrangements within existing power structures and relationships, but rather changes the complex relationships among these elements at multiple levels simultaneously."	Waddell et al. 2015

Table Source: Authors.

Transformations are often demarcated from incremental changes, which are defined as adjustments to elements or processes within an existing system that do not fundamentally alter its essence or integrity.[e] Viewed from a climate perspective, for example, new policies that increase energy efficiency can help reduce greenhouse gases emitted from the current energy system in an incremental way, but efforts to phase out fossil fuels represent a transition to an entirely new system that supplies energy without releasing CO_2 into the atmosphere. Although often conceptualized as a binary, these typologies of change are not mutually exclusive. Incremental shifts can sometimes create an enabling environment for future transformations and, in some instances, a progressive series of these lower-order changes can come together in ways that successfully "lock in" a transition to a new system.[f]

Sources:
[a] For example, IPCC 2018, 2022; Sachs et al. 2019; Steffen et al. 2018; Victor et al. 2019; IEA 2021b; Puri 2018; UN 2019a; UNFCCC Secretariat 2021; WBCSD 2021.
[b] Feola 2015; Patterson et al. 2017; Few et al. 2017; Hölscher et al. 2018.
[c] Feola 2015; Few et al. 2017.
[d] Folke et al. 2010.
[e] Few et al. 2017; IPCC 2018, 2022.
[f] Levin et al. 2012; ICAT 2020; Termeer et al. 2017.

2. Selection of targets and indicators

As noted above, the *State of Climate Action* series translates transformations across power, buildings, industry, transport, forests and land, and food and agriculture into a discrete set of critical shifts for each sector. The series also identifies key changes that must occur to support the rapid scale-up of carbon removal technologies and climate finance. For each shift, we select quantitative global targets for the near term (2030 and 2035) and the long term (primarily 2050), with associated indicators (see Table A1, Appendix A).[4] The selected near-term targets can inform immediate action, particularly in the context of ratcheting up ambition and enhancing nationally determined contributions during this decade, while mid-century targets[5] indicate the longer-term changes required to support transformations to a net-zero world.

Establishing 1.5°C-aligned targets, with accompanying indicators, also allows us to evaluate recent collective efforts made toward combating the climate crisis by comparing historical rates of change to the rates of change required to reach these mitigation goals. Although this quantitative analysis does not directly measure transformational change from today's predominant GHG emissions–intensive sectors to qualitatively different, more sustainable ones, it does provide a snapshot of progress across each sector that can help the world take stock of shared efforts to mitigate climate change.

2.1 Target selection

Multiple sources informed our selection of targets, including modelled pathways limiting global temperature rise to 1.5°C with no or limited overshoot from IAMs included in IPCC (2018) and IPCC (2022); bottom-up modelling studies that identify sector-specific mitigation road maps for limiting warming to 1.5°C; and bottom-up assessments of both technical and cost-effective mitigation potential.

Consequently, we present targets either as a single number or as a range of values. Where possible, we include a range of values to account for differences in assumptions, uncertainties, and distinct underlying methodologies and modelling approaches. In the power sector, for example, the more and less ambitious bounds reflect varying degrees of trade-offs in decarbonization with other sectors and/or uncertainty in terms of technical feasibility (CAT 2023). Reaching the least-ambitious targets[6] across all sectors will not likely be sufficient for delivering the Paris Agreement's 1.5°C global temperature limit. Only by achieving the more ambitious bound of some targets (e.g., phasing out coal as quickly as possible) will the world create room for some sectors to achieve their least-ambitious bounds where decarbonization is difficult and therefore slower.

It is critical to note that many selected targets are interdependent. Changes in one target can further or hinder another; for example, greater penetration of zero-carbon power on the electric grid would enable significant progress in decarbonizing transport and industrial production, while failure to sustainably increase crop yields could result in agricultural expansion across forests, spurring increases in deforestation and associated GHG emissions.

2.1.1 Environmental and social safeguards

In selecting 1.5°C-aligned targets for inclusion in the *State of Climate Action* series, we employed several environmental and social safeguards where possible and appropriate, to minimize the risks associated with four specific mitigation measures: bioenergy with carbon capture and storage (BECCS), afforestation and reforestation, carbon capture and utilization (CCU), and carbon capture and storage (CCS).

BECCS features prominently in many modelled pathways that limit global temperature rise to 1.5°C with no or limited overshoot, with this technology delivering a median of 3.8 gigatonnes of carbon dioxide per year ($GtCO_2$/yr) of carbon removal by 2050 and, in some pathways, upwards of 14.6 $GtCO_2$/yr (IIASA n.d.). Yet deployment of BECCS—a process in which biomass is combusted for energy production, its emissions are captured before they are released into the atmosphere, and then captured emissions are sequestered either via underground storage or storage in long-lived products—risks generating negative impacts on food security, biodiversity, and/or net emissions from land-use changes associated with producing biomass feedstocks. For example, if land that would otherwise be used for crop production is allocated to produce monoculture biomass feedstocks for BECCS, that food production would need to happen elsewhere—perhaps displacing a natural carbon sink like a forest, thereby reducing biodiversity and increasing net GHG emissions due to the indirect land-use change (Creutzig et al. 2021; Fajardy et al. 2019; Hanssen et al. 2022).

To minimize these risks, we excluded scenarios that rely too heavily on this technology when deriving targets from modelled pathways that limit warming to 1.5°C with no or limited overshoot from IPCC (2018) and IPCC (2022)—see Box 2 and Box 3 for more information on the filtering criteria we applied to scenarios from IPCC (2022) and IPCC (2018), respectively. More specifically, we constrained BECCS deployment to an average of 5 $GtCO_2$/yr from 2040 to 2060—a level considered sustainable by Fuss et al. (2018) and reaffirmed in IPCC (2018). While more recent estimates of the sustainable mitigation potential for BECCS are considerably lower than 5 $GtCO_2$/yr (e.g., Deprez et al. 2024), we retained this higher limit as a pragmatic approach. BECCS remains the primary carbon removal technology in most IAMs, which are only beginning to incorporate more nascent innovations like direct air carbon capture and storage (DACCS) and carbon mineralization. In this way, BECCS may be seen as a proxy for a range of technological carbon removal measures in the pathways, including DACCS. If we excluded these pathways with higher amounts of BECCS due to more stringent constraints, we would lose valuable insights from IAMs that do not yet incorporate other carbon removal technologies (e.g., Climate Analytics 2023).[7] Also, the median amount of BECCS deployment in these filtered scenarios falls well below our upper bound at 3.6 $GtCO_2$/yr in 2050, an amount that is closer to more recent estimates of sustainable potential (e.g., Deprez et al. 2024). Still, given pervasive uncertainty around the feasibility of large-scale carbon removal technologies, rapidly reducing GHG emissions to minimize reliance on these nascent innovations remains the most robust mitigation strategy (Grant et al. 2021), and we will continue to refine total and pathway-specific estimates of technological carbon removal as more carbon removal technologies are incorporated into IAMs.

We also limited carbon removals from afforestation and reforestation (A/R). When implemented appropriately (e.g., by focusing on recovering forests' ecological functions, rather than solely on reestablishing trees), this mitigation measure can generate substantial benefits for adaptation, sustainable development, and biodiversity at relatively low costs (IPCC 2022). But if deployed at large scale and without following forest landscape restoration principles, A/R can generate unintended consequences, such as fueling land competition, spurring increases in food prices, and intensifying food insecurity (IPCC 2022). Accordingly, we constrained our assessment of IPCC (2018) modelled pathways that limit warming to 1.5°C with no or limited overshoot to those that feature an average of 3.6 $GtCO_2$/yr from 2050 to 2100 (see Box 3). For IPCC (2022) modelled pathways, we relied on updated filtering criteria from Climate Analytics (2023) and Grant et al. (2021), which constrain A/R to an average of 3.6 $GtCO_2$/yr from 2040 to 2060 and an average of 4.4 $GtCO_2$/yr from 2050 to 2100 (see Box 2).[8] These limits to A/R represent the upper bound of carbon removal within the filtered scenario sets and are consistent with Deprez et al.'s (2024) estimate of sustainable mitigation potential from A/R. Moreover, the median amount of A/R within these modelled pathways remains relatively low—for example, at less than 1 $GtCO_2$/yr throughout the century in the filtered set of IPCC (2022) scenarios.

Similarly, when deriving targets from bottom-up sectoral modelling and estimates of technical and cost-effective mitigation potentials for forests and land and food and agriculture, we selected those that, if achieved, would not threaten food security, spur biodiversity loss, or limit fiber production. All targets for reforestation and restoration, specifically, do not exceed the areas associated with Griscom et al. (2017)'s global "maximum additional mitigation potentials," which are technical estimates of mitigation potential constrained by social and environmental safeguards. In calculating this maximum additional mitigation potential for reforestation, for example, Griscom et al. (2017) limited forest cover gain to lands that are ecologically appropriate for forests, removed all existing croplands from their estimate of maximum potential extent to avoid dampening yields, and excluded the boreal region due to changes in albedo that would have a net warming effect. The area associated with this maximum additional mitigation potential is 678 million hectares (Mha) (Griscom et al. 2017). Our reforestation target not only falls well below this threshold but also aligns with Deprez et al. (2024)'s more recent estimate of sustainable mitigation potential from A/R. Similarly, our food and agriculture targets seek to avoid additional ecosystem conversion, and to free up farmland for reforestation and restoration, by reducing agriculture's land footprint below its 2010 global extent, while mitigating GHG emissions from production processes and feeding nearly 10 billion people (Searchinger et al. 2019, 2021).

Large-scale deployment of CCU and CCS—technologies that capture CO_2 at a point source (e.g., a power plant or oil refinery) and then either use that CO_2 in various processes and products (e.g., production of chemicals and concrete) or store that CO_2 underground in suitable geological formations—also generates risks and, accordingly, we limited reliance on these technologies in the definition of Paris-compatible targets.[9] More specifically, these technologies can cause harmful environmental impacts (e.g., through high water requirements) as well as increase energy demand and, subsequently, GHG emissions from upstream fossil fuel production, including fugitive methane emissions. Carbon capture technologies used in both CCU and CCS also face the challenge of incomplete CO_2 capture rates, and are therefore not zero-carbon in operation. While these capture rates do vary, they are generally lowest for industrial process emissions—for example, carbon capture technologies installed on retrofitted blast furnaces capture only about 50–60 percent of CO_2 emissions (Fan and Friedmann 2021). In fossil power generation applications, these rates are higher. Today's technologies can capture about 90 percent of CO_2 emissions from an individual facility (IEA 2021a), although many existing facilities report lower values (Robertson and Mousavian 2022). Future capture rates may increase, but even under the most idealized, theoretical conditions most systems would still fall short of capturing 100 percent of CO_2 emissions (Brandl et al. 2021).[10] And for CCU, specifically, captured CO_2 is held only temporarily in products, many of which have short lifetimes after which the captured CO_2 is rereleased into the atmosphere. CCU's efficacy in reducing CO_2 emissions, then, depends on the source of CO_2, the emissions intensity of energy required for converting the captured CO_2 into the product, and that product's lifetime (e.g., if a product is recycled, less CO_2 would be released into the atmosphere than if it is incinerated). Relying too heavily on either CCS or CCU, then, risks locking in GHG emissions–intensive infrastructure and associated emissions.

To minimize these risks, we limited deployment of both CCU and CCS technologies where possible. For industrial decarbonization, we adopted targets derived from CAT's (2020a) bottom-up, sectoral modelling, which prioritized other decarbonization technologies where available and to the extent possible when constructing scenarios. For example, alternative binders play a prominent role in the cement sector to avoid process emissions, while the steel sector sees a high reliance on the development of green hydrogen–based ironmaking (CAT 2020a). Each of these alternative technologies has a lower emissions intensity than CCS, so CAT (2020a) prioritized them accordingly. But in the power sector, the filtered scenarios included in IPCC (2022) (see Box 2)—the primary source for our electricity generation targets—showed an extremely limited role for both technologies, such that CAT (2023) did not need to further constrain deployment of CCU and CCS.

2.1.2 Economic constraints

We did not systematically consider cost in selecting our targets. We derived some targets from models that optimize for least-cost pathways—e.g., from IAMs compiled by IPCC (2018) and (2022), IEA (2021b), and BNEF (2021)—while for others, we selected those that the literature considers cost-effective at specific carbon prices (e.g., Roe et al. 2021). For targets presented as ranges, the less ambitious bound is often informed by least-cost scenarios modelled by IAMs, and the more ambitious bound does not account for cost effectiveness (e.g., CAT 2020a, 2023). Other targets, particularly those focused on mitigation within the food and agriculture sector, still do not include cost considerations (e.g., Searchinger et al. 2019). This variation reflects the broader diversity in top-down and bottom-up estimates of mitigation potential for specific actions as well as our decision to prioritize other factors, such as social and environmental safeguards, over cost in our selection of targets.

BOX 2 | Methods for filtering scenarios from IPCC's Sixth Assessment Report

For *State of Climate Action 2023*, we revised 2030, 2035, and 2050 targets across power, buildings, industry, and technological carbon dioxide removal to incorporate CAT (2023)'s analysis of modelled pathways that limit warming to 1.5°C with no or limited overshoot from IPCC (2022). Using the IPCC's AR6 (Sixth Assessment Report) Scenario Explorer and Database of IAMs,[a] CAT (2023) initially identified 97 scenarios, with each representing a pathway for the energy system based on different socioeconomic and technical assumptions (e.g., final energy demand, mix of technologies deployed, speed of decarbonization) as well as at different spatial and temporal resolutions. CAT (2023) then filtered these scenarios to include only those that met three criteria identified by Climate Analytics (2023):

- Scenarios were published in 2018 or after, with the exception of the low-energy demand scenario, as it offers a unique perspective on the transformational changes required on the demand side, such as reducing energy use, to limit global temperature rise to 1.5°C, while still achieving the United Nations Sustainable Development Goals.
- A sustainable amount of carbon removal is used—specifically, BECCS deployment is restricted to an average of 5 $GtCO_2$/yr from 2040 to 2060, and carbon removal from afforestation and reforestation is limited to an average of 3.6 $GtCO_2$/yr from 2040 to 2060 and to an average of 4.4 $GtCO_2$/yr from 2050 to 2100.
- Scenarios limiting warming to 1.5°C with no or limited overshoot are also consistent with achieving net-zero GHG emissions in the second half of the century, as stated in Article 4.1 of the Paris Agreement.

A total of 33 scenarios from the IAMs met these three criteria. These scenarios indicate least-cost pathways to limiting global temperature rise to roughly 1.5°C with no or limited overshoot and, critically, do not consider an equitable distribution of costs and required action. To better account for regional differences in circumstances and capabilities, CAT (2023) then employed another set of methods that required additional filtering; due to limitations in the granularity of data from IAMs, this secondary filtering varied by sector:

- CAT (2023) retained 32 of these 33 scenarios when setting targets for the power sector, selecting only those with the regional resolution in data sufficient for downscaling modelled pathways to the country level. By downscaling these scenarios, CAT (2023) was able to make further adjustments to national and global electricity generation benchmarks that more effectively consider equity and feasibility constraints relevant to power sector decarbonization. See Box 4 for further details on these methods.
- For the buildings and industry sectors, data limitations in modelled pathways prevented CAT (2023) from following a similar approach. Instead, CAT (2023) applied a more simplistic filter to these 33 scenarios and retained only those in which the rate of decline in GHG emissions between 2020 and 2030 is steeper in developed countries than in developing countries. Just 24 scenarios met this additional criterion, which CAT (2023) then used to establish decarbonization targets for both sectors.
- Responsibility to mitigate climate change, as well as the capacity to deploy carbon removal technologies, varies enormously by country. But given the large uncertainties associated with the magnitude of technological carbon removal required to limit warming to 1.5°C, as well as the feasibility of scaling up these approaches,[b] CAT (2023) opted to retain all 33 scenarios in target-setting for this indicator. This decision reflects the importance of capturing the broadest possible range of perspectives on the role that technological carbon removal could play in achieving this Paris Agreement temperature goal, while remaining within literature-defined sustainability constraints. Future analysis could explore how integrating equity concerns into the analysis could affect the global deployment of technological carbon dioxide removal.

Despite these efforts to better account for regional differentiation in circumstances and capabilities, achieving the global targets derived from these modelled scenarios still implies that substantial financial transfers are made among countries, that wealthier countries decarbonize more quickly than in the underlying models, or a combination of both.[c] More information about how this filtering process was undertaken is described in the original analysis published by CAT (2023).

Sources: [a] IIASA n.d. [b] Grant et al. 2021. [c] Bauer et al. 2020.

BOX 3 | Methods for filtering scenarios from IPCC's Special Report on Global Warming of 1.5°C

In *State of Climate Action 2023*, we retained several targets informed by CAT (2020a)'s analysis of modelled pathways from the IPCC's *Special Report on Global Warming of 1.5°C*.[a] More specifically, CAT (2020a) filtered these IPCC (2018) scenarios to those that met four conditions:

- Global warming is limited to 1.5°C with no or limited overshoot.
- A sustainable amount of carbon removal is used—specifically, BECCS deployment is restricted to 5 $GtCO_2$/yr in 2050, while afforestation and reforestation is constrained to 3.6 $GtCO_2$/yr between 2050 and 2100.
- Biomass is used sustainably (i.e., power generation from biomass in these scenarios is limited to around 8,000 terawatt-hours of electricity).
- Scenarios have complete data and relatively high temporal resolution.

Just 11 scenarios met these criteria. These scenarios indicate least-cost pathways to limiting global temperature rise to roughly 1.5°C with no or limited overshoot and, critically, do not consider an equitable distribution of costs and required action. Achieving the global targets derived from these modelled scenarios, then, implies that either substantial financial transfers are made among countries, that wealthier countries decarbonize more quickly than in the underlying models, or a combination of both.[b]

Sources: [a] IPCC 2018. [b] Bauer et al. 2020.

2.2 Indicator selection

We primarily selected indicators that correspond directly to our targets, such as the carbon intensity of electricity generation or the share of electric vehicles in light-duty vehicle sales. Some targets, however, cannot be tracked directly, and for those, we selected the best available proxy indicators. For example, we used tree cover gain to assess progress made toward our reforestation targets. Yet tree cover gain does not exclusively measure reforestation. Instead, this indicator measures the establishment of tree canopy in areas that previously had no tree cover, including gains due to harvesting cycles in areas that are already established as plantations and afforestation in non-forested biomes. Despite these limitations, we used tree cover gain because its accompanying dataset relies on satellite imagery, rather than infrequent, oftentimes outdated field surveys. We provide additional details on proxy indicators used in the relevant sections below.

2.3 Target and indicator selection by sector

2.3.1 Power

Decarbonizing power generation is essential to limiting global warming to 1.5˚C. This requires transforming the sector from one that relies heavily on fossil fuels to produce electricity to another fundamentally different sector that generates zero-carbon power. Such a transition will entail both the immediate scale-up of zero-carbon power sources as well as the rapid phaseout of coal and unabated[11] natural gas (IPCC 2022; IEA 2021b).[12] Together, these actions can dramatically reduce the carbon intensity of electricity generation.

To track progress made toward accelerating this sectoral transformation, we identified five key indicators of progress included in major reports from the IPCC and International Energy Agency (IEA), among others, as shown in Table 1 (IPCC 2018, 2022; IEA 2021b). Carbon intensity of electricity generation measures CO_2 emissions per kilowatt-hour of generated electricity and represents the most straightforward means by which to track decarbonization of the power system. Nested under this indicator, we monitor the phaseout of major fossil fuels contributing to high carbon intensity of electricity, as well as the scale-up of necessary zero-carbon power[13] sources like renewables.

For each indicator, we adopted targets developed by CAT (2023), which were informed by top-down modelled pathways that limit global temperature rise to 1.5°C with no or limited overshoot from IAMs included in IPCC (2022), as well as a literature review of bottom-up, sector-specific modelling studies that outline 1.5°C-compatible roadmaps for decarbonizing the power sector. CAT (2023) first identified modelled pathways that limited warming to 1.5°C with no or

BOX 4 | Adjusting 1.5°C pathways to account for equity considerations and feasibility constraints

Global least-cost mitigation pathways have been criticized for not accounting for regional circumstances that may limit the pace of energy system transitions in developing countries.[a] Additionally, some modelled pathways show an expansion of fossil gas infrastructure in the 2020s, particularly in developing countries, before rapidly reducing gas-fired power generation in the 2030s—a course of action that, if followed, would lead to substantial asset stranding and, in the wake of the ongoing gas crisis, create energy security concerns. To account for these challenges, CAT (2023) derived median values for coal, fossil gas, and non-biomass renewables power generation from the set of 32 filtered pathways described in Box 2 and then adjusted these baseline values based on two key assumptions:

1. That developed countries can follow a more accelerated phaseout of fossil fuels in power generation, which would allow for a still rapid, but slightly slower and more feasible, fossil fuel phaseout in developing countries[b]
2. That both existing coal generation and new zero-carbon power generation can replace this projected fossil gas power generation, which carries a high risk of asset stranding

More specifically, CAT (2023) downscaled the filtered set of scenarios to the country level and then followed these steps:

- CAT first assumed that developed countries can accelerate fossil fuel phaseout following the 75th percentile (more ambitious than the median) of the set of filtered pathways, rather than the median value. CAT then calculated the difference between this 75th percentile and the median (50th percentile) to determine the GHG emissions saved, and reallocated these to developing countries to allow for a slightly slower reduction in coal power generation in the near term. This redistribution was weighted by the following two factors:
    - The rate at which coal generation falls from 2020 to 2030 in the initial downscaled pathways—the faster the reductions in coal, the more headroom for GHG emissions was allocated to this country
    - The Human Development Index (HDI) of the country—CAT allocated more headroom for GHG emissions to countries with lower HDI scores
- To prevent the build-out of fossil gas power plants and minimize the risk of stranded assets across both developed and developing countries, CAT (2023) limited future gas-fired power generation to what is possible based on each country's current gas-fired power fleet (as of 2022), thereby preventing any new fossil gas power generation beyond this level for all countries. The authors then reallocated any GHG emissions savings that would result from this to the coal-fired power fleet within the same country.
- CAT (2023) then evaluated whether the resulting generation pathway was aligned with total generation in the median value of the scenario distribution for each country and, if there was any difference, adjusted total renewables generation at the country level to keep total in-country generation consistent with the median. Doing so ensured that zero-carbon power sources would fill any gaps in generation that may have occurred as a result of the previous adjustments.
- Finally, CAT summed the generation values for all countries to scale back up to the global level and derive global targets.

This method uses the full range of the filtered IAM scenarios to determine a technically feasible, 1.5°C-compatible pathway that simultaneously accounts for feasibility and equity concerns that have yet to be fully incorporated into IAM scenarios. Accordingly, these adjustments also impact global pathways to 1.5°C, featuring a slightly slower coal phaseout, a faster fossil gas phaseout, and a faster scale-up of zero-carbon power sources.

Sources: [a] Muttitt et al. 2023. [b] Muttitt et al. 2023. [c] CAT calculates national pathways from IAM global scenarios using downscaling methods that are described here: https://1p5ndc-pathways.climateanalytics.org/methodology/#from-global-to-national-pathways.

TABLE 1 | Design of power indicators and targets

INDICATOR	TARGET				ADDITIONAL INFORMATION
	2030	2035	2050	SOURCE(S)	
Share of zero-carbon sources in electricity generation (%)[a]	88–91	96	99–100	CAT 2023	N/A
Share of wind and solar in electricity generation (%)	57–78	68–86	79–96	CAT 2023	N/A
Share of coal in electricity generation (%)	4	1	0–1 (2040) 0 (2050)	CAT 2023	N/A
Share of unabated fossil gas in electricity generation (%)	5–7	2	1 (2040) 0 (2050)	CAT 2023	N/A
Carbon intensity of electricity generation (gCO_2/kWh)	48–80	15–19	<0[b]	CAT 2023	N/A

Notes: gCO_2/kWh = grams of carbon dioxide per kilowatt-hour; N/A = not applicable.
[a] Zero-carbon sources include solar, wind, hydropower, geothermal, nuclear, marine, and biomass technologies.
[b] Achieving below-zero carbon intensity implies biomass power generation with carbon capture and storage. Our targets limit bioenergy with carbon capture and storage use to five gigatonnes of carbon dioxide per year in 2050.
Source: Authors.

limited overshoot from IPCC (2022) and then filtered them, following the criteria outlined in Box 2. The median values from this filtered subset of 32 scenarios formed a baseline for each indicator that CAT (2023), in turn, adjusted to account for equity concerns and practical limitations that may hinder power sector transformation in many developing countries (see Box 4 for more details on these methods). Once adjusted, these median values formed one bound of each power sector target.

To complement its analysis of IPCC (2022) scenarios, CAT (2023) also conducted a literature review of bottom-up, sector-specific modelling studies that presents power sector roadmaps aligned with limiting warming to 1.5°C. CAT then examined the carbon intensity reductions in power generation across these bottom-up, sectoral modelling studies and selected those with declines in carbon intensity that aligned with at least one of the 32 scenarios that CAT (2023) downscaled to the country level. Only one met this criterion—a study by the Energy Watch Group and Lappeenranta-Lahti University of Technology (Ram et al. 2019). This paper provides a detailed exploration of a transition to a decarbonized electricity system by 2050 that is fully aligned with the 1.5°C temperature goal and, therefore, served as a key complement to the IPCC (2022) modelled pathways. CAT (2023) extracted data for all power sector indicators from this study to form the other bound of each target.

Finally, CAT (2023) combined its analysis of modelled pathways from IAMs with its review of bottom-up, sectoral modelling to set electricity generation targets. Notably, for some indicators, the bottom-up, sectoral modelling study produced more ambitious targets, while for others, the analysis of top-down scenarios from IPCC (2022) did. This difference in ambition between these two sources stems primarily from distinct modelling assumptions and methodologies. Each indicator’s target, then, is represented as a range, with each source forming one bound of the benchmark in a given year (see Table 1). More details on the top-down method, bottom-up method, and the integration methodology can be found in CAT (2023, Sections 3.2–3.5).

In previous reports, our targets for coal and fossil gas power generation excluded “abated” coal and gas power units—those that are fitted with CCS—due to the various challenges associated with the application of CCS in fossil fuel power plants, including high costs, energy penalties, residual emissions, and the risk of locking in fossil fuel–fired generation. However, when revising our targets to be aligned with IPCC (2022) pathways that limit warming to 1.5°C with no or limited overshoot, we found that the new filtered set of scenarios better incorporates these challenges than older scenarios, and they show an extremely limited role for CCS in decarbonizing the power sector. For example, there is effectively no coal with CCS in this filtered set of scenarios, such that our targets would be the same whether we include coal plants fitted with CCS or not. Restricting the indicator to "unabated" coal-fired power generation would imply a role for abated coal power generation that doesn't exist in this filtered set of scenarios. Accordingly, *for State of Climate Action 2023*, we defined the indicator as the share of all coal in electricity generation. This filtered set of scenarios also shows a very limited role for fossil gas with CCS (0.1 percent of power generation in 2030, 0.3 percent in 2040, and 0.5 percent in 2050), such that the targets for the share of unabated fossil gas in electricity generation would be quite similar to those for the share of all unabated and abated fossil gas in electricity. But they would not be exactly the same, so we maintained our focus on fossil gas excluding CCS to emphasize the need for a complete phaseout of unabated fossil gas.

2.3.2 Buildings

Operational emissions in the buildings sector are driven by energy use and the carbon intensity of that energy. Decarbonization of these operational emissions requires energy use to be minimized, with the remaining energy supply thereafter decarbonized. Energy-efficient technologies, electrification, on-site renewable power generation, and decarbonization of the power grid are thus fundamental components of ensuring buildings are zero-carbon in operation (IPCC 2022).

Two of the four[14] indicators and targets assessed in this report (Table 2) directly track progress toward decarbonizing building operations—energy intensity and carbon intensity of building operations. We set another two supporting targets to capture progress made in accelerating action, including the deep retrofitting rate of existing buildings and construction of new buildings that are zero-carbon in operation, which will be required to achieve these targets for energy intensity and carbon intensity.

We adopted targets for both the energy intensity and carbon intensity of buildings from CAT (2023), which relied on three lines of evidence to establish these benchmarks.[15] CAT first identified modelled pathways that limit global temperature rise to 1.5°C with no or limited overshoot from IPCC (2022) and then filtered them down to 24 scenarios, following the criteria outlined in Box 2. CAT (2023) also analyzed modelled pathways from IAMs that focus specifically on the buildings sector, rather than the broader energy system. To ensure that these additional building-specific scenarios were consistent with the criteria outlined in Box 2, CAT (2023) included only those scenarios that limited warming to 1.5°C by 2100 with no or limited overshoot in its analysis. Nine buildings-specific scenarios met this criterion, bringing the total number of modelled pathways in CAT's (2023) analysis to 33. Notably, additional safeguards (e.g., sustainable carbon removal limits for BECCS and A/R) outlined in Box 2 were not applicable to the buildings sector and, therefore, were not used to filter buildings-specific scenarios.

CAT (2023) then reviewed existing global targets in the buildings sector to gain a second line of evidence. The authors searched the academic literature, as well as reports, declarations, and commitments from leading multilateral institutions and global multistakeholder coalitions focused on decarbonizing the buildings sector (e.g., IEA, C40, Global Alliance for Buildings and Construction, World Green Building Council) for these targets.

Bottom-up, sector-specific modelling conducted by CAT (2023) served as the third line of evidence for these two indicators. More specifically, this bottom-up analysis split building sector GHG emissions and energy use by component—namely, cooling, heating (space and water), lighting, appliances, and cooking. CAT (2023) then used this information, alongside outputs from a building stock-turnover model, to determine targets for each energy use component for 2030, 2035, and 2050.

CAT (2023) established the targets for the energy and carbon intensity of building operations by merging these three lines of evidence. Analysis from IPCC (2022) modelled pathways, as well as buildings-specific scenarios, served as a starting point for both indicators—minimum values from this filtered scenario set formed the more ambitious bounds of each target, while the 66th percentile comprised the less ambitious bounds. CAT (2023) then compared targets derived from the second and third lines of evidence with these preliminary targets. For energy intensity, benchmarks fell within the given range. But for carbon intensity of building operations, these lines of evidence expanded the target range, with values from the literature review, specifically IEA (2021b), forming the less ambitious bound and results from CAT's (2023) bottom-up modelling forming the more ambitious bound.

For the retrofitting rate and share of new buildings that are zero-carbon in operation, we adopted targets from CAT (2020a),[16] which conducted bottom-up, sector-specific modelling to develop 1.5°C-compatible targets for the buildings sector. To then verify these targets, CAT (2020a) compared the resulting sectoral emissions

TABLE 2 | Design of buildings indicators and targets

INDICATOR	TARGET				ADDITIONAL INFORMATION
	2030	2035	2050	SOURCE(S)	
Energy intensity of building operations (kWh/m^2)	85–120	Forthcoming	55–80	CAT 2023	Energy intensity covers all building operations: space and water heating, space cooling, lighting, cooking, and appliances.
Carbon intensity of building operations ($kgCO_2/m^2$)	13–16	Forthcoming	0–2	CAT 2023	The carbon intensity targets for building operations assume that the power sector targets for improvements in the emissions intensity of electricity generation are met.
Retrofitting rate of buildings (%/yr)	2.5–3.5	2.5–3.5	3.5 (2040)	CAT 2020a	For the retrofitting rate of buildings indicator, CAT combined the current building stock and projected growth in floor area with different retrofitting and demolish and rebuild rates to determine which rates would be required to retrofit the full building stock by 2050 and ensure that the carbon intensity benchmarks are 1.5°C compatible. Higher retrofitting rates were required in countries where much of the building stock already exists. As with the other targets, the retrofitting rates were checked for consistency with other literature (CAT 2020a).
Share of new buildings that are zero-carbon in operation (%)[a]	100	100	100	CAT 2020a	The target date for achieving a 100% share of new buildings that are zero-carbon in operation is 2030, although an earlier target would reduce the need for retrofits in the future. Developed countries should already be constructing buildings that do not rely on fossil fuels for energy supply. The definition of zero-carbon buildings here includes those that will be truly zero-carbon only when the power sector is fully decarbonized (i.e., they rely either on on-site renewables or electricity but not on-site use of fossil fuels).

Notes: kWh/m^2 = kilowatt-hours of energy per square meter; $kgCO_2/m^2$ = kilograms of carbon dioxide per square meter; %/yr = percent per year; °C = degrees Celsius; N/A = not applicable.
[a] We added share of new buildings that are zero-carbon in operation as a new indicator to *State of Climate Action 2023*. See Appendix A for more information.
Source: Authors.

with those from filtered scenarios described in Box 3. Critically, these two targets developed using CAT (2020a) methods are not global in scope; rather, they are for the United States, the European Union, Brazil, India, China, and South Africa.[17] Because developing targets for buildings at the global level is difficult due to the high diversity of weather conditions, building stock, and data availability, CAT (2020a) created global targets by aggregating the results of this subset of countries, which are representative of different regions.

Finally, before including these two targets on retrofitting rates and new buildings in the *State of Climate Action 2023*, we reviewed them to ensure consistency with the updated benchmarks for energy intensity and carbon intensity, as well as other recent literature. More information about target and indicator design for each of these indicators is provided in Table 2.

The materials and energy used to construct and furnish buildings also lead to substantial embodied emissions, and mitigating them to fully decarbonize the sector will require additional actions that range widely, from lowering the need for new builds, reducing the emissions intensity of existing construction materials, and, in some cases, adopting novel construction materials (e.g., bio-based materials) (PEEB 2021; Bourbia et al. 2023). While we included indicators that monitor the decarbonization of two major construction materials—steel and cement—in the series' Industry section, we were not able to identify any data to track progress toward reducing embodied emissions in buildings more broadly and therefore excluded them from the *State of Climate Action* series. For the same data limitation reasons and because 1.5°C-aligned targets were not available, we also omitted analysis of growing floor area,[18] an indicator of the activity level in the buildings sector.

2.3.3 Industry

Transforming the industry sector will require four key shifts. First, lowering the demand for industrial products through increased circularity, demand-side management, and material substitution can play a critical role in industrial decarbonization. Second, although the mitigation potential of energy efficiency measures is limited in the industry sector, adopting the best available technologies to improve efficiency could achieve some GHG emissions reductions in the short term, while reducing levels of effort needed across other shifts. Third, thermal energy demand in the industry sector is currently largely met by fossil fuels. As such, these processes will need to be decarbonized through large-scale electrification, coupled with decarbonization of the electricity supply within the global power sector. Fourth, because the industry sector is responsible for a significant share of process emissions[19] and depends on high-temperature heat for some of these processes, large-scale electrification pursued alongside the decarbonization of the global energy supply will not be sufficient to mitigate all industry sector emissions—new fuels, feedstocks, and technologies also need to be developed and commercialized (IPCC 2022; IRENA 2021; ETC 2021).

We selected the industry sector indicators and their respective targets (Table 3) with the aim of gauging overall progress across the sector, as well as progress made in achieving the aforementioned required shifts. More specifically, for the third shift (electrification), we monitored the share of electricity in industry's final energy demand. We then tracked the second (efficiency) and fourth (new fuels, feedstocks, and technologies) shifts through a closer look at the production of cement and steel[20]—two subsectors that together account for about 40 percent of direct GHG emissions from the industrial sector (Minx et al. 2021; European Commission and JRC 2022). Reductions in the carbon intensity of cement and steel production reflect improvements in energy efficiency, alongside progress made in implementing mitigation measures that go beyond efficiency (e.g., electrifying medium-heat processes; adopting new fuels; reducing process emissions to the greatest extent possible; expanding carbon capture, usage, and storage). The report also tracks green hydrogen production from zero-carbon electricity under the fourth shift, as it is one of the most promising non-carbon chemical feedstocks (e.g., for steel production) and could also be used as an energy carrier for high-temperature heat generation. We do not track progress in the first shift (lowering demand) due to a lack of both publicly available data and appropriate Paris-compatible targets.

For each indicator in the industry sector, we derived the targets from three main sources: CAT (2023), CAT (2020a), and IEA (2022b). More specifically, we adopted targets for the share of electricity in the industrial sector's final energy demand from CAT (2023), which employed a top-down approach to establishing near- and long-term targets for this indicator. CAT (2023) identified modelled pathways that limit global temperature rise to 1.5°C with no or limited overshoot from IPCC (2022) and then filtered them, following the criteria outlined in Box 2. The median from this filtered set of 24 scenarios formed the less ambitious bound of the target range, while the 95th percentile served as the more ambitious bound. Insufficient data, as well as limited peer-reviewed literature on bottom-up, sectoral modelling of industrial decarbonization consistent with achieving the Paris Agreement temperature goals, prevented CAT (2023) from integrating additional sources into this

TABLE 3 | Design of industry indicators and targets

INDICATOR	TARGET				ADDITIONAL INFORMATION
	2030	2035	2050	SOURCE(S)	
Share of electricity in the industry sector's final energy demand (%)	35–43	43–46	60–69	CAT 2023	N/A
Carbon intensity of global cement production ($kgCO_2$/t cement)	360–370[a]	Forthcoming	55–90[a]	CAT 2020[a]	N/A
Carbon intensity of global steel production ($kgCO_2$/t crude steel)[b]	1,340–1,350[a]	Forthcoming	0–130[a]	CAT 2020[a]	N/A
Green hydrogen production (Mt)	58[c]	Forthcoming	330[c]	IEA 2022[b]	N/A

Notes: $kgCO_2$/t = kilograms of carbon dioxide per tonne; Mt = million tonnes; N/A = not applicable.
[a] Targets include direct and indirect greenhouse gas emissions.
[b] The carbon intensity of global steel production accounts for both primary and secondary steel.
[c] Targets refer to what is needed for the whole economy to decarbonize and, thus, are not only for the industry sector.
Source: Authors.

target-setting exercise. Instead, CAT exclusively relied on the range from these 24 scenarios to establish 1.5°C-compatible targets for industrial electrification.

For the carbon intensities of global cement production and global steel production, we retained targets derived from CAT (2020a), which employed bottom-up methods to establish near- and long-term targets, as well as top-down methods to validate these goals. Because IAMs provide less granularity and are thus limited in terms of their potential for defining sectoral targets, CAT (2020a) relied on bottom-up, sectoral modelling tools, which allowed the authors to apply a wider range of mitigation options that would enable full decarbonization of the subsector as quickly as possible. Academic and gray literature assessing the technical and feasible potential of these mitigation options within the industry sector informed this bottom-up, sectoral modelling. CAT (2020a) then compared the targets derived from this bottom-up, sectoral modelling with those from the filtered set of IPCC (2018) scenarios (Box 3) to ensure that if there was any discrepancy, the targets taken from the bottom-up, sectoral modelling would be more ambitious in achieving decarbonization more rapidly. For the carbon intensity of global cement production indicator, specifically, CAT (2020a) considered both direct emissions and indirect emissions generated by power used during production.

Finally, we sourced the green hydrogen production targets from IEA (2022b), which modelled the projected demand for electrolytic hydrogen across sectors by 2030 and 2050 to reach net-zero emissions by 2050.

2.3.4 Transport

While technological solutions, such as electric vehicles, are capturing the zeitgeist with major vehicle manufacturers and countries announcing their moves away from the internal combustion engine (see IEA 2021b), fully decarbonizing the transport sector efficiently requires more than just a change in propulsion technology (BNEF 2022). An often-used framework that helps organize the multiple solutions needed to decarbonize transport is "avoid-shift-improve" (Dalkmann and Brannigan 2014). Under this approach, the sector should work toward avoiding the need for motorized travel by using land-use and urban planning approaches that bring opportunities closer to residents; shifting travel toward more efficient, less carbon-intensive forms of mobility, such as public transport, walking, and cycling; and finally improving the carbon intensity of the remaining travel modes through technological developments, such as electric vehicles and zero-emissions fuels.

Together, the targets and indicators used within the *State of Climate Action* series (see Table 4) specifically cover the shift and improve components of this avoid-shift-improve framework (Bongardt et al. 2019). More specifically, the first three transport indicators in Table 4 measure whether and how people are shifting to lower-emitting modes of transportation, while the remaining seven indicators measure improvements to existing modes. The avoid segment of this framework is not covered in this report because there is little consensus to date around 1.5°C-aligned targets and little publicly available data in this category.

We adopted two transport targets (i.e., share of electric vehicles in light-duty vehicle sales and share of electric vehicles in light-duty vehicle fleet) from CAT (2020a), which employed a combination of top-down and bottom-up methods to establish near- and long-term targets. CAT first identified modelled pathways that limit global temperature rise to 1.5°C with no or limited overshoot from IPCC (2018) and then filtered them, following the criteria outlined in Box 3. The authors complemented this analysis of IAM scenarios with analysis from both bottom-up sectoral modelling efforts (e.g., for electric vehicles) and other independent, peer-reviewed literature to derive targets from the range of values presented across these sources. CAT then compared each target derived from this bottom-up analysis with targets derived from the filtered set of scenarios modelled by the IAMs in IPCC (2018) to ensure that, if there was any discrepancy, the targets derived from the bottom-up approaches were more ambitious in achieving decarbonization more rapidly.

We derived another five targets from 1.5°C-compatible pathways in the literature, including the IEA's *Net Zero by 2050* report, Mission Possible Partnership's *Making Net-Zero Aviation Possible*, the Global Maritime Forum's *Five Percent Zero Emission Fuels by 2030 Needed for Paris-Aligned Shipping Decarbonization*, and academic

TABLE 4 | Design of transport indicators and targets

INDICATOR	TARGET				ADDITIONAL INFORMATION
	2030	2035	2050	SOURCE(S)	
Number of kilometers of rapid transit per 1 million inhabitants (km/1M inhabitants)	38	Forthcoming	N/A	Teske et al. 2021; Moran et al. 2018; ITDP 2021; UN 2019b	We aligned this target with Teske et al. (2021), who identified the need to double the capacity of public transport from 2021 levels through 2030 to enact changes in modal shifts that align with a 1.5°C carbon budget. We created an aggregate indicator by dividing the total number of kilometers in the top 50 emitting cities worldwide by 1 million urban inhabitants to get a rapid-transit–to–resident ratio and calculated the target by doubling this number through 2030. For the city selection, we selected the top 50 emitting cities from Moran et al. (2018) and used the ITDP rapid transit database to identify the number of kilometers of rapid transit (bus rapid transit, light-rail, and metro) (Moran et al. 2018; ITDP 2021). For the cities not included in ITDP's database, our primary data source, we collected additional data from official government documents. We then used population estimates from the United Nations' *2018 Revision of World Urbanization Prospects,* which presents data in five-year increments (UN 2019b).

Number of kilometers of high-quality bike lanes per 1,000 inhabitants (km/1,000 inhabitants)	2	Forthcoming	N/A	Moser and Wagner 2021; Mueller et al. 2018; Moran et al. 2018	We followed the target identified by Moser and Wagner (2021) of 2 km of high-quality infrastructure/1,000 inhabitants by 2030, which is aligned with a 1.5°C carbon budget. This indicator metric was derived from Mueller et al. (2018), who looked at the relationship between the modal share of cycling and the availability of high-quality cycling infrastructure. Similar to above, we also selected the top 50 emitting cities from Moran et al. (2018) and used OpenStreetMap to calculate the number of high-quality (i.e., a level of traffic stress[a] of 1 or 2) kilometers of cycling infrastructure for each year and each city from 2010 to today. Our method filtered for tags that indicated low-stress, high-quality bike lanes within the overall bike network, defined as any street or passageway where biking is permitted. This included discrete bike paths and trails, cycle tracks, and buffered cycle lanes. This kind of filtering did not count some street types that might be low stress for cyclists but are not explicitly designed for bikers, such as low-volume and/or low-speed residential streets or multiuse paths without dedicated space for cyclists. The result was aggregated at the city level, giving the total kilometers of protected, low-stress segments within the city boundaries. It is important to note here that not all cities around the world are well mapped in OpenStreetMap, especially when it comes to bike lanes built in earlier years (during the first decade of monitoring). In those cities with limited mapping activities, mapping progress over the years might indicate more the extent to which volunteers have contributed to OpenStreetMap rather than the actual number of bike lanes in the city. On the other hand, cities can use this historical information as a benchmark to identify their own progress. We also used population estimates from the United Nations' *2018 Revision of World Urbanization Prospects,* which presents data in five-year increments (UN 2019b).

Share of kilometers traveled by passenger cars (% of passenger -km)	35–43	Forthcoming	N/A	BNEF 2021	To establish this 2030 target, we compared the bottom and top of the range for electric vehicle uptake (the fifth indicator in this table, in which electric vehicle penetration is 20–40 percent of global vehicle stock by 2030) against its projected BAU scenario (BNEF 2021). In the BAU scenario, EVs make up 12 percent of the global vehicle stock in 2030. There is therefore a gap of 8–28 percentage points in the number of EVs between a BAU and our own penetration scenario. We propose closing this gap by shifting trips that would be done in EVs (cars and light trucks) to nonmotorized vehicle modes, including walking, cycling, and motorized public transport. In this analysis, we assumed that these nonmotorized vehicle modes will be either zero emissions (e.g., walking and cycling) or fully electrified (for motorized modes) by 2030.
Share of electric vehicles in light-duty vehicle sales (%)	75–95	100	100	CAT 2020a	N/A
Share of electric vehicles in the light-duty vehicle fleet (%)	20–40	Forthcoming	85–100	CAT 2020a	N/A
Share of electric vehicles in two- and three-wheeler sales (%)[b]	78	100	100	IEA 2023b	N/A
Share of battery electric vehicles, plug-in hybrid electric vehicles, and fuel cell electric vehicles in bus sales (%)	56	90	100	IEA 2023b	N/A

Share of battery electric vehicles, plug-in hybrid electric vehicles, and fuel cell electric vehicles in medium- and heavy-duty commercial vehicle sales (%)	37	65	100	IEA 2023b	N/A
Share of sustainable aviation fuels in global aviation fuel supply (%)	13	28–32	100	MPP 2022	N/A
Share of zero-emissions fuels in maritime shipping fuel supply (%)	5	Forthcoming	100	Baresic et al. 2023	In a 1.5°C-aligned modelled scenario, Osterkamp et al. (2021) find that the share of zero-emissions fuels in maritime shipping fuel supply reaches 93% by 2046. The authors, however, do not explicitly state a value for 2050. Building on this analysis, Baresic et al. (2023) clarify that this share should reach 100% by 2050.

Notes: km = kilometer; M = million; N/A = not applicable; °C = degrees Celsius; ITDP = Institute for Transportation and Development Policy; BAU = business as usual; EV = electric vehicle.

[a] Level of traffic stress (LTS) is an approach that quantifies the amount of discomfort that people feel when they bicycle close to traffic. The methodology was developed in 2012 by the Mineta Transportation Institute and San Jose State University. The LTS methodology assigns a numeric stress level to streets and trails based on attributes such as traffic speed, traffic volume, number of lanes, frequency of parking turnover, ease of intersection crossings, and other factors (MCP 2017).

[b] We added this indicator on the share of electric vehicles in two- and three-wheeler sales to *State of Climate Action 2023* because there are almost as many motorized two- and three-wheelers (e.g., motorcycles, rickshaws, tricycles) on the road as four-wheeled passenger vehicles. In certain regions, such as Southeast Asia, motorcycles and motorized scooters are the dominant mode of transport, accounting for around 80 percent of vehicle kilometers traveled (Le and Yang 2022).

Source: Authors.

studies that expand upon this initial analysis (IEA 2021b; MPP 2022; Osterkamp et al. 2021; Baresic et al. 2023). The sources and methodological approaches used for the remaining three targets and indicators that focus on modal shifts—designed by World Resources Institute (WRI)—are described in Table 4.

2.3.5 Forests and land

Well-designed and appropriately implemented land-based mitigation measures from forests, peatlands, coastal wetlands, and grasslands can deliver significant reductions in GHG emissions and, unlike other sectors, enhance carbon sequestration. Protecting, restoring, and sustainably managing these ecosystems represent the primary shifts needed for mitigation in this sector (IPCC 2022).

Yet deriving targets for these measures from IAM modelled pathways that limit global temperature rise to 1.5°C with no or limited overshoot—one of the primary approaches employed across energy-supply and end-use sectors (i.e., power, buildings, industry, and transport)—poses several key challenges. IAMs include just a third of the land-based mitigation measures that previous bottom-up studies of mitigation potential across agriculture, forestry, and other land uses (AFOLU) have shown can reduce GHG emissions and/or enhance carbon sequestration (e.g., Griscom et al. 2017). Similarly, some IAM baselines already contain several land-based mitigation measures, either because they feature small carbon prices that encourage implementation of these actions or because they assume some reduction in deforestation. Both could result in an underestimation of the sector's mitigation potential. Finally, due to cost optimization constraints, IAMs with scenarios that overshoot 1.5°C generally delay a significant proportion of land-based mitigation until after 2050, particularly for measures that remove carbon from the atmosphere (Roe et al. 2021).

Establishing targets based on bottom-up estimates of technical or cost-effective mitigation potential for individual land-based measures—a commonly used alternative approach—also comes with several limitations. Aggregating individual measures' mitigation potential estimates from studies that employ different methods may result in double-counting across land-based measures, leading to an overestimation of the sector's overall mitigation potential. Forests, peatlands, coastal wetlands, and grasslands, for example, are not mutually exclusive ecosystems—peat soils can be found within forests, coastal wetlands, and grasslands, while some coastal wetlands—namely, mangroves—are also forests. And unlike IAMs, this approach also does not fully account for the interactions or trade-offs among land-based mitigation measures, such as competition over land (Roe et al. 2021).

Given the challenges associated with both methods, we relied on recent, well-cited studies that compare estimates of modelled mitigation potential for the AFOLU sector broadly, as well as for individual mitigation options, with bottom-up estimates of technical and cost-effective mitigation potential. Roe et al. (2019), for example, reconciled the median of bottom-up global mitigation potential estimates across AFOLU with those identified in modelled pathways from IAMs that limit global warming to 1.5°C to establish an overarching mitigation target of 14.0 gigatonnes of carbon dioxide equivalent per year ($GtCO_2e$/yr) in 2050. Roe et al. (2019) then divided this required effort for AFOLU into priority measures—or wedges—that consider cost effectiveness, as well as food security, biodiversity, and fiber production safeguards. They accounted for additional safeguards for other wedges. For example, the reforestation wedge excludes land-use changes across the world's boreal biome, as adding trees to these landscapes could alter the reflectivity of the planet's surface in ways that could increase global warming. Together, these wedges form the "land sector roadmap for 2050" in Roe et al. (2019).

Relying on literature published since Roe et al. (2019) and recently updated data, Roe et al. (2021) revised these bottom-up estimates of technical and cost-effective global mitigation potential for each wedge, as well as those modelled by IAMs. The authors found that, together, measures across AFOLU can mitigate between 8 and 13.8 $GtCO_2e$/yr from 2020 to 2050 at a cost of up to US$100 per tonne of carbon dioxide equivalent (tCO_2e), which they considered cost-effective. Roe et al. (2021) noted that the upper end of this range, which represents the bottom-up, cost-effective estimate,[21] is in line with pathways that limit global warming to 1.5°C, including the 14 $GtCO_2e$/yr mitigation target established in Roe et al. (2019). Protecting, restoring, and sustainably managing the world's forests, peatlands, coastal wetlands, and grasslands, specifically, delivers 48 percent of this cost-effective mitigation potential for AFOLU at 6.6 $GtCO_2e$/yr in 2050 (Roe et al. 2021). These findings are aligned with IPCC (2022), which similarly estimates that, at the same price, protecting, restoring, and sustainably managing these ecosystems can deliver between 4.2 and 7.3 $GtCO_2e$/yr from 2020 to 2050.

We followed Roe et al. (2019, 2021) in using the bottom-up estimates of mitigation potentials to account for a broader range of land-based mitigation measures, and although this decision comes with a risk of double-counting mitigation potentials across these wedges, Roe et al. (2019, 2021) adopted methods designed to minimize this risk and create wedges independent of one another. More specifically, we used the area estimates associated with the global bottom-up, cost-effective mitigation potentials from Roe et al. (2021) for reduced mangrove loss, reforestation, peatland restoration, and mangrove restoration to determine near- and long-term targets for the *State of Climate Action* series. For our deforestation and peatland degradation indicators, we used the mitigation potentials identified in Roe et al. (2019)'s 1.5°C-aligned "land sector roadmap for 2050." Our deforestation indicator follows the paper's "implementation roadmap to 2050" to establish 2030 and 2050 targets, while our peatland degradation indicator relies on the rate of avoided peatland degradation and ramp-down assumptions from the underlying source paper (Griscom et al. 2017) cited by Roe et al. (2019). Table 5 includes further information on our methodology to develop the targets for each indicator. We excluded indicators and targets for improved forest management and improved fire management across grasslands due to data limitations in assessing their progress.[22] Similarly, we followed Roe et al. (2021) in narrowing our coastal wetlands indicator to mangrove forests, thereby excluding seagrass meadows and salt marshes.

Because the area estimates for each land-based mitigation measure in Roe et al. (2021) are averaged across a 30-year period, from 2020 to 2050, translating them into targets for 2030, 2035, and 2050 required an understanding of ramp-up (or ramp-down) assumptions—the date by which the reduced rate of mangrove loss is reached and then sustained, as well as the amount of reforestation, peatland restoration, and mangrove restoration that occurred each year and the date by which the total area reforested or restored is

TABLE 5 | Design of land and forest indicators and targets

INDICATOR	TARGET				ADDITIONAL INFORMATION
	2030	2035	2050	SOURCE(S)	
Deforestation (Mha/yr)	1.9[a]	1.5	0.31	Roe et al. 2019	We did not use the avoided deforestation area estimate associated with Roe et al. (2021)'s bottom-up, cost-effective mitigation potential (3.56 $GtCO_2e$/yr from 2020 to 2050) because one of the source papers used (Busch et al. 2019) does not exclude temporary cycles of forest loss associated with managed forests in its baseline. This is inconsistent with other estimates (e.g., Griscom et al. 2017; Roe et al. 2019; Griscom et al. 2020) and prior *State of Climate Action* reports (Boehm et al. 2021; Lebling et al. 2020), which constrain this measure to the permanent conversion of forests to other land uses. Instead, we derived 2030 and 2050 targets from Roe et al.'s (2019) "land sector roadmap for 2050," which identifies the reductions in GHG emissions from deforestation needed to achieve a similar mitigation potential (3.6 $GtCO_2e$/yr in 2050). More specifically, this roadmap calls for reducing GHG emissions from deforestation by 70% by 2030 and 95% by 2050, relative to 2018 levels. To derive the area-based targets for this indicator, we assumed that the area of deforestation will also need to be reduced by 70% by 2030 and 95% by 2050, following the same approach used in *State of Climate Action 2021* (Boehm et al. 2021). We then used data from Global Forest Watch to calculate the 2030 and 2050 targets based on these percentage reductions from the 2018 level (6.2 Mha, see "Use of Proxy Indicators" below). Finally, to establish a 2035 target, we assumed a linear ramp down in deforestation between the 2030 and 2050 area-based targets. Because the mitigation potential for this wedge is roughly similar in Roe et al. (2019)—3.6 $GtCO_2e$/yr in 2050—and Roe et al. (2021)—3.56 $GtCO_2e$/yr from 2020 to 2050—we assumed that these targets will still provide the bottom-up, cost-effective mitigation potential estimated by Roe et al. (2021).

Peatland degradation (Mha/yr)	0	0	0	Roe et al. 2019	We did not use the avoided peatland degradation area estimate associated with Roe et al. (2021)'s bottom-up, cost-effective mitigation potential because it is not defined relative to a historical baseline. Rather, it is the difference in peatland degradation in 2035 between two Shared Socioeconomic Pathway 2–Representative Concentration Pathway 2.6 (SSP2-RCP2.6) scenarios modelled by Humpenöder et al. (2020), using a model called MAgPIE that combines biophysical and economic approaches to simulate spatially explicit global land-use scenarios (Humpenöder et al. 2020). Instead, we followed Roe et al. (2019)'s "land sector roadmap for 2050," which identifies the reductions in GHG emissions from peatland degradation needed to help achieve the sector's target of mitigating 14 $GtCO_2e$/yr in 2050. Roe et al. (2019) derived this GHG emissions reduction estimate from Griscom et al. (2017)'s "maximum additional" mitigation potential for peatland degradation, which was estimated by assuming that recent rates of peatland degradation fall to 0 by 2030 and that no additional degradation occurs between 2030 and 2050. Finally, because the mitigation potential for this wedge is higher in Roe et al. (2019) and Griscom et al. (2017)—0.75 $GtCO_2e$/yr in 2050—than in Roe et al. (2021)—0.21 $GtCO_2e$/yr from 2020 to 2050—we assumed that these targets are still in line with 1.5°C pathways.
Mangrove loss (ha/yr)	4,900	4,900	4,900	Roe et al. 2021	Roe et al. (2021) define the bottom-up, cost-effective mitigation potential for avoided GHG emissions from mangrove loss (0.07 $GtCO_2e$/yr from 2020 to 2050) as 90% adoption of the technical potential from Griscom et al. (2020), expanded to include non-tropical countries. This technical potential was defined as avoiding all potential mangrove loss, estimated using average annual gross mangrove loss rates from 1996 to 2016. We therefore calculated a 90% reduction in this rate to derive our targets. Following ramp-down assumptions from Griscom et al. (2020), we set our target to achieve this reduction by 2030, with no further increase in the rate of loss between 2030 and 2050 (Griscom et al. 2020).

Reforestation (total Mha)	100 (2020–2030)[b,c,d]	150 (2020–2035)[b,c,d]	300 (2020–2050)[b,c,d]	Roe et al. 2021	For this indicator, we were unable to determine the ramp-up assumptions from the source papers (Busch et al. 2019; Austin et al. 2020) in Roe et al. (2021) because the mitigation potentials and associated area estimates were averaged across the two source papers by country and over the 30-year period. Instead, we assumed a linear ramp-up in total reforested area from 2020 to 2050—that the reforested area would increase each year by the average annual "cost-effective area" provided by Roe et al. (2021) (9.84 Mha/yr) to reach roughly 100 Mha by 2030, 150 Mha by 2035, and 300 Mha by 2050.[c] To validate that this assumption would provide the bottom-up, cost-effective mitigation potential estimated by Roe et al. (2021)—1.2 $GtCO_2e$/yr from 2020 to 2050—we used the average aboveground and belowground carbon removal rate for reforestable land (as defined in Griscom et al. [2017]) from Cook-Patton et al. (2020)—11.57 tonnes CO_2 per hectare per year—to estimate the potential mitigation under the assumption of linear ramp-up in reforested area. The resulting estimate for the annual mitigation potential averaged across the 30-year period is 1.8 $GtCO_2e$/yr—roughly 0.6 Gt $GtCO_2e$ higher than in Roe et al. (2021). We therefore believe that a linear ramp-up in reforested area is a reasonable assumption because our estimate meets the mitigation potential identified by Roe et al. (2021).

Peatland restoration (total Mha)	15 (2020–2030)[d]	16 (2020–2035)[d]	20–29 (2020–2050)[d]	Roe et al. 2021; Humpenöder et al. 2020	Roe et al. (2021) define the bottom-up, cost-effective mitigation potential for avoided GHG emissions from the restoration of degraded peatlands (0.59 $GtCO_2e$/yr from 2020 to 2050) as the difference in the global area of rewetted peatlands between two SSP2-RCP2.6 scenarios modelled by Humpenöder et al. (2020), using MAgPIE, in 2035. The first scenario assumes land-based climate policies that include peatland protection and restoration, while the second assumes land-based climate policies that include only peatland protection (Humpenöder et al. 2020). The resulting area is roughly 16 Mha of degraded peatlands restored by 2035. For our targets, we generally followed the ramp-up assumptions in Humpenöder et al. (2020)'s scenario that includes peatland protection and restoration policies, which entail restoring approximately 15 Mha by 2030 and 20 Mha by 2050. Note that our ramp-up assumptions involve restoring 16 Mha by 2035, which ensures alignment with the sector's total contribution to 1.5°C pathways (13.8 $GtCO_2e$/yr), as estimated by Roe et al. (2021). We set a second, more ambitious, target than Roe et al. (2021) because some studies (e.g., Leifeld et al. 2019; Kreyling et al. 2021) argue that restoring nearly all degraded peatlands by around mid-century will be required to limit warming to 1.5°C or below, as emissions from drained peatlands may otherwise consume a large share of the global carbon budget associated with this temperature limit. However, as IPCC (2022) notes, restoring all degraded peatlands may not be possible (e.g., those upon which cities have been constructed, that are subject to saltwater intrusion, that have experienced significant subsidence, or that have already been converted into plantation forests). While it remains to be determined with certainty what percentage can be feasibly rehabilitated, particularly at costs of up to $100/$tCO_2e$, several papers find that restoring roughly 50% of degraded peatlands is needed to help deliver AFOLU's contribution to limiting global temperature rise to 1.5°C (e.g., Searchinger et al. 2019; Roe et al. 2019). We followed these studies and set a more ambitious target than Roe et al. (2021) for 2050. The lower bound of this range involves restoring 20 Mha as estimated by Humpenöder et al. (2020), while the upper bound of this range entails restoring roughly half of degraded peatlands, recently estimated at 57 Mha globally by UNEP (2022). Our target, then, represents an important starting point rather than a definitive goal for policymakers.

Mangrove restoration (total ha)	240,000 (2020–2030)[d]	N/A	N/A	Roe et al. 2021	Roe et al. (2021) define the bottom-up, cost-effective mitigation for enhanced carbon sequestration from mangrove restoration (0.01 $GtCO_2e$/yr from 2020 to 2050) as 30% adoption of the technical potential from Griscom et al. (2020), expanded to include non-tropical countries. Technical potential is defined as the restoration of mangroves lost since 1996, excluding those lost to erosion or urbanization (Griscom et al. 2020). We therefore calculated 30% of the area associated with the technical potential to derive our targets. Following ramp-up assumptions from Griscom et al. (2020), we set our target to achieve this restoration by 2030, resulting in a target for 2030 only (Griscom et al. 2020). Griscom et al. (2020) note that this target is conservative as it excludes mangrove forests lost before 1996, and previous studies suggest that mangrove losses in the 1980s and 1990s were significant (Friess et al. 2019), so much so that the world may have lost as much as 35% of its mangrove forests during these two decades (Valiela et al. 2001). This target, therefore, likely represents the area of mangroves that, at a minimum, needs to be restored to achieve climate mitigation goals.

Notes: Mha/yr = million hectares per year; ha/yr = hectares per year; GHG = greenhouse gas; CO_2 = carbon dioxide; $GtCO_2e$/yr = gigatonnes of carbon dioxide equivalent per year; tCO_2e = tonnes of carbon dioxide equivalent; AFOLU = agriculture, forestry, and other land uses; °C = degrees Celsius.
[a] These reduced deforestation targets largely align with existing goals and commitments around forests that aim to rapidly reduce deforestation, such as Goal 1 of the New York Declaration on Forests to end natural forest loss by 2030 and the Glasgow Leaders' Declaration on Forests and Land Use, under which countries committed to halt and reverse forest loss by 2030.
[b] Although our targets to reforest 100 Mha by 2030, 150 Mha by 2035, and 300 Mha by 2050 cover only approximately 86 percent of the restoration targets set by the Bonn Challenge and the New York Declaration on Forests, they focus solely on reforestation, while both international commitments include pledges to plant trees across a broader range of land uses, such as agroforestry systems, and to restore a broader range of degraded landscapes.
[c] We rounded the total area from Roe et al. (2021)—295 Mha—to 300 Mha, our 2030 target from 98 Mha to 100 Mha, and our 2035 target from 148 Mha to 150 Mha.
[d] Reforestation, peatland restoration, and mangrove restoration targets are additional to any reforestation and restoration that occurred prior to 2020, and these targets are cumulative either from 2020 to 2030, from 2020 to 2035, or from 2020 to 2050.
[e] As Griscom et al. (2017) note, the marginal abatement cost literature lacks a precise understanding of the complex, geographically variable costs and benefits associated with peatland restoration and, therefore, estimates of cost-effective peatland restoration vary.
Source: Authors.

reached. Wherever possible, we relied on the ramp-up (or ramp-down) assumptions from the underlying source papers that Roe et al. (2021) cited for each land-based measure. These ramp-up (and ramp-down) assumptions are further described in Table 5.

Across all reforestation and restoration indicators, targets focus solely on actions needed to limit global warming to 1.5°C. Those designed to conserve biodiversity would likely call for more ambitious reforestation, peatland rewetting, and mangrove restoration (Dinerstein et al. 2019, 2020), as well as halting net loss in ecosystems (Díaz et al. 2020).

Use of proxy indicators

Throughout the "Forests and land" section, we use proxy indicators to track progress toward near- and long-term targets. Generally, indicators that track changes in the global extent of ecosystems rely on data collected by field surveys or remotely sensed data. Although field surveys play a critical role in validating remotely sensed data, they are time-consuming, expensive, and infrequently conducted, resulting in data that quickly become outdated. Data derived from satellite imagery—the primary alternative—have greater spatial and temporal resolution, and for some ecosystems (e.g., forests and mangroves), they are publicly available and updated annually or near annually. Yet indicators that rely on remotely sensed data, such as tree cover loss or tree cover gain, can only approximate our indicators, such as those for deforestation and reforestation. Critically, maps derived from remotely sensed data also contain inaccuracies that can stem from a number of factors, including the mapping or modelling process and the data used to create the map; accordingly, any map-derived area estimates contain an inherent degree of uncertainty (Olofsson et al. 2014). We highlight additional limitations for each proxy indicator, as well as methods taken to address these limitations where possible, below.

Deforestation

To monitor deforestation globally, we estimated gross tree cover loss (million hectares per year; Mha/yr)[23] that likely resulted in permanent conversion of forest cover to new, non-forested land cover or land uses. We relied on a combination of four datasets available on Global Forest Watch: tree cover loss (Hansen et al. 2013) updated to the most recent year of data, tree cover loss by dominant driver (Curtis et al. 2018) updated to the most recent year of data, humid tropical primary forests (Turubanova et al. 2018), and tree cover loss due to fire (Tyukavina et al. 2022) updated to the most recent year of data. To estimate deforestation rates, we summed the area of all tree cover loss (Hansen et al. 2013) within areas whose dominant driver, as defined by Curtis et al. (2018), was classified as commodity-driven deforestation and urbanization, in addition to humid tropical primary forest loss due to the expansion of shifting agriculture (Turubanova et al. 2018), as these losses are likely to represent permanent deforestation. We excluded all tree cover loss due to fire (Tyukavina et al. 2022), which is likely to be more temporary in nature,[24] to allow us to better observe trends in permanent forest conversion without the interannual variability linked to extreme weather events. Similarly, we excluded the Curtis et al. (2018) shifting agriculture class outside of humid tropical primary forests (Turubanova et al. 2018), as well as the forestry and wildfire classes, as these are likely to be more temporary in nature and followed by forest regrowth. Finally, we removed any areas that overlapped with our data on mangrove loss (Murray et al. 2022) to avoid double-counting.

Our deforestation proxy indicator has several limitations. The Curtis et al. (2018) data on global forest loss drivers, which we used to filter the tree cover loss data for this indicator, are currently available only at a coarse spatial and temporal resolution—10 kilometers (km), representing the dominant driver over the entire time series from 2001 to 2022—which may lead to inaccuracies at smaller scales since individual 10-km grid cells may have more than one driver of tree cover loss within the same year or over multiple years (WRI 2022). Additionally, the Hansen et al. (2013) tree cover loss data may underestimate smaller-scale forest clearings due to the limitations of detecting such losses with medium-resolution satellite data, and the accuracy of the data varies by biome. Finally, the Hansen et al. (2013) tree cover loss dataset has undergone improvements over time, including algorithm adjustments that increase sensitivity to the detection of smaller-scale disturbances, as well as changes in satellite image availability with the launch of new Landsat satellites (Weisse and Potapov 2021). Due to these data inconsistencies, we did not use data prior to 2015 to calculate the historical linear trendline, and changes to the methodology have been minimal since 2015. Detailed assessments of the accuracy of each dataset used for the deforestation proxy can be found in the source publications.

Peatland degradation

We used data on the annual change in the area of histosols (i.e., soils comprised primarily of organic matter) drained for agriculture, including the cultivation of crops and grazing, from Conchedda and Tubiello (2020) as a best available proxy for peatland degradation. Using these data, we calculated the total increase in the area of histosols drained for agriculture over the study time period (1993–2018)[25] and divided the total increase in area by the number of years to determine the average annual rate of drainage. Using the Harmonized World Soil Database, Conchedda and Tubiello (2020) define histosols as soils with a thick layer of strongly decomposed acidic organic material (70 centimeters thick), with continuous rock at 80 centimeters, that develop in environments with a large excess of precipitation (Conchedda and Tubiello 2020; FAO and IIASA 2012).

While the area of histosols drained for agriculture represents a best available proxy for peatland degradation, these data may underestimate peatland degradation for several reasons. First, the data estimate drainage of histosols solely for agricultural activities, and although agriculture is a primary driver of peatland degradation globally, other causes of degradation—including road and infrastructure development, forestry, oil sands mining, and peat extraction, among others—are not included in the estimates (Conchedda and Tubiello 2020; UNEP 2022). Moreover, the threshold of peat depth used to define peatland varies by country, and some countries have yet to establish a nationally recognized definition of peat altogether (e.g., Myanmar, Lao People's Democratic Republic, Cambodia) (Sulaeman et al. 2022). In nations where this threshold is lower than the depth of organic material used to define organic soil in Conchedda and Tubiello (2020), peatland degradation may not be included in these estimates of drained organic soils. For example, if the threshold used to define peatlands is two meters of organic matter, but the threshold used to define organic soils is three meters of organic matter, then these peatlands would be excluded from this estimate of organic soils. As a result, the global extent of histosols is significantly lower than most recent estimates for peatland area (e.g., Xu et al. 2018; UNEP 2022), and estimates of the area of histosols drained for agricultural activities (25 Mha) are substantially lower than estimates of the global area of degraded peatlands (57 Mha) (Conchedda and Tubiello 2020; UNEP 2022).

Mangrove loss

To monitor mangrove loss globally (in hectares per year; ha/yr), we used a dataset on tidal wetland change that estimates gross area of loss of tidal flats, tidal marshes, and mangroves from 1999 to 2019 (Murray et al. 2022). Murray et al. (2022) define mangrove loss as the replacement of mangroves with non-intertidal ecosystems at the 30-meter pixel scale, which includes both natural and human-caused losses, and, using this definition, estimated mangrove loss in three-year epochs. To convert these estimates to annual rates, we divided the gross loss for each epoch by the number of years in the epoch to determine the average annual loss rate in hectares per year. There are several limitations in using these data to assess progress toward our target for mangrove loss. Because loss area is estimated for three-year epochs, fewer data points are available from which to derive the historical trendline, and the trendline for this indicator was derived from the area of mangrove loss across four epochs. Furthermore, this dataset may also underestimate changes that occur at smaller scales or in narrow linear features such as waterways due to the limitations of detecting such changes with medium-resolution satellite imagery (Murray et al. 2022). A detailed assessment of the accuracy of these data can be found in Murray et al. (2022).

Global Mangrove Watch, another commonly used dataset on mangrove extent and change, recently released a version 3.0 dataset that contains estimates of mangrove extent from 1996 to 2020 (Bunting et al. 2022). However, Bunting et al. (2022) recommend using only their net change estimates, rather than gross loss or gain, due to misregistration errors with the JAXA L-Band Synthetic Aperture Radar (SAR) data, which can lead to overestimation of individual loss and gain in some areas. JAXA is currently reprocessing all L-band SAR global mosaics, which will likely resolve this limitation in future versions of the Global Mangrove Watch data.

Reforestation

We used tree cover gain (total gross area gained from 2000 to 2020) as the best available proxy indicator for reforestation (Potapov et al. 2022). Potapov et al. (2022) define tree cover gain as the establishment or recovery of tree cover (woody vegetation with a height of greater than or equal to five meters) by the year 2020 in areas that did not have tree cover in the year 2000.

However, there are several key limitations in using tree cover gain to approximate reforestation. Notably, the tree cover gain data include all tree cover gain occurring both within and outside of forests and/or historically forested land, including afforestation, as well as regrowth from industrial tree plantations. Therefore, not all tree cover gain meets the standard definition of reforestation.[26] Additionally, because Potapov et al. (2022) use a conservative definition of height change to eliminate noise in the data, tree cover gain may be underestimated in some cases. Finally, because tree cover gain occurs gradually, it is generally more difficult to detect from satellite data within short time frames, limiting the temporal resolution of the data for this indicator. Thus, current global data on tree cover gain represent only a cumulative total area from 2000 to 2020, and annual data are not available. A detailed assessment of the accuracy of these data can be found in Potapov et al. (2022).

Mangrove restoration

Murray et al. (2022) estimate gross area of mangrove gain from 1999 to 2019, defining gain as mangrove establishment in areas where mangroves were not present in 1999 (Murray et al. 2022). Murray et al. (2022) estimate that the vast majority of mangrove gain from 1999 to 2019 was due to natural, broad-scale coastal processes, with only 8 percent (approximately 15,000 hectares) likely attributable to direct human interventions, such as mangrove planting and other restoration activities. Therefore, we used direct mangrove gain as a proxy for mangrove restoration.

However, there are a number of limitations in using mangrove gain due to direct human activities as a proxy for mangrove restoration. As with forests, mangroves grow gradually, and therefore mangrove gain is more challenging to monitor on shorter time scales, as gain may not be detected until mangrove trees reach a certain level of maturity. Therefore, recently established plantings may not be included in these estimates. Moreover, the establishment of mangrove trees does not always indicate restoration of the ecological function of these ecosystems and, in some cases, this addition of mangroves can lead to negative consequences (e.g., the loss of other tidal wetland ecosystems) or short-lived gains if tree planting is not implemented appropriately

(Lee et al. 2019). Therefore, this proxy may include mangrove gain that would not be considered mangrove restoration. A detailed assessment of the accuracy of these data can be found in Murray et al. (2022).

2.3.6 Food and agriculture

Transforming the world's food and agriculture sector would significantly mitigate climate change. Measures that sustainably intensify production—those that increase yields without expanding croplands or pasturelands while minimizing the release of methane and nitrous oxide—can lower GHG emissions from both land-use change and cultivation. Similarly, reducing consumption of emissions-intensive food like ruminant meat and lowering food loss and waste can help decrease agricultural land demand (and associated CO_2 emissions from land-use change), production-related GHG emissions, and the amount of GHGs released across food supply chains (Searchinger et al. 2019; IPCC 2022). Moreover, increasing agricultural soil carbon sequestration, as well as adding additional aboveground carbon via agroforestry and silvopasture systems, has the potential to reduce net emissions related to agricultural production (Roe et al. 2021), although additional sequestration potential on working agricultural lands is likely limited (Poulton et al. 2018; Henderson et al. 2015).

For each of these critical shifts, we primarily adopted targets established in Searchinger et al. (2019). For that publication, CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement; French Agricultural Research Centre for International Development), INRA (Institut National de la Recherche Agronomique; French National Institute for Agriculture, Food and Environment), WRI, and Princeton University jointly developed a global accounting and biophysical model called GlobAgri-WRR to quantify the effects of food production and consumption patterns on agricultural land-use demands, GHG emissions, and food security. Searchinger et al. (2019) then modelled several detailed scenarios to see which one would achieve three overarching goals by 2050:

- Feed nearly 10 billion people
- Reduce agriculture's land footprint below its 2010 global extent to eliminate GHG emissions from land-use change and free up enough farmland for restoration to enhance carbon sequestration in natural ecosystems
- Limit GHG emissions from agricultural production to no more than 4 $GtCO_2e$/yr, which is aligned with a 1.5°C pathway, assuming the world also effectively halts deforestation and achieves large-scale reforestation and peatland restoration as described in the *State of Climate Action* series' "Forests and land" targets.[27]

Of all scenarios modelled in Searchinger et al. (2019), only the most ambitious "Breakthrough Technologies" scenario achieved all three targets, while also freeing up approximately 800 Mha of agricultural land to allow for large-scale ecosystem restoration.[28]

In total, this Breakthrough Technologies scenario includes more than 15 mitigation wedges that reduce growth in demand for food and other agricultural products, increase food production without expanding agricultural land, boost fish supply, lower GHG emissions from agricultural production, and liberate land to protect and restore natural ecosystems. We translated those wedges with the highest mitigation potential—reducing GHG emissions from agricultural production, boosting crop yields, increasing livestock productivity, lowering food loss and waste, and shifting to more sustainable diets—into near- and long-term targets that collectively achieve a significant percentage of the mitigation potential identified in Searchinger et al. (2019) (Table 6).

We adopted targets for the GHG emissions intensity of agricultural production,[29] crop yields, ruminant meat productivity, and ruminant meat consumption in high-consuming regions (primarily the Americas, Europe, and Oceania) from Searchinger et al.'s (2019) Breakthrough Technologies scenario, with some adjustments where appropriate. The dietary shift associated with the ruminant meat consumption indicator, specifically, does not apply to populations within high-consuming regions that already consume fewer than 60 kilocalories per capita of ruminant meat per day, have micronutrient deficiencies, and/or do not have access to affordable and healthy alternatives to ruminant meat. The statistical database of the Food and Agriculture Organization of the United Nations, FAOSTAT, defines Oceania to include Australia, New Zealand, Melanesia, Micronesia, and Polynesia.

To establish a target for the GHG emissions intensity of agricultural production, specifically, we first scaled the values for absolute GHG emissions from agricultural production published in Searchinger et al. (2019) to FAOSTAT values by comparing the 2010 data in the two sources. Next, we calculated the mean between GHG emissions from agricultural production in 2010[30] and the 2050 projection for these emissions in the Breakthrough Technologies scenario, effectively creating a linear pathway between the observed value in 2010 and the target in 2050. We set our 2030 target as the midpoint (the mean between the 2010 and 2050 values) of that pathway. To convert these GHG emissions targets into GHG emissions intensity targets, we used data

TABLE 6 | Design of food and agriculture indicators and targets

INDICATOR	TARGET				ADDITIONAL INFORMATION
	2030	2035	2050	SOURCE(S)	
GHG emissions intensity of agricultural production (gCO_2e/1,000 kcal)	500	450	320	Searchinger et al. 2019	Before the 2023 report, we measured (absolute) GHG emissions from agricultural production, with targets of 4.6 $GtCO_2e$ in 2030 and 3.6 $GtCO_2e$ in 2050 adapted from Searchinger et al. (2019). Starting in the 2023 report, we divided these absolute emissions by the amount of kilocalories projected in the global food supply in each target year, using data from FAOSTAT.
Crop yields (t/ha)	7.8	8.2	9.6	Searchinger et al. 2019; Searchinger et al. 2021	N/A
Ruminant meat productivity (kg/ha)	33	35	42	Searchinger et al. 2019	N/A
Share of food production lost (%)[a]	6.5	6.5	6.5	UN 2015	We updated these targets in the 2023 report due to significant changes to the FAO food loss dataset (including the base year data).
Food waste (kg/capita)[b]	61	61	61	UN 2015	N/A
Ruminant meat consumption (kcal/capita/day)	79	74	60	Searchinger et al. 2019	While all other targets are global in scope, this goal focuses solely on lowering ruminant meat consumption in high-consuming regions (primarily the Americas, Europe, and Oceania) for equity reasons. We calculated historical data points for each past year by taking an average (weighted by population size) of the availability of ruminant meat (i.e., bovine, sheep, and goat meat) in the food supply for all subregions where ruminant meat availability was greater than 60 kcal/person/day in 2017. Other regions' consumption levels were below the 60-kilocalorie threshold in 2017 and, accordingly, were not included. This target also does not apply to populations within high-consuming regions that already consume fewer than 60 kcal/capita/day of ruminant meat, have micronutrient deficiencies, and/or do not have access to affordable and healthy alternatives to ruminant meat.

Note: gCO_2e/1,000 kcal = grams of carbon dioxide equivalent per 1,000 kilocalories; GHG = greenhouse gas; $GtCO_2e$/yr = gigatonnes of carbon dioxide equivalent per year; t/ha = tonnes per hectare; kg/ha = kilograms per hectare; kg/capita = kilograms per capita; kcal/capita/day = kilocalories per capita per day; N/A = not applicable.
[a] Food loss occurs before food gets to market.
[b] Food waste occurs at the retail level and in homes and restaurants, among other locations.
Source: Authors.

on kilocalories in the global food supply, published annually by FAOSTAT, as the denominator. Using a similar target-setting approach, we took the projection from Searchinger et al. (2019) that global kilocalorie demand would grow by 55 percent between 2010 and 2050 to estimate the size of the global food supply in our target years, again assuming that future growth will be linear. Finally, we divided the absolute agricultural production emissions targets in 2030 and 2050 by the projected number of kilocalories in the global food supply for each year to obtain targets for GHG emissions intensity of agricultural production in terms of grams of CO_2e per 1,000 kilocalories. To be more current, we set the baseline year at 2017 instead of 2010.

Our targets for crop yields initially came from Searchinger et al. (2019), but we updated them in 2021 to account for more recent crop demand forecasts for 2050 from Searchinger et al. (2021) that were relative to a 2017 base year. We estimated a 2030 target by setting a linear pathway between 2017 and 2050 and making the 2030 target 13/33 (39 percent) of the needed increase to reach the 2050 target. Similarly, we derived the 2035 target by taking 18/33 (55 percent) of the needed increase. As with the emissions target, we used a base year of 2017.

Finally, we opted for food loss and waste targets derived from Target 12.3 of the Sustainable Development Goals (UN 2015), which are more ambitious than Searchinger et al. (2019) and involve halving the rates of food loss and waste by 2030 instead of 2050. We decided to use these more ambitious targets in the *State of Climate Action* series because the 2030 waste reduction of 50 percent has already been widely adopted by governments and businesses around the world. The 50 percent reduction target was also maintained through 2035 and 2050.

A major caveat regarding the baseline and target values in this section is the reliance on historical data in FAOSTAT. Although FAOSTAT data have several strengths, including coverage of most countries, relatively consistent methods across countries, and open access, they rely on national data submissions, which can be subject to differences in definitions and quantification methods across countries and time. As such, there can be discrepancies among methods used to generate FAOSTAT data and other measurement methods (e.g., using satellite data to map cropland and pastureland, or dietary surveys to estimate per capita food consumption patterns). Previous versions of FAOSTAT emissions data used global warming potentials (GWPs) from the IPCC's *Second Assessment Report*, but in 2021, FAOSTAT updated these GWPs to include those from the IPCC's *Fifth Assessment Report* (FAOSTAT 2022).

To meet the projected higher demand for meat in 2050 (Komarek et al. 2021), improvements in ruminant meat productivity, especially in the tropics where productivity is lowest, will be key to reducing emissions from livestock. But a specific limitation for the ruminant meat productivity indicator is that FAOSTAT does not differentiate pasturelands for ruminant meat production versus those for dairy production. As globally consistent datasets improve, it may become necessary in the future to reestimate baseline and target values for these indicators.

For the 2023 installment of the *State of Climate Action* series, we slightly adjusted the food loss target because FAO made a significant update to its food loss dataset that affected the base year data. Because the 2030, 2035, and 2050 targets are expressed as a 50 percent reduction from the base year, it made sense to adjust those targets accordingly.

2.3.7 Technological carbon removal

Very large reductions in GHG emissions are essential to reaching net-zero CO_2 emissions by around mid-century and should remain the top global priority. But these reductions will not be enough to limit global warming to 1.5°C. The world will also need to pull CO_2 out of the air to counterbalance GHG emissions that will prove difficult to mitigate in the coming decades (e.g., from long-haul aviation, heavy industry, and agriculture) and to deal with excess CO_2 already in the atmosphere (IPCC 2022). This can be done through scaling up a range of carbon removal approaches and technologies, including strategies generally considered natural or land-based (e.g., reforestation and coastal wetland restoration) and those considered more technological (e.g., DACCS), which we assess here. We recognize that this natural versus technological categorization is not binary, will depend on how the approach or technology is applied, and leaves out some dimensions of each approach or technology.

There is only one indicator for this shift in the report series, which tracks the annual amount of CO_2 removed from the atmosphere and sequestered permanently from any carbon removal technology (Table 7). These technologies currently include DACCS; biomass carbon removal and storage, including BECCS and approaches that include pyrolysis or gasification of biomass; and mineralization, though future development of additional technologies is expected. The indicator tracks progress across a range of carbon removal technologies, indicating the expected scale of carbon removal that will need to be met by existing and not-yet-developed technologies.

To establish technological carbon removal targets, CAT (2023) filtered modelled pathways that limit global temperature rise to 1.5°C with no or limited overshoot from IPCC (2022), following the criteria outlined in Box 2. Critically, biomass cultivation for carbon removal within this filtered subset of 33 scenarios adheres to sustainability safeguards outlined in Fuss et al. (2018) and reaffirmed in IPCC (2018).[31] CAT (2023) then used the 5th percentile (in 2030, 2035, and 2050) from these 33 scenarios to set the lower bound of each target and the 95th percentile to establish the upper bound. Adopting targets with such a wide range reflects the high level of uncertainty associated with the amount of technological carbon removal ultimately needed to limit warming to 1.5°C, as this depends on the magnitude of GHG emissions reductions simultaneously achieved. The lower bound of each target, for example, represents scenarios that feature more ambitious GHG emissions reductions and, consequently, minimize reliance on technological carbon removal.

The data used to track progress come from a variety of sources as there is not yet a centralized source tracking tonnes of carbon removal. Only delivered removals are counted toward the total each year (rather than advance purchases that are not yet delivered). Removals are counted both from tonnes of carbon that are sold on the voluntary market and from removal projects that are not selling tonnes on the voluntary market. We included only projects where data are publicly available. Further, we excluded projects that use captured CO_2 to produce additional oil (i.e., enhanced oil recovery) given life cycle considerations of the produced oil.

TABLE 7 | Design of technological carbon removal indicator and target

INDICATOR	TARGET				ADDITIONAL INFORMATION
	2030	2035	2050	SOURCE(S)	
Technological carbon removal ($MtCO_2$/yr)	30–690	150–1,700	740–5,500	CAT 2023	N/A

Note: $MtCO_2$/yr = million tonnes of carbon dioxide per year; N/A = not applicable.
Source: Authors.

2.3.8 Finance

Finance is a key means by which to enable climate action, with investment and aligned financial incentives playing a critical role in unlocking all other sectoral transformations covered in the *State of Climate Action* series. Indeed, to facilitate vast decarbonization across all sectors, sufficient finance from both public and private actors must be made available, and the financial system must be reoriented so that it no longer supports the fossil economy and is aligned with the Paris Agreement's goals.

In the *State of Climate Action* series, we examine seven indicators (Table 8) for insight into how finance can unlock greater climate action.[32] We used a variety of methodological approaches to design 2030, 2035, and 2050 targets for each indicator. Because the design of our targets for total climate finance, public climate finance, and private climate finance aggregates information from multiple sources and requires a lengthy methodological explanation, we provide an in-depth description in Box 5. Table 8 includes justification for the target design for all other indicators.

TABLE 8 | Design of finance indicators and targets

INDICATOR	TARGET				ADDITIONAL INFORMATION
	2030	2035	2050	SOURCE(S)	
Global total climate finance (trillion $/yr)[a]	5.2	Forthcoming	5.1	IPCC 2018, 2022; IEA 2021b; OECD 2017; UNEP 2021a, 2021b	See Box 5 for an overview of how we used these sources to design our targets. This indicator includes public and private, as well as domestic and international, flows.
Global public climate finance (trillion $/yr)[b]	1.31–2.61	Forthcoming	1.29–2.57	IPCC 2018, 2022; IEA 2021b; OECD 2017; UNEP 2021a, 2021b	See Box 5 for an overview of how we used these sources to design our targets. This indicator includes both domestic and international flows.
Global private climate finance (trillion $/yr)[b]	2.61–3.92	Forthcoming	2.57–3.86	IPCC 2018, 2022; IEA 2021b; OECD 2017; UNEP 2021a, 2021b	See Box 5 for an overview of how we used these sources to design our targets. This indicator includes both domestic and international flows.
Ratio of investment in low-carbon to fossil-fuel energy supply[c]	7:1	Forthcoming	10:1	Lubis et al. 2022	Shifting investment from fossil fuels to low-carbon energy is critical to holding global temperature rise to 1.5°C. Based on an analysis of scenarios from the IPCC, IEA, and Network for Greening the Financial System regarding long-term investment requirements for 1.5°C-aligned pathways, analysts at BNEF derived target ratios for investment in low-carbon to fossil energy supply[d] of 4:1 for 2021–2030 (range of 2:1 to 6:1), 6:1 for 2031–2040 (range of 5:1 to 9:1), and 10:1 for 2041–2050 (range of 6:1 to 16:1) (Lubis et al. 2022). For the 2030 target, we used the 7:1 ratio BNEF calculated based on a linear growth trajectory from the current ratio to meet the decadal average targets. We used the 10:1 ratio for the decade 2041–2050 as the target for 2040, which will need to be sustained through 2050.

Share of global GHG emissions under mandatory corporate climate risk disclosure (%)[e]	75	100	100	CA and WRI 2021	This indicator uses the share of global GHG emissions under mandatory corporate climate risk disclosure as a proxy to monitor the number and significance of countries mandating climate risk disclosure. We designed the target for 2030 to correspond to the share of global GHG emissions that the G20 countries are responsible for—namely, about three-quarters of global emissions (CA and WRI 2021). Although we expect the G20's leadership on climate action, we did not restrict the indicator to only the G20 since there are countries outside of the group that are adopting mandatory climate disclosures (e.g., New Zealand). Our targets for 2035 and 2050 require all countries to implement mandatory disclosures, reflecting both the accelerated pace in adoption of these regimes and projections that developing countries will comprise the bulk of annual GHG emissions by 2040 (Bhattacharya et al. 2023). The launch of sustainability standards by the International Sustainability Standards Board, for example, has enabled developing countries to implement mandatory disclosures more easily, as evidenced by the endorsements and announced plans for adoption (IFRS 2023). These targets, then, recognize that while all countries have a responsibility to address climate change, some have a responsibility to move faster due to greater GHG emissions and more capability to invest in climate action. Lastly, it is important to note that not all emissions are subject to corporate disclosure. National disclosure regulations may also have cross-border impacts as major multinational corporations operate supply chains spanning multiple countries.
Weighted average carbon price in jurisdictions with emissions pricing systems (2015 $/t$CO_2$e)	170–290	Forthcoming	430–990	IPCC 2022	The IPCC's Sixth Assessment Report includes estimates of the marginal abatement cost of carbon (i.e., the optimal carbon price) for pathways that limit warming to 1.5°C with no or limited overshoot as $220/t$CO_2$, with an interquartile range of $170–290/t$CO_2$, in 2030 and $630/t$CO_2$, with an interquartile range of $430–990/t$CO_2$, in 2050, both in 2015 US dollars (IPCC 2022). The weighted average was calculated based on the percentage of global GHG emissions covered by each carbon price for each year.

Total public financing for fossil fuels (billion $/yr)	0	0	0	IEA 2021b; IPCC 2022; G20 2009; G7 2016; UNFCCC 2022	IEA (2021b) found that beyond projects already committed to in 2021, no new investment in fossil fuel supply is required to meet global energy needs, a finding echoed by the IPCC's Sixth Assessment Report (IEA 2021b; IPCC 2022). Both the G20 and G7 have made long-standing commitments to phase out "inefficient fossil fuel subsidies,"[f] with the former stating in 2009 that it would do so "over the medium term" and the latter in 2016 setting a deadline for doing so by 2025 (G20 2009; G7 2016). At COP26, Parties to the UNFCCC likewise called for the "phase-out of inefficient fossil fuel subsidies" (UNFCCC 2022). The year 2030 would be 21 years after the G20 commitment was made, stretching the limit of the definition of "medium term." In addition, at COP26, 34 countries and 5 financial institutions committed to ending international public finance for unabated fossil fuels by the end of 2022 (COP26 Presidency 2021). Therefore, our target is for public financing for fossil fuels to be phased out globally by 2030, with G7 countries and international financial institutions achieving this by 2025, in line with their commitments.

Notes: BNEF = BloombergNEF; IPCC = Intergovernmental Panel on Climate Change; IEA = International Energy Agency; G20 = Group of 20; G7 = Group of Seven; °C = degrees Celsius; COP26 = the 26th United Nations Climate Change Conference of the Parties; GHG = greenhouse gas; tCO_2e = tonnes of carbon dioxide equivalent; N/A = not applicable.

[a] This indicator includes public and private, as well as domestic and international, flows.

[b] These indicators include domestic and international flows.

[c] In 2023, we added a new indicator to the *State of Climate Action* series, the ratio of investment in low-carbon to fossil fuel energy supply, to track the shift in investment flows in line with 1.5°C pathways.

[d] The BNEF study defines "low-carbon energy supply" as "low-carbon power supply (electricity generation, storage, transmission and distribution); hydrogen infrastructure and uses; carbon capture and storage (CCS); [and] fossil fuel-based electricity generation with abatement technology." It defines "fossil fuel energy supply" as "extraction and processing of coal, oil and gas; upstream, midstream, and downstream components; [and] includes unabated fossil fuel-based electricity supply" (Lubis et al. 2022).

[e] Jurisdictions included in 2022 are Brazil, Egypt, India, Japan, New Zealand, Singapore, Switzerland, the United Kingdom (UK), and the European Union. Disclosure requirements are not uniform among countries and apply to different or select types of firms (e.g., financial institutions or publicly traded firms) with diverse implementation timelines. We considered jurisdictions that implemented any form of mandatory requirement during the year it was approved, even if it enters into force in phases with different timelines. This approach can result in an overestimation as implementation timelines are enforced over the years in different stages.

[f] The original G20 commitment describes inefficient fossil fuel subsidies as ones that "encourage wasteful consumption, reduce our energy security, impede investment in clean energy sources and undermine efforts to deal with the threat of climate change" (G20 2009). However, the Organisation for Economic Co-operation and Development and IEA's review has noted the problem of there being no universally agreed definitions of "fossil fuel subsidies," "inefficient," and "wasteful consumption." Several countries, including Italy and Peru, have stated that they deem all fossil fuel subsidies as inefficient, while the UK Climate Change Committee does not categorize any fossil fuel subsidies in the UK as "efficient" (OECD and IEA 2021).

Source: Authors.

BOX 5 | Methodology for designing global targets for total, public, and private climate finance

To limit global temperature rise to 1.5°C and build climate-resilient societies, there is a need for significantly increased investment across nearly all sectors.[a] To this end, the first finance target—that global climate finance flows[b] reach $5.2 trillion per year by 2030 and $5.1 trillion by 2050—covers these overarching global climate finance needs.

It is challenging to accurately project climate financing needs. Datasets are incomplete or frequently change due to an evolving understanding of climate science, changing technology costs, and broader societal shifts.[c] To ensure the target was designed to be as robust as possible, we took the mean of estimates from four studies on energy and infrastructure needs estimated for 1.5°C and/or 2°C pathways, drawing on the approach used to estimate finance requirements in IPCC (2018)[d]:

1. The IPCC's review of integrated assessment models of global energy investment needs for a 1.5°C scenario found a mean value of $2.32 trillion annually between 2015 and 2035, in 2010 US dollars.[e]
2. The compilation of sector studies covering energy, transport, and AFOLU in the IPCC's Sixth Assessment Report to determine average annual mitigation financing found investment needs until 2030 of $2.4 trillion to $4.8 trillion per year, in 2015 US dollars under a mixture of 1.5°C and 2°C scenarios.[f] We subtracted the AFOLU figures ($0.1 trillion–$0.3 trillion) from this total, since they are covered by the nature-based finance estimate from the United Nations Environment Programme (UNEP) (see below).
3. The IEA's net-zero roadmap for 1.5°C projected that total energy investment needs will be $4.98 trillion per year by 2030, of which $4.4 trillion will be for clean energy systems, and $4.53 trillion by 2050, of which $4.2 trillion will be for clean energy systems, in 2019 US dollars.[g]
4. The Organisation for Economic Co-operation and Development assessed global infrastructure investment needs across the energy, transport, water, sanitation, and telecommunication sectors for a 2°C scenario to be $6.9 trillion annually between 2016 and 2030, of which $0.6 trillion was incremental to a baseline scenario without additional climate action, in 2015 US dollars.[h]

We adjusted all nominal figures to 2020 US dollars, giving an average of $4.71 trillion per year in 2030. Only the IEA included an energy investment needs estimate for 2050, of $4.28 trillion. To these energy-focused figures we then added estimates of finance needs from sectoral studies not covered:

- UNEP estimated finance needed for nature-based solutions to meet climate change, biodiversity, and land degradation targets to be $354 billion per year in 2030 and $536 billion per year in 2050, in 2018 US dollars.[i]
- UNEP estimated annual adaptation finance needs in developing countries to be from $155 billion to $330 billion by 2030 and from $310 billion to $555 billion by 2050.[j] These figures are updated to 2020 US dollars from the original 2016 estimates[k] that were used in *State of Climate Action 2021*. While the rest of the *State of Climate Action* series focuses on mitigation, we included adaptation finance within our total climate investment needs estimate because adaptation and mitigation financing are closely connected; failure to adequately invest in mitigation will lead to increased adaptation costs and vice versa. To this end, starting in the 2022 report, we used the low end of UNEP's range of estimated adaptation finance needs—$155 billion in 2030 and $310 billion in 2050—which corresponds with a 2°C scenario, whereas the high end of the range corresponds with a 4°C scenario. UNEP's assessment of more recent adaptation cost estimates suggests that adaptation costs could be at the higher end of the ranges, especially if the 1.5°C limit is not met.[l]

Summing these figures results in a total investment need of $5.2 trillion per year in 2030 and $5.1 trillion per year in 2050. See Table B5.1 for a breakdown of these totals.

TABLE B5.1 | Estimated annual climate investment needs (trillion $)

SECTOR, SCOPE, AND TEMPERATURE PATHWAY	SOURCE	2030		2050	
		NOMINAL (YEAR)	REAL (2020)	NOMINAL (YEAR)	REAL (2020)
Energy; global; 1.5°C	IPCC 2018	$2.3 (2010)	$2.95	N/A	N/A
	IEA 2021b	$4.4 (2019)	$4.48	$4.2 (2019)	$4.28
Energy, energy efficiency, and transport; global; 1.5°C and 2°C	IPCC 2022	$3.4 (range $2.3–$4.5) (2015)	$3.76	N/A	N/A
Energy, transport, water, sanitation, and telecommunication infrastructure; global; 2°C	OECD 2017	$6.9 (2015)	$7.64	N/A	N/A
Energy-focused assessments, mean		*$4.3*	*$4.71*	*$4.2*	*$4.28*
Nature-based solutions; global; 2°C (to meet both climate and biodiversity targets)	UNEP 2021b	$0.35 (2019)	$0.36	$0.54 (2019)	$0.55
Adaptation finance; developing countries; 2°C	UNEP 2021a	$0.15 (2020)	$0.15	$0.31 (2020)	$0.31
Total		**$4.8**	**$5.22**	**$5.1**	**$5.14**

Table Note: °C = degrees Celsius; N/A = not applicable.
Table Source: Authors.

For our indicators on public and private climate finance, it was difficult to determine the precise breakdown of public and private finance needed given that it depends on the social and political choices made about the ideal mix of market and state intervention in economies. Based on historical tracking of global flows from 2012 to 2020, public and private climate finance have been about equally balanced, so if this is maintained, it would imply that global climate finance needs should be split 50/50. The IPCC's *Special Report on Global Warming of 1.5°C* cites a projection that a quarter of global climate investment will come from public sources, including both domestic and international flows.[m] We therefore have a target range of 25–50 percent of global climate finance needs coming from public sources and 50–75 percent from private sources.

Box Notes: [a] IPCC 2022. [b] There is substantial debate about what should and should not be counted as climate finance, both in terms of sectors and types of financial flows. For the purposes of this section, we used the operational definition of the United Nations Framework Convention on Climate Change's Standing Committee on Finance, which has also been used by the IPCC: "Climate finance aims at reducing emissions, and enhancing sinks of greenhouse gases and aims at reducing vulnerability of, and maintaining and increasing the resilience of, human and ecological systems to negative climate change impacts" (UNFCCC SCF 2014; IPCC 2022). [c] IPCC 2022. [d] IPCC 2018. [e] IPCC 2018. [f] IPCC 2022. [g] IEA 2021b. [h] OECD 2017. [i] UNEP 2021b. [j] UNEP 2021a. [k] UNEP 2016. [l] UNEP 2021a. [m] IPCC 2018.

3. Selection of datasets

To assess global progress made toward 1.5°C-aligned targets, we first collected historical data for every indicator. Our selection of these datasets followed the subsequent six principles to ensure that all data included in the *State of Climate Action* series are open, independent of bias, reliable, and robust:

- **Relevance.** Datasets are directly relevant to each indicator and were created following a methodology that allows them to measure progress toward their respective targets.
- **Accessibility.** Datasets prioritized for inclusion in the *State of Climate Action* series are readily accessible to the public. They are generally not hidden behind paywalls, and they are ideally subject to an open data license. We note in each report when data-sharing agreements had to be established to access a dataset.
- **Accuracy.** Datasets are from reputable, trustworthy sources, with well-documented, openly accessible, and peer-reviewed methodologies that clearly note limitations. They are taken from data providers, including both authors of articles and organizations hosting datasets, that are either well-recognized as core data providers or known experts in their fields as suggested by authors and reviewers.
- **Completeness.** Datasets have sufficient temporal and spatial coverage, and each report notes where the best available data are not globally available or not published annually.
- **Timeliness.** Datasets selected represent the most up-to-date data available to reflect recent developments, and there is evidence that data have been and will be updated regularly. However, in many instances, there is a time lag before the best available data are published (between one and three years for most indicators, but roughly five years for some). As a result, the year of most recent data varies among indicators.
- **Ease of collection.** Datasets prioritized for each indicator are relatively easy to collect (e.g., those that require minimal processing or that are directly downloadable). However, in some instances, data selected required some processing (e.g., geospatial data).

Within each *State of Climate Action* report, datasets used to assess global progress are clearly noted for each respective indicator. In some cases, data limitations prevented us from assessing global progress toward a target, and we note these in each report accordingly.

4. Assessment of global progress

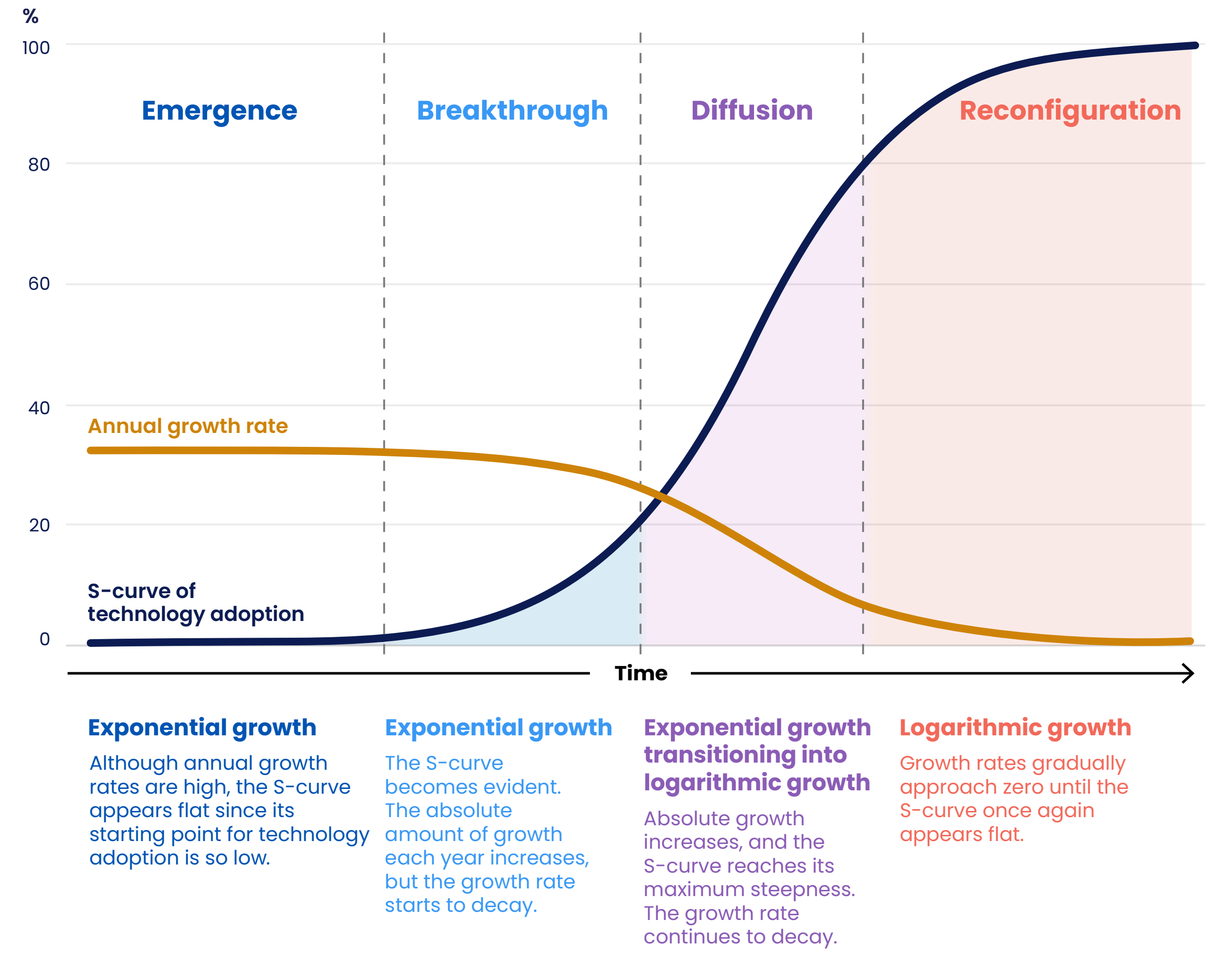
In this section, we provide an overview of our methodology for assessing global progress of all indicators toward their near-term targets. We first discuss why some indicators may follow nonlinear paths, and then explain the different methods we used to determine whether indicators are on track to meeting their near-term targets.

4.1 Background on the potential for nonlinear change

Assessing the gap between recent progress and future action needed to meet 1.5°C-compatible targets required projecting a trajectory of future change for each indicator. The simplest approach was to assume that growth continues at its current rate of change following a purely linear trajectory, and this was indeed an effective method for many indicators. However, it is unlikely that all indicators will follow a linear path. For example, the adoption of new technologies has often followed an S-curve trajectory (Figure 1). At the emergence stage of an S-curve, annual growth rates are high as promising research, development, and demonstration projects are underway, but adoption of the new technology remains quite low. Then, in the breakthrough stage, adoption of the technology bends upward, with sustained exponential growth rates. Once the technology begins to diffuse more widely, the rate of adoption of the technology reaches its steepest slope and exponential growth begins to decay. Finally, as society reconfigures around the new technology, adoption reaches a saturation point and growth rates approach zero. Notably, this S-curve concept can also be expanded beyond a specific technology to describe the broader transition from one sociotechnical system to another (e.g., transformation across the entire power sector).

The point at which an S-curve reaches the breakthrough stage can also be conceptualized as a tipping point—defined broadly as a critical threshold beyond which a system reorganizes often abruptly or irreversibly (IPCC 2022). In this context, tipping points generally occur when the cost of a new technology falls below that of the incumbent, such that the value of switching to the new technology is greater than its cost. Factors beyond monetary cost, such as an improvement in the technology or an increase in the value of the technology as more people adopt it, can also push technology adoption past a tipping point. Oftentimes, seemingly

FIGURE 1 | Illustration of an S-curve



Source: Authors.

small changes in these factors can trigger these disproportionately large responses within systems that catalyze the transition to a different state (Lenton et al. 2008; Lenton 2020).

Crossing tipping points can trigger self-amplifying feedbacks that help accelerate the diffusion of new technologies by pushing down costs, enhancing performance, and increasing social acceptance (Arthur 1989; Lenton 2020; Lenton et al. 2008). Learning by doing in manufacturing, for example, can generate progressive advances that lead to more efficient production processes, while reaching economies of scale enables companies to progressively lower unit costs. Similarly, as complementary technologies (e.g., batteries) become increasingly available, they can boost functionality and accelerate uptake of new innovations (e.g., electric vehicles) (Sharpe and Lenton 2021). These gains allow companies that adopt new technologies to expand their market shares, deepen their political influence, and amass the resources needed to petition for more favorable policies. More supportive policies, in turn, can reshape the financial landscape in ways that incentivize investors to channel more capital into these new technologies (Butler-Sloss et al. 2021).[33] Such reinforcing feedbacks, then, can spur adoption and help new innovations supplant existing technologies (Victor et al. 2019).

Widespread adoption of new technologies, in turn, can also have cascading effects, requiring the development of complementary innovations, the construction of supportive infrastructure, the adoption of new policies, and the creation of regulatory institutions (Box 6). It can also prompt changes in business models, availability of jobs, behaviors, and social norms, thereby creating a new community of people who support (or sometimes oppose) further changes (Victor et al. 2019). Meanwhile, incumbent technologies may become caught in a vicious spiral, as decreases in demand cause overcapacity and lead to lower utilization rates. These lower utilization rates, in turn, can increase unit costs and lead to stranded assets. Thus, for technologies with adoption rates that are already growing nonlinearly or that could be expected to grow at an exponential pace in the future, it is unrealistic to assess progress

BOX 6 | Upward cascade of tipping points

In some nested systems, the activation of one tipping point has the potential to trigger a cascade of tipping points across systems at progressively larger scales. In the power sector, for instance, a few early movers, including Denmark, Germany, Spain, and the US state of California, implemented policy portfolios that supported deployment of solar and wind energy technologies. More countries, such as China and India, soon followed suit, causing global demand for renewables to increase and prices to drop. These rapid declines in cost, in turn, spurred widespread adoption of renewables, as solar and wind energy recently supplanted coal and natural gas as the cheapest sources of electricity for at least two-thirds of the world's population.[a]

These knock-on effects can also catalyze change among interconnected sectors, as illustrated in Figure B6.1. For example, electric vehicles reaching price parity with gasoline-fueled cars in a small number of countries that, together, account for the majority of the world's automobile sales could trigger a global transition away from the internal combustion engine. Following this transformation in road transportation, oil companies would likely lose their largest market, which in turn could prompt investors to divest and channel their funds into more sustainable fuels for aviation, shipping, and heavy industry.[b]

FIGURE B6.1 | Upward cascade of positive tipping points

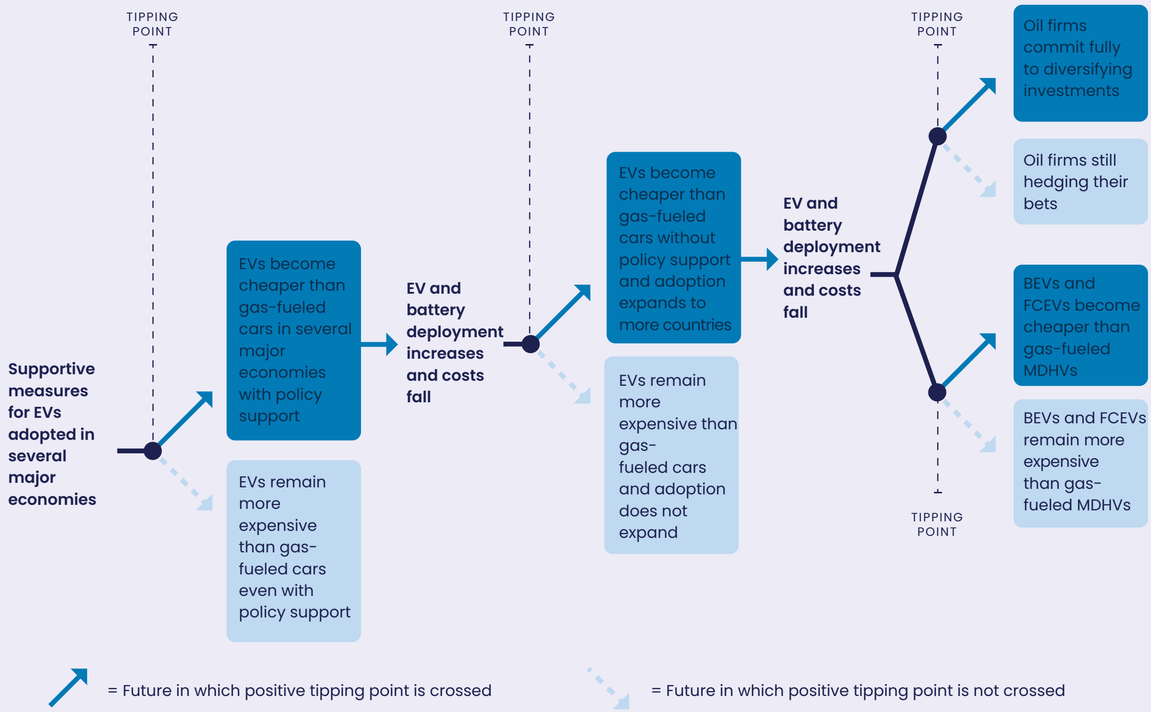


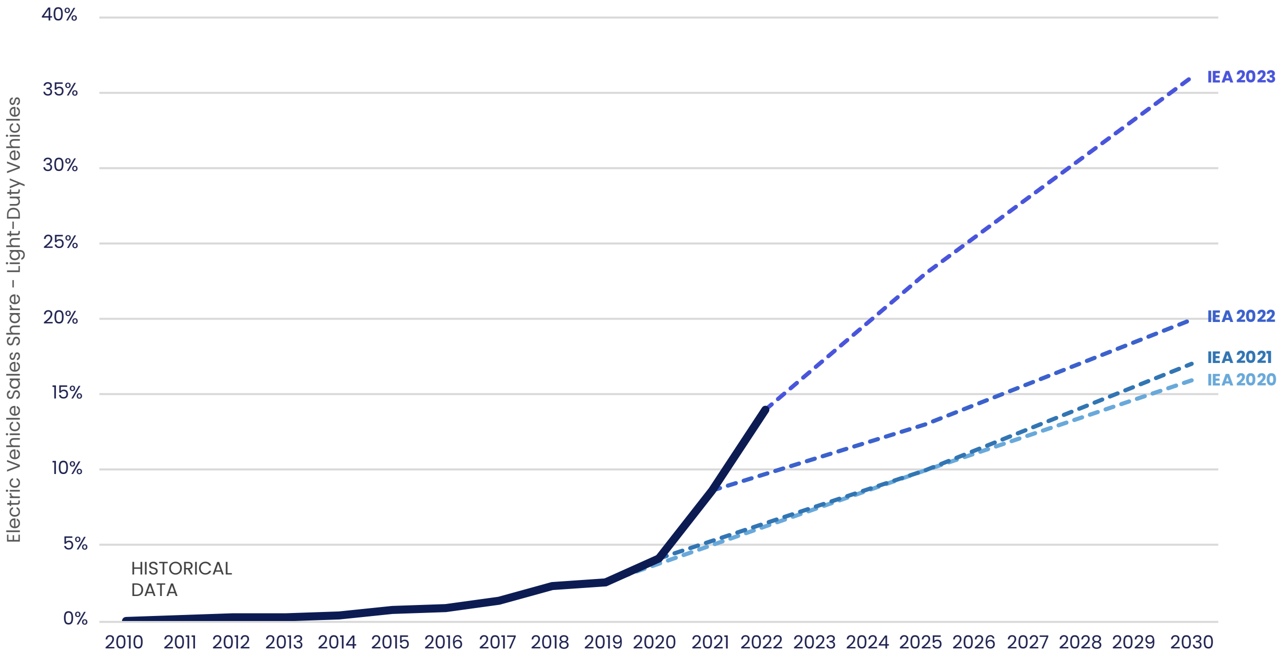
Figure Note: EV = electric vehicle; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; MDHV = medium- and heavy-duty vehicle.

Figure Source: Reproduced from Boehm et al. (2021), who adapted the figure from Sharpe and Lenton (2021).

Sources:

[a] Sterl et al. 2017; Eckhouse 2020. [b] Sharpe and Lenton 2021.

FIGURE 2 | The International Energy Agency's Stated Policy Scenarios have not accounted for the possibility of rapid, nonlinear growth in electric vehicles



Note: Electric vehicles include both all-electric vehicles and plug-in hybrid electric vehicles.
Source: Authors' analysis of IEA (2023a) and previous IEA *Global EV Outlook* reports from 2018 to 2022, all of which can be accessed at IEA (n.d.).

by assuming that future uptake will follow a linear trajectory (Abramczyk et al. 2017; Mersmann et al. 2014; Trancik 2014).

Nonetheless, many mainstream assessments still use linear assumptions for technology adoption forecasts in situations where they are not always applicable. For example, in its Stated Policies Scenarios, the IEA historically assumed that future growth in solar photovoltaic (PV) generation would be largely linear, but it had to repeatedly increase these forecasts as growth in solar PV accelerated. In 2012, for example, the IEA estimated that global solar energy generation would increase to 550 terawatt-hours in 2030, but that number was reached by 2018. More recent IEA projections for solar, however, now account for some nonlinear acceleration, as adoption of supportive policies continues to increase (IEA 2022b). However, the same linear assumptions are still being used for other technologies like electric vehicles (Figure 2) (IEA 2023a). For example, the IEA predicted it would take four years (2021–2025) for light-duty all-electric vehicles and plug-in hybrid electric vehicles to grow from 9 percent to 13 percent, but it took only one year. Such nonlinear growth in technologies remains difficult to predict, which is one reason why projections stick to roughly linear assumptions even if it is likely that technologies will experience S-curve dynamics. These linear assumptions often suffice for short-term projections, but longer-term projections should consider the potential for nonlinear growth.

Finally, it is important to note here that, in addition to technology adoption, social and political forces can also contribute to or hinder nonlinear change (Moore et al. 2022). Our assessment of recent progress made toward near-term targets did not consider them fully, given the challenges of modelling these effects and data limitations. However, a body of research is emerging on this topic, and further consideration is warranted in future research.

4.2 Methodology to assess global progress

To assess global progress made toward 1.5°C-compatible targets, we first determined the likelihood that indicators would follow an S-curve and classified their trajectories as S-curve likely, S-curve possible, and S-curve unlikely. We then employed three methods to assess progress made for each group of indicators.

4.2.1 Determining each indicator's potential for nonlinear change

We first evaluated the likelihood that indicators would follow an S-curve trajectory in the future, placing them into one of three categories based on our understanding of the literature and consultations with experts:

- *S-curve unlikely*: We identified indicators that we do not expect to follow the S-curve dynamics seen in technology diffusion given that they do not specifically track technology adoption. These occurred primarily within the food and agriculture, forests and land, and finance sections (e.g., reforestation, restoration, reducing food waste, increasing finance flows).
- *S-curve likely*: We considered indicators that directly track the adoption of specific technologies or, in some instances, a set of closely related technologies (e.g., solar and wind power) to be prime candidates for experiencing S-curve dynamics in the future. These technologies are innovative, often displacing incumbent technologies (e.g., renewable energy, electric vehicles, green hydrogen). Critically, categorizing an indicator as S-curve likely does not guarantee that it will experience rapid, nonlinear change over the coming years; rather, it signifies that, if and when adoption rates of these technologies begin to increase, such growth will likely follow an S-curve.
- *S-curve possible*: Finally, we identified indicators that do not fall neatly within the first two categories. These indicators do not track zero- or low-emission technology adoption directly, but adoption of new technologies will likely have some impact on their future trajectories, alongside many other factors such as increases in resource efficiency. Thus, although these indicators have generally experienced linear change in the past, they could experience some unknown form of rapid, nonlinear change in the coming decades if the nonlinear aspects begin to outweigh the linear ones. For example, reducing carbon intensity in the power sector is dependent on multiple trends: an increase in the efficiency of fossil fuel power, which is linear; switches between higher-emitting and lower-emitting fossil fuel power sources, which are generally nonlinear; and a switch from all types of fossil fuel power to zero-carbon power, which is expected to be nonlinear. If the nonlinear growth in zero-carbon power overtakes the linear growth in efficiency, the trajectory of carbon intensity could follow an inverted S-curve.

See Table 9 for a description of how we categorized indicators.

TABLE 9 | Further explanation of the likelihood indicators will follow an S-curve

S-curve unlikely

SECTOR	INDICATOR	EXPLANATION
Buildings	Energy intensity of building operations	Changes in this indicator are based on improvements in energy efficiency, which is an incremental process.
	Retrofitting rate of buildings	Changes in this indicator are based on an activity, not a technology.
Transport	Number of kilometers of rapid transit per 1 million inhabitants	Changes in these indicators are not based on innovative technology adoption.
	Number of kilometers of high-quality bike lanes per 1,000 inhabitants	
	Share of kilometers traveled by passenger cars	Changes in this indicator are based on behavior change, not technology adoption.

Forests and land	Deforestation Peatland degradation Mangrove loss Reforestation Peatland restoration Mangrove restoration	Changes in forests and land use are based on changes in activities, behavior, and other incremental processes, not technology adoption.
Food and agriculture	GHG emissions intensity of agricultural production Crop yields Ruminant meat productivity Share of food production lost Food waste Ruminant meat consumption	Changes in food and agriculture indicators are based on changes in behavior, policies, and on-farm practices. Although technology will play a role in mitigation and adaptation, none of the indicators within the *State of Climate Action* series are associated with the adoption of specific technologies.
Finance	Global total climate finance Global public climate finance Global private climate finance Ratio of investment in low-carbon to fossil fuel energy supply Share of global GHG emissions under mandatory corporate climate risk disclosure Weighted average carbon price in jurisdictions with emissions pricing systems Total public financing for fossil fuels	Changes in finance flows and policy are based on public and private policies and action, not technology adoption.

S-curve likely

SECTOR	INDICATOR	EXPLANATION
Power	Share of zero-carbon sources in electricity generation	Changes in these indicators are based on the adoption of an innovative technology.
Industry	Green hydrogen production	
Transport	Share of electric vehicles in light-duty vehicle sales	
	Share of electric vehicles in the light-duty vehicle fleet	
	Share of electric vehicles in two- and three-wheeler sales	
	Share of battery electric vehicles, plug-in hybrid electric vehicles, and fuel cell electric vehicles in bus sales	
	Share of battery electric vehicles, plug-in hybrid electric vehicles, and fuel cell electric vehicles in medium- and heavy-duty commercial vehicle sales	
	Share of sustainable aviation fuels in global aviation fuel supply	
	Share of zero-emissions fuels in maritime shipping fuel supply	

S-curve possible

SECTOR	INDICATOR	EXPLANATION
Power	Share of coal in electricity generation	Changes in these indicators partly depend on the adoption of renewable energy technologies, as well as other factors like switches among multiple types of fossil fuel and changes in overall electricity demand.
	Share of unabated fossil gas in electricity generation	
	Carbon intensity of electricity generation	Changes in this indicator partly depend on the adoption of renewable energy technologies, as well as other factors like efficiency of fossil power and the relative cost of different fossil fuel generation.
Buildings	Carbon intensity of building operations	Changes in this indicator partly depend on the adoption of technologies, including those for zero-carbon heating and cooling, as well as other factors like innovations or changes in behavior that improve energy efficiency.
	Share of new buildings that are zero-carbon in operation	Changes in this indicator partly depend on the adoption of technologies, including those for zero-carbon heating and cooling, as well as other factors like changes in behavior that improve energy efficiency.
Industry	Share of electricity in the industry sector's final energy demand	Changes in this indicator depend on adoption of multiple technologies and on the price of electricity.

	Carbon intensity of global cement production	Changes in this indicator partly depend on the adoption of multiple technologies, including those for zero-carbon cement, as well as innovations, new practices, or changes in behavior that improve energy efficiency.
	Carbon intensity of global steel production	Changes in this indicator partly depend on the adoption of multiple technologies, including low-carbon steel; the supply of green hydrogen; and innovations or changes in behavior that improve energy efficiency.
Carbon removal	Technological carbon removal	Changes in this indicator depend on technology adoption, but technological carbon removal is not replacing an existing technology or entering an existing market and depends mainly on policies and finance for advancement so may not follow the market adoption dynamics of other clean technologies.

Note: GHG = greenhouse gas.
Sources: Authors.

4.2.2 S-curve unlikely indicators: assessment of progress based on linear trendline

For "S-curve unlikely" indicators with sufficient historical data, we calculated a linear trendline based on the most recent five years of data. For several indicators, most notably those in the forests and land sector, we calculated a linear trendline based on 10 years of historical data to account for natural interannual variability, where possible.[34] We then extended this trendline out to 2030 and compared this projected value to the indicator's target for that same year. Doing so enabled us to assess whether recent progress made toward the target was on track. This is an important methodological update from *State of Climate Action 2021*, where we calculated the linear trend by drawing a straight line between the most recent data point and the data point from five years prior, therefore using just two moments in time.[35] We made the change because a line of best fit better reflects trends, as it is less impacted by small fluctuations, uncertainties in the data, and outliers, such as outliers in 2020 values due to the COVID-19 pandemic (Box 7). Using a line of best fit ensures that the current value and the value from five years ago influence the linear trend but do not exclusively determine it.[36]

Next, we calculated an "acceleration factor" for each indicator with sufficient historical data by dividing the average annual rate of change needed to achieve the indicator's 2030 target[37] by the average annual rate of change derived from the historical 5-year (or 10-year) trendline. For example, over the past five years, the share of coal in electricity generation has fallen on average by 0.54 percentage points per year, but it needs to fall by 3.94 percentage points on average every year until 2030; 3.94 percentage points divided by 0.54 percentage points equals an acceleration factor of approximately seven times. These acceleration factors quantify the gap in global action between current efforts and those required to limit global warming to 1.5°C. They indicate whether recent historical rates of change need to increase by twofold, fivefold, or tenfold, for example, to meet 2030 targets.[38] We then used these acceleration factors to assign our indicators one of five categories of progress:

- ✓ *Right direction, on track.* The recent historical rate of change is equal to or above the rate of change needed. Indicators with acceleration factors between 0 and 1 fall into this category. However, we do not present these acceleration factors since the indicators are on track.
- ! *Right direction, off track.* The historical rate of change is heading in the right direction at a promising yet insufficient pace. Extending the historical linear trendline would get the indicators more than halfway to their near-term targets, so indicators with acceleration factors between 1 and 2 fall into this category.
- ✕ *Right direction, well off track.* The historical rate of change is heading in the right direction but well below the pace required to achieve the 2030 target. Extending the historical linear trendline would get them less than halfway to their near-term targets, so indicators with acceleration factors of greater than or equal to 2 fall into this category.

Wrong direction, U-turn needed. The historical rate of change is heading in the wrong direction entirely. Indicators with negative acceleration factors fall into this category. However, we do not present these acceleration factors since a reversal in the current trend, rather than an acceleration of recent change, is needed for indicators in this category.

Insufficient data. Limited data make it difficult to estimate the historical rate of change relative to the required action.

Note that we did not calculate acceleration factors needed to reach 2050 targets, primarily because some targets for 2030 are "front-loaded," such that the magnitude of change required by 2030 is significantly larger than what is needed between 2030 and 2050 (e.g., deforestation). In these instances, the acceleration factors are considerably lower if calculated from the 2030 target to the 2050 target than if estimated from the most recent year of data to 2050. The latter approach would yield an acceleration factor that would indicate the pace required to achieve mid-century targets from the most recent year of data, but if decision-makers focused global efforts on achieving this acceleration factor, they would fall short of delivering the 2030 targets. For a small set of indicators (e.g., technological carbon removal), the reverse is also true—the magnitude of change required to reach 2050 targets is greater than that needed to achieve 2030 targets. In these instances, we established these mid-century targets, with the assumption that the 2030 targets would be reached along the way, and noted that progress must accelerate from 2030 to 2050 to stay aligned with efforts to limit global temperature rise to 1.5°C.

BOX 7 | COVID-19's impact on progress assessment

Government responses to the COVID-19 pandemic caused changes in behavior, such as decreased time spent in commercial building spaces and fewer trips made, that likely impacted many of the indicators assessed in this series. For some indicators, these changes are likely temporary, as there is little evidence that they have spurred structural shifts, and preliminary analysis suggests that GHG emissions are already rebounding (e.g., buildings sector emissions dropped by around 10 percent from 2019 to 2020, but evidence from 2021 and 2022 suggests that emissions in the sector have already rebounded and that progress was likely not sustained).[a] But for others, new policies or practices adopted during COVID-19 may have long-term impacts (e.g., the rollback of environmental regulations in some countries or increased public financing for fossil fuels). It may take many decades to evaluate the permanence of measures adopted during the pandemic, and their impacts on global progress made toward our targets. Changes in carbon intensity indicators, for example, cannot be clearly attributed to measures adopted to slow the spread of COVID-19.

Thus, for each indicator with a 2020 data point, we defaulted to keeping this value in our linear trendline calculations unless the latest science indicated that this change was temporary (e.g., we are already seeing a rebound in the data). In such cases, we removed the 2020 data point from our linear trendline calculations (and clearly noted this removal where applicable), but we still visualized the 2020 data point in our figures. More specifically, if 2020 was our most recent year of data, we calculated the linear trendline based on five years of data from 2015 to 2019. But if 2020 was not the most recent data point and data were available after 2020, we calculated the linear trendline using four years of data, rather than five (e.g., a trendline of 2022, 2021, 2019, and 2018).

Sources:
[a] IEA 2022a; UNEP 2021c.

4.2.3 S-curve possible indicators: assessment of progress based on linear trendline

For indicators categorized as “S-curve possible,” we followed the same methods as above and used a linear trendline to calculate acceleration factors and categorize progress, as recent historical data for these indicators have been following roughly linear trajectories. However, we noted in our analysis that, should nonlinear change begin, progress could unfold at significantly faster rates than expected, and the gap between the existing rate of change and required action would shrink.

4.2.4 S-curve likely indicators: assessment of progress accounting for nonlinear change

For indicators that will likely follow an S-curve, acceleration factors based on linear trendlines would be inappropriate. Instead, we based our assessment of progress on multiple lines of evidence, including literature reviews, expert consultations, and fitting S-curves to the historical data where appropriate. More specifically, we followed these five steps:

Step 1: Calculate an acceleration factor following the methods described above and use this linear assessment as a starting point. While relying on a purely linear assessment of progress would be inappropriate, it does provide a baseline for some indicators' progress. For indicators in the early stages of an S-curve, for example, future growth will likely be steeper than the current linear trendline. But for other indicators in the later stages of an S-curve, future growth will likely be less steep than the current linear trendline. Given these limitations, we do not present acceleration factors in the report for “S-curve likely” indicators.

Step 2: Review the literature and consult with experts. For some indicators, existing academic and gray literature evaluating their progress already employs a range of methodologies that consider nonlinear change. For example, current policy projections from institutions like BloombergNEF and the IEA now account for more than linear growth in some of their forecasts. We reviewed these studies to assess the likelihood that each indicator's future growth will outperform (or underperform) continued linear growth. We then weighed our findings against each method's rigor and the extent to which consensus exists across sources. This literature review is particularly important when considering indicators that track the adoption of relatively nascent technologies, where data limitations prevent an analysis of five-year trends. If the literature indicates that the development and deployment of these technologies is advancing, even in the emergence stage, we could reasonably assume that progress made toward an indicator's target is heading in the right direction but remains “well off track.” If the literature clearly indicates that a breakthrough is near, we considered upgrading the category further. Finally, we invited sectoral experts from around the world to review each *State of Climate Action* report and solicited their comments on our assessment of each indicator's progress. We took these comments into consideration when categorizing progress.

Step 3: Consider what stage of an S-curve the indicator is in. The future path of an S-curve depends on which stage—emergence, breakthrough, diffusion, or reconfiguration—the technology is in. More specifically, our confidence that an indicator's growth will follow an S-curve in the near term increases as it moves from the emergence stage to the breakthrough stage, and the stage of the S-curve also impacts whether future growth will outperform or underperform a linear trajectory.

To help identify which stage of an S-curve the indicator is in, we considered both the shape of the curve and how far the curve has gotten toward its saturation level (i.e., the maximum level that the indicator is expected to achieve). We first calculated what the current value of the indicator is as a proportion of its saturation level, which we assumed was the same as the upper bound of the long-term target. For example, the share of electric vehicles in light-duty vehicle sales needs to reach 100 percent by 2035. The current share of 10 percent means that the indicator has achieved 10 percent of its final saturation level. In another example, green hydrogen production needs to reach 330 Mt by 2050. The current amount of 0.027 Mt means that the indicator has achieved 0.008 percent of its saturation value. These are not always perfect estimates but are useful approximations. Next, we evaluated each indicator's shape of change over the last five years by comparing the historical data to a linear trendline, an exponential trendline, and a logarithmic trendline. We determined which of these trendlines was the best fit to the historical data. Using these two elements, we placed each indicator into one of the four stages of the S-curve.

- An indicator is in the **emergence stage** if the current value is less than 5 percent of the way to its saturation level or if there are not enough data because the technology is so nascent.
- An indicator is in the **breakthrough stage** if the current value is between 5 percent and 50 percent of its saturation level and the exponential trendline is the best fit for the past five years of data.

- An indicator is in the **diffusion stage** if the current value is between 5 percent and 80 percent of its saturation level, it is going upward, and the linear trendline is the best fit for the past five years of data.
- An indicator is in the **reconfiguration stage** if the current value is greater than 50 percent of its saturation level and the logarithmic trendline is the best fit for the past five years of data.

We also determined instances in which an indicator is not following a smooth S-curve because none of these criteria were met. This is the case if an indicator is experiencing flat or logarithmic growth before reaching 50 percent of the saturation value or is going downward at any point. It also may be that no type of trendline is a good fit. Many technologies run into obstacles or barriers, which could prevent them from following a smooth S-curve.

Note that sources in the literature do not agree on where to delineate the stages of an S-curve or on the names for these stages. We have chosen the criteria above such that the stages have the most relevance for informing trajectories of future growth. We will continue to monitor the literature and consider the need to amend the stages or their criteria.

Step 4: Fit an S-curve to the existing historical data where appropriate. For indicators with sufficient data in the breakthrough, diffusion, or reconfiguration stages, we fitted an S-curve to the historical data. We used a standard logistic S-curve function, which is based on three main inputs: the saturation level, which we assumed to be the indicator's long-term target; the maximum growth rate; and the midpoint of the S-curve. We then adjusted the growth rate and the midpoint of the function until the S-curve most closely fit all historical data. To do this, we minimized the sum of squared residuals between the historical data and the S-curve.

We then compared the S-curve's projected value for 2030 to our near-term target for each indicator. An S-curve extrapolation above the target suggests that the indicator is "on track." An S-curve that gets more than half of the way from the current value and the 2030 target indicates that the indicator is likely to be "off track," and if the extrapolation is less than half of the way from the current value to the 2030 target, the indicator is likely to be "well off track." For the few indicators for which this analysis is appropriate, we present the full results of the S-curve fitting in the appendix of the report.

For indicators in the emergence stage, we did not fit an S-curve to historical data due to uncertainties in the early stages. Rather, we defaulted to "well off track" in our categorization of progress. But where we found compelling evidence that a breakthrough was near based on the literature and expert consultation, we upgraded the indicator to a higher category than "well off track."

Similarly, for indicators that are not following a smooth S-curve, we did not fit an S-curve to the historical data, and we relied on linear acceleration factors, a review of the literature, and consultation with experts to assess recent progress.

Ultimately, determining whether "S-curve likely" indicators are on track carries considerable uncertainties, which is why we never use S-curve extrapolations as the only line of evidence for categorizing an indicator. Accurately projecting adoption rates for new technologies that are just beginning to emerge or diffuse across society is an enormously difficult endeavor. Any small fluctuations in the initial growth rate will create statistical noise, which introduces uncertainty into predictions that can reach orders of magnitude (Kucharavy and De Guio 2011; Crozier 2020; Cherp et al. 2021). Indeed, it is not until growth has reached its maximum speed (the steepest part of an S-curve trajectory) that robust projections for future growth can be made with more confidence (Cherp et al. 2021). Even then, additional assumptions must be made about the shape of the S-curve and the saturation point at which growth rates stabilize. For example, whether deceleration at the end of the S-curve mirrors the acceleration at the beginning significantly impacts the speed at which a technology reaches full saturation. Yet no S-curve in the real world is perfectly symmetric, and evidence from past transitions suggests that S-curves can be highly asymmetric (Cherp et al. 2021). Technologies can also encounter obstacles as they diffuse, such as supply chain constraints, that alter or limit the shape of the growth, but these challenges are similarly difficult to anticipate.

Step 5: Categorize progress. If we found relative consensus across multiple lines of evidence from the previous steps, then the decision was straightforward. If sources disagreed, we made a judgment call about which lines of evidence were most compelling and explained our reasoning. We will likely adjust these methods in future *State of Climate Action* reports as data availability improves and the literature on nonlinear growth increases. But given the immediate need to move beyond linear thinking, it is important to acknowledge and grapple with the possibility of nonlinear growth, while recognizing that assessing it entails considerable uncertainties.

4.3 Drawing illustrative S-curves to the targets

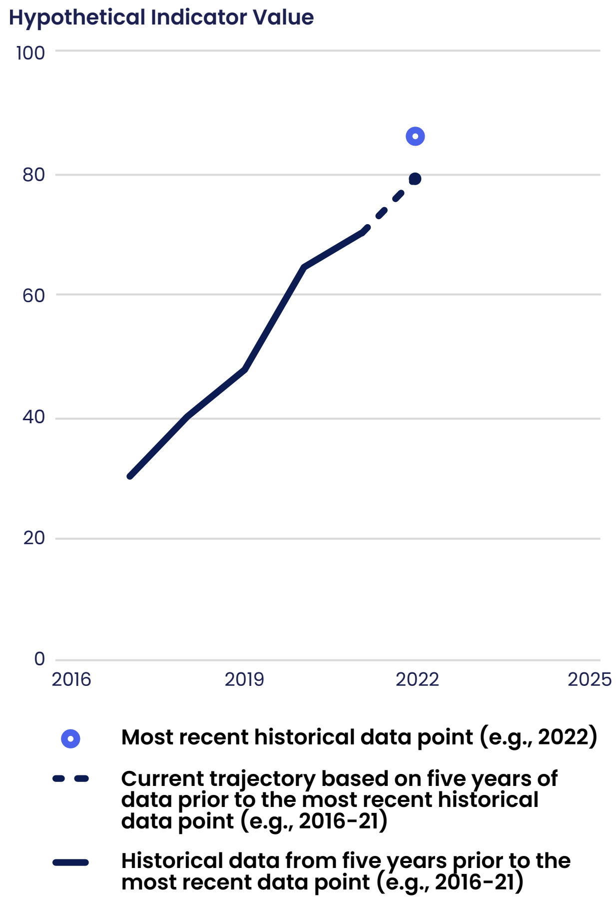
In addition to fitting S-curves to the historical data for certain "S-curve likely" indicators to show the current trend, we also use S-curves to show one possible pathway for what's needed to meet the near- and long-term targets. These S-curves are simply illustrative drawings. They are not intended to be the only pathways to reach the targets and are not predicting what future growth will be. We used a simple logistic S-curve formula to create these figures and adjusted the S-curves manually in some cases to ensure they matched up with the targets and were not too steep or shallow. Generally, our drawings are symmetrical, with the speed of acceleration in the first half mirrored with the speed of deceleration in the second half; however, this may not be the case in reality. Another limitation is that when we drew S-curves, we made sure the target years were aligned with 1.5°C. However, we were not able to determine whether all the other years on the illustrative curve were consistent with 1.5°C based on an accounting of the carbon budget.

4.4 Analysis of whether the most recent data point represents a change from previous trendlines

In addition to assessing progress made toward 2030 targets, we also analyzed whether an indicator's most recent data point represents an improvement or worsening relative to its historical trendline if sufficient data were available. Essentially, we extended the historical trendline from the previous 5 years of data (or 10 years for forests and land indicators, where possible) to project a data point for the most recent year for which we had data. For example, if our most recent data point was 2022, then we would use data from 2017 to 2021 to construct a historical trendline and then extend that trendline to project a data point for 2022.

We then compared our most recent data point to this projected data point on the extended historical trendline. If the most recent data point, for example, was more than 5 percent higher than the projected value on the extended trendline for an indicator that needs to increase to achieve its 2030 target, we noted that the most recent year of data for this indicator represents an improvement relative to the historical trendline (see Figure 3 as an example). But if the most recent data point fell more than 5 percent below the projected value on the extended historical trendline for the same indicator, we noted that the most recent year of data for this indicator represents a worsening relative to the historical trendline. However, it is critical to note that determining the extent to which an improvement or worsening is temporary or part of a longer-term trend will be possible only in future years.

FIGURE 3 | Method for comparing most recent year of data to extended historical trendline



Source: Authors.

5. Key limitations

In the following subsections, we outline key limitations to the methodological approach underpinning the *State of Climate Action* series. With new annual installments, we will seek to address these limitations as we improve our methodology.

5.1 Constraints in aggregating targets

As described in "Selection of Targets and Indicators," we selected near- and long-term targets for all sectors from a number of underlying sources and using a variety of methods—an approach that comes with several limitations. Because our targets were not all derived from one common model or model ensemble, we cannot definitively state that achieving all targets, together and on time, would collectively deliver the GHG emissions reductions and carbon removal needed to limit warming to 1.5°C with no or limited overshoot. Similarly, because the targets featured in the *State of Climate Action* series do not cover every shift needed to transform all global sectors, the collective mitigation potential of all targets together may also fall short of limiting global temperature rise to 1.5°C. Still, we opted for this approach—adopting separate 1.5°C targets from different studies—because there are merits and drawbacks to strategies for developing targets that vary significantly across power, buildings, industry, transport, forests and land, food and agriculture, technological carbon removal, and finance. To accommodate these challenges, we strove to select the best available targets using the most appropriate and rigorous methods for each unique sector. Doing so allowed us to identify targets across a more comprehensive set of GHG emissions–intensive sectors.

Finally, because we took the approach of identifying individual 1.5°C-aligned targets across each sector, we cannot robustly account for interaction effects that likely occur among sectors. For example, different models allocate different quantities of land for various emissions reduction and removal approaches. The competition for this land area for food production, energy production, carbon removal, and more may not be thoroughly accounted for in our targets.

5.2 Limitations in mapping connections between targets or indicators

Translating the transformational changes needed to limit global temperature rise to 1.5°C involves some degree of simplifying complex, interconnected sectors, and not all targets and indicators within the series are perfectly independent from one another. Within some sectors, there is a clear hierarchy of indicators—for example, changes in the share of zero-carbon power sources in electricity generation, the share of coal in electricity generation, and the share of unabated fossil gas in electricity generation all influence the carbon intensity of electricity generation. Similarly, indicators in one sector may depend on those in another, with reforestation, peatland restoration, and mangrove restoration influenced significantly by indicators that track the productivity per hectare of ruminant meat and crop yields. Given the difficulties in fully mapping out these relationships, we did not comprehensively consider dependencies, trade-offs, and conflicts among indicators and targets.

Within this context, it's also critical to note that simply summing the number of indicators that are on or off track cannot provide a complete picture of progress for a particular sector. If two out of five indicators in a particular sector are on track to meeting their 2030 targets, it does not mean that that sector is 40 percent on track. Instead, progress must be evaluated in a more holistic way. Relatedly, some sectors have more indicators than others; this does not mean that those sectors are more important than others, but rather that we are exploring more ways to monitor change within them.

5.3 Inherent uncertainty of future projections

Assessing whether an indicator is on track to reaching its targets comes with inherent uncertainties. Even at the outset, classifying indicators as "S-curve change unlikely," "S-curve likely," or "S-curve possible" is subjective. While we used criteria to determine which indicators fit into which category, the decisions were not always clear-cut, and we ultimately relied on author judgement to finalize them. Relatedly, the terms "unlikely," "possible," and "likely" also do not refer to specific likelihood percentiles, as they do in other publications, such as the IPCC's reports. Instead, they are descriptive categories that we assigned based on the nature of the indicator (i.e., whether the indicator is based on technology adoption fully, partially, or not at all).

For "S-curve likely" indicators, if nonlinear change does occur, the shape of that change is impossible to predict in the early stages. Most of the technologies that we track in this report are very early in their development, so small fluctuations in the growth rate introduce uncertainty into predictions (Kucharavy and De Guio 2011; Crozier 2020; Cherp et al. 2021). Moreover, with such limited data, we cannot yet know what the exact shape, midpoint, or saturation point of an S-curve will be. This is why we relied on author judgment based on a variety of factors in addition to S-curve fitting to determine whether "S-curve likely" indicators are on track. And, as described in "Methodology to Assess Global Progress," when we present S-curves in this report, either as current trendlines or as indications of the pace needed to reach targets, they are for illustrative purposes.

For the "S-curve possible" indicators, many of these same limitations also apply. Moreover, even for the "S-curve unlikely" indicators, there is still some possibility of nonlinear change. For indicators within both categories, we defaulted our methods to looking at acceleration factors assuming continued linear change, as described in "Methodology to Assess Global Progress." However, these values should be seen as just a general guide to inform how much faster change needs to happen compared with what has occurred over the past five years. We did not make quantitative predictions based on changing economics, supply chain constraints, or expected policy factors, and acknowledge that there are multiple potential pathways.

5.4 Incomplete consideration of biodiversity and equity

Because many of the sectors within the *State of Climate Action* series are interconnected (e.g., the expansion of agricultural lands drives deforestation or the amount of GHG emissions from buildings depends partly on the energy sources that power utilities use to generate electricity), small changes within the bounds of one can have wide-ranging impacts across others. The influence of these effects extends beyond climate change mitigation to other important societal goals as well, including efforts to improve political, social, and economic equity, as well as those to slow biodiversity loss. The broader effects of climate change mitigation can be positive, in some instances improving health outcomes across communities disproportionately impacted by air pollution from fossil-fueled cars, restoring biodiversity across degraded landscapes, or increasing farmers' incomes through crop yield gains. But they can also cause harm, creating unwanted and unintended consequences that decision-makers must proactively manage. Large-scale reforestation, for example, can threaten ecological function and structure, displace communities, and adversely impact water availability across watersheds if implemented inappropriately (IPCC 2022), while mining critical minerals like lithium and cobalt to produce low-carbon technologies can spur ecological damage and pollution that harm nearby communities' health and livelihoods. Mining these materials can also involve exploitative or unsafe working conditions (IEA 2021c).

A comprehensive assessment of equity and biodiversity impacts is beyond the scope of this series. The modelled pathways from which we derived targets, for example, did not consider the distributional impacts of achieving them. Additional studies consulted during our target selection process also did not systematically consider equity. Similarly, although we strove to identify 1.5°C-aligned targets designed with social and environmental safeguards wherever possible, there are some for which these criteria were not available. Acknowledging this limitation, we qualitatively highlight potential co-benefits, dependencies, and trade-offs associated with achieving our 1.5°C-aligned targets in each report, as well as outline essential components and emerging examples of key considerations for a just transition across all sectors.

5.5 Incomplete consideration of social, political, and economic systems

Transformations across power, buildings, transport, industry, forests and land, and food and agriculture, as well as the immediate scale-up of technological carbon removal, often unfold within social, political, and economic systems. These complex, dynamic entities determine, for example, who holds power in society, who has a voice in decision-making processes, how the costs and benefits of change are distributed, how progress will be measured, and what is valued—dynamics that can either support or stymie efforts to limit global temperature rise to 1.5°C. Indeed, successfully transitioning to a net-zero future requires contending with power and politics (Patterson et al. 2017; Meadowcroft 2011).

We included targets for the finance sector that will contribute to transformations in the other sectors, but we did not include explicit targets for other social, political, and economic systems that should be considered as the world attempts to realize the Paris Agreement's 1.5°C global temperature limit. These include the following:

- Ensuring good governance at all levels of decision-making—for example, by safeguarding substantive and procedural environmental rights; ensuring participatory, transparent, and accountable decision-making; and reducing corruption
- Improving social equity and inclusion by universalizing access to basic goods, services, and opportunities; redistributing wealth; and ensuring just transitions to a net-zero future

- Shifting to new economic paradigms by moving away from growth-centered economies to those that more equitably meet society's needs without compromising the well-being of people and the planet

Looking ahead, members of the climate community must pay greater attention to these transformations—and intentionally consider how these transitions can accelerate (or stymie, if stalled) critical shifts within these GHG emissions–intensive sectors—if we are to avoid increasingly dangerous and irreversible climate impacts.

5.6 Data limitations

A lack of high-quality, consistently updated, and publicly available data constrained our assessment of global progress across several sectors. For some indicators, data were patchy, and continuous time series of annual data were not available. While the data that were available do provide some indication of progress, they did not allow us to conduct robust trend analyses. Similarly, for other indicators, we could find only a single historical data point, and this lack of data prevented us from projecting a linear trendline and categorizing progress for "S-curve unlikely" and "S-curve possible" indicators. Still, other indicators with quantitative targets lacked even a single historical data point. Accordingly, we did not track progress made in accelerating all facets of transformation across key sectors, and rather focused on those that we could quantitatively monitor. Indicators without quantitative targets and/or available historical data are just as important to transitions, and as data become available, we will add them to subsequent installments.

Appendix A. Comparison of targets and indicators from *State of Climate Action* 2020, 2021, 2022, and 2023

TABLE A1 | Comparison of targets across *State of Climate Action* reports

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Power			
Increase the share of renewables in electricity generation to 55–90% by 2030 and 98–100% by 2050.	No change from previous report.	Increase the share of zero-carbon power in electricity generation to 74–92% by 2030 and 98–100% by 2050. We changed our 2022 indicator to measure all "zero-carbon power" in electricity generation (including nuclear power)—nuclear power was excluded from the definition of "renewables" in 2020 and 2021. This increase in scope accounted for the increased 2030 targets in our 2022 report.	Increase the share of zero-carbon sources in electricity generation to 88–91% by 2030, 98–99% by 2040, and 99–100% by 2050. Following CAT (2023), we updated our targets based on new analysis of scenarios that limit global warming to 1.5°C with no or limited overshoot from the IPCC's AR6 Scenario Explorer and Database (IIASA n.d.), as well as recently published literature.
Lower the share of coal in electricity generation to 0–2.5% by 2030 and 0% by 2050.	No change from previous report.	No change from previous report.	Lower the share of coal in electricity generation to 4% by 2030, 0–1% by 2040, and 0% by 2050. We updated our targets based on analysis of scenarios that limit global warming to 1.5°C with no or limited overshoot from the IPCC's AR6 Scenario Explorer and Database (IIASA n.d.), as well as recently published literature. We also corrected an error in the literature review from CAT (2020a), which led to a slight increase in the lower end of the range in 2030. There is a negligible role for coal with CCS in the scenarios we assessed, so we changed to tracking total coal, rather than unabated coal, as the results are the same.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
N/A	N/A	Lower the share of unabated fossil gas in electricity generation to 17% by 2030 and 0% by 2050. This target and indicator were new in 2022.	Lower the share of unabated fossil gas in electricity generation to 5–7% by 2030, 1% by 2040, and 0% by 2050. We updated our targets based on analysis of scenarios that limit global warming to 1.5°C with no or limited overshoot from the IPCC's AR6 Scenario Explorer and Database (IIASA n.d.), as well as recently published literature. We also corrected an error in the literature review from CAT (2020a), which led to a decrease in the upper end of the range in 2030.
Reduce the carbon intensity of electricity generation to 50–125 gCO_2/kWh by 2030 and below zero in 2050.	No change from previous report.	No change from previous report.	Reduce the carbon intensity of electricity generation to 48–80 gCO_2/kWh by 2030, 2–6 gCO_2/kWh by 2040, and below zero by 2050. We updated our targets based on analysis of scenarios that limit global warming to 1.5°C with no or limited overshoot from the IPCC's AR6 Scenario Explorer and Database (IIASA n.d.), as well as recently published literature.
Buildings			
Decrease the energy intensity of residential building operations in key countries and regions by 20–30% by 2030 and 20–60% by 2050, relative to 2015; reduce the energy intensity of commercial building operations in key countries and regions by 10–30% by 2030 and 15–50% by 2050, relative to 2015.	No change from previous report.	No change from previous report.	Decrease the energy intensity of building operations to 85–120 kWh/m^2 by 2030 and 55–80 kWh/m^2 by 2050. Previously, the target for this indicator was split into residential and commercial buildings, but limited historical data made it difficult to track progress. Given improvements in global data, we updated this indicator and its targets to encompass all buildings.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Reduce the carbon intensity of operations in select regions by 45–65% in residential buildings and 65–75% in commercial buildings by 2030, relative to 2015; reach near zero-carbon intensity globally by 2050.	No change from previous report.	No change from previous report.	Reduce the carbon intensity of building operations to 13–16 $kgCO_2/m^2$ by 2030 and 0–2 $kgCO_2/m^2$ by 2050. Previously, the target for this indicator was split into residential and commercial buildings, but limited historical data made it difficult to track progress. Given improvements in global data, we updated this indicator and its targets to encompass all buildings.
Increase the annual retrofitting rate of buildings to 2.5–3.5% by 2030 and 3.5% by 2040, as well as ensure that all buildings are well insulated and fitted with zero-carbon technologies by 2050.	No change from previous report.	No change from previous report.	No change from previous report.
N/A	N/A	N/A	Ensure all new buildings are zero-carbon in operation by 2030. We added a new indicator and target in 2023 to address the operational emissions of new buildings. This indicator was not included in previous reports due to insufficient data to track progress. Although there are still no data to track this indicator, we have decided to include it this year to acknowledge the importance of new buildings in this sector and to draw attention to the lack of data.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Industry			
Increase the share of electricity in the industry sector's final energy demand to 35% by 2030, 40–45% by 2040, and 50–55% by 2050.	No change from previous report.	No change from previous report.	Increase the share of electricity in the industry sector's final energy demand to 35–45% by 2030, 51–54% by 2040, and 60–69% by 2050. We updated our targets based on analysis of scenarios that limit global warming to 1.5°C with no or limited overshoot from the IPCC's AR6 Scenario Explorer and Database (IIASA n.d.), as well as recently published literature.
Lower the carbon intensity of global cement production to 360–370 $kgCO_2$/t cement by 2030 and 55–90 $kgCO_2$/t cement by 2050, with an aspirational target to achieve 0 $kgCO_2$/t cement by 2050.	No change from previous report.	No change from previous report.	No change from previous report.
Lower the carbon intensity of global steel production to 1,335–1,350 $kgCO_2$/t crude steel by 2030 and 0–130 $kgCO_2$/t crude steel by 2050.	No change from previous report.	No change from previous report.	No change from previous report, but the presentation of the target has been rounded to two significant figures in keeping with the rest of the targets.
N/A	Build and operate 20 low-carbon commercial steel facilities, each producing at least 1 Mt annually by 2030; ensure that all steel facilities are net-zero GHG emissions by 2050. This target and indicator were new in 2021.	This target and indicator were removed in 2022. Other selected indicators for the industry sector aim to track the overall progress of the sector, while the number of low-carbon steel facilities indicator was more useful for tracking drivers that influence a certain outcome (in this case, the carbon intensity of global steel production).	N/A

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
N/A	Boost green hydrogen production capacity to 0.23–3.5 Mt (25 GW cumulative electrolyzer capacity) by 2026 and 500–800 Mt (2,630–20,000 GW cumulative electrolyzer capacity) by 2050. This indicator and target were new in 2021.	Increase green hydrogen production capacity to 84 Mt by 2030 and 322 Mt by 2050. The green hydrogen production targets within the 2022 report were sourced from IEA (2021b), which models the projected demand for green hydrogen across sectors by 2030 and 2050 to reach net-zero emissions by 2050. We chose to use IEA's hydrogen targets in this report series—an update from the 2021 targets, which were derived from Race to Zero (2021)—given their close alignment with the upper bound of IPCC Sixth Assessment Report estimates for 2050 (IPCC 2022).	Increase green hydrogen production capacity to 58 Mt by 2030 and 330 Mt by 2050. The IEA recently revised its *World Energy Outlook 2022* (IEA 2022b), including its projections for green hydrogen production. We updated this target to reflect these new findings from the IEA.
Transport			
N/A	N/A	Double the coverage of public transport infrastructure across urban areas by 2030, relative to 2020. This target and indicator were new in 2022.	No change from previous report.
N/A	N/A	Reach 2 km of high-quality bike lanes per 1,000 inhabitants across urban areas by 2030. This target and indicator were new in 2022.	No change from previous report.
N/A	Reduce the percentage of trips made by private LDVs to between 4% and 14% below BAU levels by 2030. This target and indicator were new in 2021.	No change from previous report.	Reduce the percentage of trips made in passenger cars to 35–43% by 2030. The target was updated to be represented as an absolute target rather than a target relative to BAU.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Reduce the carbon intensity of land-based passenger transport to 35–60 gCO_2/pkm by 2030 and reach near zero by 2050.	No change from previous report.	No change from previous report.	This target and indicator were removed in 2023 due to significant overlaps with the other indicators for land-based transport.
Increase the sale of EVs as a percentage of all new car sales to 45–100% by 2030 and 95–100% by 2050.	Increase the share of EVs to 75–95% of total annual LDV sales by 2030 and 100% by 2035. The EV share of the global LDV sales benchmark was changed in 2021 to reflect the date at which the underlying internal CAT model achieves 100% sales, which is 2035. This is also in line with other global electric vehicle sales benchmarks in existing literature, including CAT (2016), Kuramochi et al. (2018), and Climate Transparency (2020).	No change from previous report.	No change from previous report.
Expand the share of EVs to account for 20–40% of total LDV fleet by 2030 and 85–100% by 2050.	No change from previous report.	No change from previous report.	No change from previous report.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
N/A	N/A	N/A	Increase the share of EVs to 85% of total annual two- and three-wheeler sales by 2030 and 100% by 2050. We added this indicator to more comprehensively track progress made in transforming the global transport sector. Worldwide, almost as many motorized two- and three-wheelers (e.g., motorcycles, rickshaws, tricycles) are on the road as four-wheeled passenger vehicles. In certain regions, such as Southeast Asia and India, motorcycles and motorized scooters are the dominant mode of transport, accounting for 83% and 80%, respectively, of vehicle kilometers traveled. This target and indicator are new in 2023.
N/A	Boost the share of BEVs and FCEVs to reach 75% of annual global bus sales by 2025 and 100% of annual bus sales in leading markets by 2030. This target and indicator were new in 2021.	Increase the share of BEVs and FCEVs to 60% of total annual bus sales by 2030 and 100% by 2050. We changed this target from "in leading markets" to a global target to align it with other global targets in the report and to adopt a target from a 1.5°C-aligned model.	No change from previous report.
N/A	Increase the share of BEVs and FCEVs to 8% of global annual MHDV sales by 2025 and 100% in leading markets by 2040. This target and indicator were new in 2021.	Increase the share of BEVs and FCEVs to 30% of total annual MHDV sales by 2030 and 99% by 2050. We changed the target for the medium- and heavy-duty vehicles indicator in 2022 to bring the benchmark interval years (2030 and 2050) and global coverage in line with other benchmarks. In *State of Climate Action 2021*, the 2040 benchmark covered only sales in leading markets.	No change from previous report.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Raise the share of low-emission fuels in the transport sector to 15% by 2030 and 70–95% by 2050.	No change from previous report.	This target and indicator were removed in 2022.	N/A
N/A	Increase sustainable aviation fuels' share of global aviation fuel supply to 10% by 2030 and 100% by 2050. This target and indicator were new in 2021.	Increase sustainable aviation fuels' share of global aviation fuel supply to 13–18% by 2030 and 78–100% by 2050. The target in 2021 came from a source that was not explicitly aligned with a 1.5°C scenario. We changed the target to one that came from a 1.5°C-aligned source.	Increase the share of sustainable aviation fuels in global aviation fuel supply to 13% by 2030 and 100% by 2050. To reduce reliance on biofuels, we adopted targets from MPP (2022), rather than the IEA (2021b).
N/A	Raise zero-emissions fuel's share of international shipping fuel to 5% by 2030 and 100% by 2050. This target and indicator were new in 2021.	Raise zero-emissions fuel's share of maritime shipping fuel to 5–17% by 2030 and 84–93% by 2050. The target in 2021 came from a source that was not explicitly aligned with a 1.5°C scenario. We changed the target to one that came from a 1.5°C-aligned source, and the scope of the new target was broader to include maritime shipping instead of just international shipping.	Increase the share of zero-emissions fuel in maritime shipping fuel supply to 5% by 2030 and 93% by 2050. To reduce reliance on biofuels, we adopted targets from UMAS (2021), rather than the IEA (2021b).

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Forests and land			
Reduce deforestation by 70% by 2030 and 95% by 2050, relative to 2019.	Reduce the rate of deforestation by 70% by 2030 and 95% by 2050, relative to 2018. We changed the target's baseline year from 2019 to 2018 to better align with Roe et al. (2019). However, because the deforestation rates in 2018 and 2019 were nearly the same (6.75 Mha in 2018 and 6.77 Mha in 2019), the difference between our targets in this report and our 2020 report is relatively minor. This indicator, however, remained unchanged.	Reduce the annual rate of gross deforestation to 1.9 Mha/yr by 2030 and 0.31 Mha/yr by 2050. While our 2030 and 2050 targets still represent a 70% decrease in the deforestation rate by 2030 and a 95% decrease in deforestation by 2050, relative to 2018, we now express them in absolute values. Additionally, we updated the underlying datasets we used to approximate deforestation. More specifically, we excluded all tree cover loss due to fire (Tyukavina et al. 2022), which is likely to be more temporary in nature, to allow us to better observe trends in permanent forest conversion without the interannual variability linked to extreme weather events. Doing so, however, changed the baseline estimate of deforestation in 2018 and, subsequently, the absolute values of our 2030 and 2050 targets.	No change from previous report.
N/A	Reduce the degradation and destruction of peatlands by 70% by 2030 and 95% by 2050, relative to 2018. This target and indicator were new in 2021.	Reduce the annual rate of peatland degradation to 0 Mha/yr by 2030. We updated our 2030 and 2050 targets, which Boehm et al. (2021) derived from Roe et al. (2019), to align with the avoidable rate of peatland degradation associated with the "maximum additional mitigation potential" estimated in Griscom et al. (2017).	No change from previous report.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
N/A	Reduce the conversion of coastal wetlands by 70% by 2030 and 95% by 2050, relative to 2018. This target and indicator were new in 2021.	Reduce the annual rate of gross mangrove loss to 4,900 ha/yr by 2030, with no additional loss from 2030 to 2050. We updated our 2030 and 2050 targets, which Boehm et al. (2021) derived from Roe et al. (2019), to align with revised global estimates of the cost-effective mitigation potential for avoided GHG emissions from mangrove loss from Roe et al. (2021). In doing so, we narrowed the scope of our target and indicator from coastal wetlands (i.e., salt marshes, seagrass meadows, mangrove forests) to mangroves only. We used the bottom-up, cost-effective mitigation potentials from Roe et al. (2021) for most targets in the forests and land sector, which collectively are in line with pathways that limit global warming to 1.5°C, including the 14 $GtCO_2e$/yr mitigation target established in Roe et al. (2019).	No change from previous report.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Restore tree cover on 350 Mha of land by 2030 and 678 Mha by 2050.	Reforest 259 Mha of land by 2030 and 678 Mha in total by 2050, relative to the 2018 level. While our indicator and 2050 target remained unchanged from 2020, the 2021 report provided an updated target for 2030, reflecting new estimates of annual carbon sequestration potential per hectare (Cook-Patton et al. 2020). To ensure alignment with the mitigation potential that Roe et al. (2019) found for reforestation (3.0 $GtCO_2$/yr by 2030), from which our carbon removal for reforestation target was derived, we used the annual carbon sequestration potential per hectare from Cook-Patton et al. (2020) to estimate the area that must be reforested by 2030 to remove 3.0 $GtCO_2$ annually. Although this new 2030 target falls below those set by the Bonn Challenge (350 Mha by 2030) and the New York Declaration on Forests (350 Mha by 2030), it focused solely on reforestation, while both international commitments include pledges to plant trees across a broader range of land uses, such as agroforestry systems or tree plantations.	Reforest 300 Mha between 2020 and 2050, reaching 100 Mha by 2030. We updated our 2030 and 2050 targets, which Boehm et al. (2021) derived from Roe et al. (2019) and Griscom et al. (2017), to align with revised global estimates of the cost-effective mitigation potential for reforestation from Roe et al. (2021). We used the bottom-up, cost-effective mitigation potentials from Roe et al. (2021) for most targets in the forests and land sector, which collectively are in line with pathways that limit global warming to 1.5°C, including the 14 $GtCO_2e$/yr mitigation target established in Roe et al. (2019).	Reforest 300 Mha between 2030 and 2050, reaching 100 Mha by 2030 and 150 Mha by 2035. We added a 2035 target following the same methods and ramp-up assumptions outlined in Schumer et al. (2022).

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
N/A	Restore 22 Mha of peatlands by 2030 and 46 Mha in total by 2050, relative to 2018. This target and indicator were new in 2021.	Restore 15 Mha of peatlands by 2030 and 20 Mha by 2050. We updated our 2030 and 2050 targets, which Boehm et al. (2021) derived from Roe et al. (2019) and Griscom et al. (2017), to align with revised global estimates of the cost-effective mitigation potential for peatland restoration from Roe et al. (2021). We also set a second, more ambitious target for 2050 to reflect the number of studies calling for restoration across a broader extent of degraded peatlands (e.g., Leifeld et al. 2019; Kreyling et al. 2021) and the uncertainties in estimating the amount of peatland restoration that's feasible, particularly at costs of up to $100/tCO_2e$. We used the bottom-up, cost-effective mitigation potentials from Roe et al. (2021) for most targets in the forests and land sector, which collectively are in line with pathways that limit global warming to 1.5°C, including the 14 $GtCO_2e/yr$ mitigation target established in Roe et al. (2019).	Restore 20–29 Mha of degraded peatlands by 2050, reaching 15 Mha by 2030. We updated the 2050 target to account for new estimates of the extent of global peatland degradation from UNEP (2022). However, we present this target as a range to account for the uncertainty in these estimates, which vary from 46 Mha to 57 Mha (Humpenoder et al. 2020; UNEP 2022).

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
N/A	Restore 7 Mha of coastal wetlands by 2030 and 29 Mha in total by 2050, relative to the 2018 level. This target and indicator were new in 2021.	Restore 240,000 ha of mangroves by 2030. We updated our 2030 and 2050 targets, which Boehm et al. (2021) derived from Roe et al. (2019) and Griscom et al. (2017), to align with revised global estimates of the cost-effective mitigation potential for mangrove restoration from Roe et al. (2021). In doing so, we narrowed the scope of our target and indicator from coastal wetlands (i.e., salt marshes, seagrass meadows, mangrove forests) to mangroves only. We used the bottom-up, cost-effective mitigation potentials from Roe et al. (2021) for most targets in the forests and land sector, which collectively are in line with pathways that limit global warming to 1.5°C, including the 14 $GtCO_2e$/yr mitigation target established in Roe et al. (2019).	No change from previous report.
Food and agriculture			
Reduce agricultural production emissions by 22% by 2030 and 39% by 2050, relative to 2017.	No change from previous report.	Target and indicator were the same. For the 2022 report, we removed “drained organic soils” (peatland emissions) from total direct agricultural emissions to avoid double-counting with the forests and land sector.	Reduce the GHG emissions intensity of agricultural production by 31% by 2030, 38% by 2035, and 56% by 2050, relative to 2017. We converted our indicator on GHG emissions from agricultural production to focus on the GHG emissions intensity of agricultural production to better match the other food and agriculture indicators, which are all intensity metrics.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Increase crop yields by 13% by 2030 and 38% by 2050, relative to 2017.	Increase crop yields by 18% by 2030 and 45% by 2050, relative to 2017. We updated the target to be consistent with Searchinger et al. (2021). The indicator remained unchanged.	No change from previous report.	Increase crop yields by 18% by 2030, 25% by 2035, and 45% by 2050, relative to 2017. We added a 2035 target following the same methods and ramp-up assumptions outlined in Schumer et al. (2022).
Increase ruminant meat productivity per hectare by 27% by 2030 and 58% by 2050, relative to 2017.	No change from previous report.	No change from previous report.	Increase ruminant meat productivity per hectare by 27% by 2030, 35% by 2035, and 58% by 2050, relative to 2017. We added a 2035 target following the same methods and ramp-up assumptions outlined in Schumer et al. (2022).
Reduce food loss and waste by 25% by 2030 and 50% by 2050, relative to 2017.	Reduce the share of food production lost by 50% by 2030 and maintain this reduction through 2050, relative to 2016. In 2021, we separated out targets for food loss and food waste. Our targets for food loss and waste were updated to better align with SDG Target 12.3. Our indicator for food loss was changed to align with the FAO's Food Loss Index, but our indicator for food waste remained the same.	No change from previous report.	No change from previous report.
	Reduce per capita food waste by 50% by 2030 and maintain this reduction through 2050, relative to 2019.	No change from previous report.	No change from previous report.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Limit increase in ruminant meat consumption to 5% above the 2017 level by 2030 and 6% above the 2017 level by 2050.	Reduce ruminant meat consumption in high-consuming regions to 79 kcal/capita/day by 2030 and 60 kcal/capita/day by 2050. Target was the same as in 2020, but the expression of it was changed by narrowing the geographic focus. Instead of showing global per capita consumption (which included all regions, thus both high and low consumers of meat) per Lebling et al. (2020), this report focused on the necessary decline in per capita consumption in high-consuming countries, given that this is the focus of the challenge at hand. The indicator remained unchanged.	No change from previous report.	Reduce ruminant meat consumption in high-consuming regions to 79 kcal/capita/day by 2030, 74 kcal/capita/day by 2035, and 60 kcal/capita/day by 2050. We added a 2035 target following the same methods and ramp-up assumptions outlined in Schumer et al. (2022).
Technological carbon removal			
N/A	Scale up technological carbon removal to 75 $MtCO_2$ annually by 2030 and 4.5 $GtCO_2$ annually by 2050. This target and indicator were new in 2021.	No change from previous report.	Scale up the annual rate of technological carbon removal to 30–690 $MtCO_2$/yr by 2030 and 740–5,500 $MtCO_2$/yr by 2050. We updated our targets based on an analysis of scenarios that limit global warming to 1.5°C with no or limited overshoot from the IPCC's AR6 Scenario Explorer and Database (IIASA n.d.), as well as recently published literature.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
Finance			
N/A	Increase total climate finance flows to $5 trillion per year by 2030 and sustain this level of funding through 2050. This target and indicator were new in 2021.	Increase global climate finance flows (public and private as well as international and domestic) to $5.2 trillion per year by 2030 and $5.1 trillion per year by 2050. In 2022, we updated these targets to include energy finance needs that were presented in IPCC (2022). We also adjusted all numbers for inflation to 2020 US dollars. The addition of IPCC (2022) values shifted the 2030 value above the value for 2050, which is consistent with IEA (2021b).	No change from previous report.
N/A	Raise public climate finance flows to at least $1.25 trillion per year by 2030 and sustain through 2050. This target and indicator were new in 2021.	Increase global public climate finance flows (domestic and international) to $1.31 trillion–$2.61 trillion per year by 2030 and $1.29 trillion–$2.57 trillion per year by 2050. In the 2021 report, we fixed global public climate finance at 25 percent of total global climate finance. In the 2022 report, we presented a range of 25–50% of total global climate finance.	No change from previous report.
N/A	Boost private climate finance flows to at least $3.75 trillion per year by 2030 and sustain through 2050. This target and indicator were new in 2021.	Increase global private climate finance flows (domestic and international) to $2.61 trillion–$3.92 trillion per year by 2030 and $2.57 trillion–$3.86 trillion per year by 2050. In the 2021 report, we fixed global private climate finance at 75 percent of total global climate finance. In 2022, we presented a range of 50–75% of total global climate finance.	No change from previous report.

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
N/A	N/A	N/A	Increase the ratio of investment in low-carbon to fossil fuel energy supply to 7:1 by 2030 and 10:1 by 2040, with the 10:1 ratio sustained through 2050. This indicator was added to track the shift in investment flows in line with 1.5°C pathways. This target and indicator are new in 2023.
N/A	Jurisdictions representing three-quarters of global emissions mandate TCFD-aligned climate risk reporting and that all of the world's 2,000 largest public companies report on climate risk in line with TCFD recommendations by 2030. This target and indicator were new in 2021.	Mandate alignment with the TCFD's recommendations on climate risk reporting in jurisdictions representing three-quarters of global emissions. We simplified this indicator to focus on the government policies that require climate risk reporting and removed the section regarding the world's 2,000 largest public companies due to a lack of a publicly available resource that reliably tracks their climate risk reporting.	Increase the share of global GHG emissions subject to mandatory disclosures of corporate climate risks aligned with the TCFD recommendations to 75% in 2030 and 100% in 2050. We changed how we describe, but not define, the indicator, as well as updated the 2050 target from 75% to 100% to set a more ambitious target for comprehensive global coverage. This change comes in light of countries outside of the G20 making climate disclosures mandatory and the projection that developing countries will comprise the bulk of annual greenhouse gas emissions by 2040 (Bhattacharya et al. 2023).

2020 TARGETS AND INDICATORS	2021 TARGETS AND INDICATORS	2022 TARGETS AND INDICATORS	2023 TARGETS AND INDICATORS
N/A	Ensure that a carbon price of at least \$135/tCO_2e covers the majority of the world's GHG emissions by 2030 and then increases to at least \$245/tCO_2e by 2050. This target and indicator were new in 2021.	Raise the median carbon price in jurisdictions with pricing systems in place to \$170–\$290/tCO_2 in 2030 and \$430–\$990/tCO_2 in 2050. In 2021, we used the assessment in IPCC (2018) of the undiscounted carbon price necessary for a 1.5°C pathway being \$135–\$6,050/tCO_2e in 2030 and \$245–\$14,300/tCO_2e in 2050, in 2010 US dollars. IPCC (2022) includes updated estimates of the marginal abatement cost of carbon (i.e., the optimal carbon price) for pathways that limit warming to 1.5°C with no or limited overshoot as \$220/tCO_2 in 2030 and \$630/tCO_2 in 2050, in 2015 US dollars. For the 2022 report, we updated the target to use these new prices from the IPCC Sixth Assessment Report.	Raise the weighted average carbon price to \$170–\$290/tCO_2e in 2030 and \$430–\$990/tCO_2e in 2050. The indicator used to describe this target was updated from 2022 to reflect a weighted average, which was calculated based on the percentage of global GHG emissions covered by each carbon price for each year.
N/A	Phase out public financing for fossil fuels, including subsidies, by 2030, with G7 countries and international financial institutions achieving this by 2025. This target and indicator were new in 2021.	No change from previous report.	No change from previous report.

Note: N/A = not applicable; °C = degrees Celsius; IPCC AR6 = Intergovernmental Panel on Climate Change Sixth Assessment Report; CCS = carbon capture and storage; gCO_2/kWh = grams of carbon dioxide per kilowatt-hour; kgCO_2/t = kilograms of carbon dioxide per tonne; Mt = million tonnes; GHG = greenhouse gas; GW = gigawatt; kWh/m^2 = kilowatt-hours of energy per square meter; kgCO_2/m^2 = kilograms of carbon dioxide per square meter; IEA = International Energy Agency; LDV = light-duty vehicle; BAU = business as usual; km = kilometer; gCO_2/pkm = grams of carbon dioxide per passenger kilometer; EV = electric vehicle; CAT = Climate Action Tracker; BEV = battery electric vehicle; FCEV = fuel cell electric vehicle; MHDV = medium- and heavy-duty vehicle; MtCO_2/yr = million tonnes of carbon dioxide per year; Mha/yr = million hectares per year; GtCO_2e/yr = gigatonnes of carbon dioxide equivalent per year; tCO_2e = tonnes of carbon dioxide equivalent; SDG = Sustainable Development Goal; FAO = Food and Agriculture Organization of the United Nations; kcal/capita/day = kilocalories per capita per day; TCFD = Task Force on Climate-Related Financial Disclosures; G20 = Group of Twenty; G7 = Group of Seven.

Sources: Lebling et al. 2020; Boehm et al. 2021; Boehm et al. 2022; Boehm et al. 2023.

ENDNOTES

1. The IPCC developed its category of "no and limited overshoot" pathways in its *Special Report on Global Warming of 1.5°C*. The IPCC's recent AR6 Working Group III report, *Climate Change 2022*: *Mitigation of Climate Change*, uses the same definition for its category C1 pathways, which are defined as follows: "Category C1 comprises modelled scenarios that limit warming to 1.5°C in 2100 with a likelihood of greater than 50%, and reach or exceed warming of 1.5°C during the 21st century with a likelihood of 67% or less. In this report, these scenarios are referred to as scenarios that limit warming to 1.5°C (>50%) with no or limited overshoot. *Limited overshoot* refers to exceeding 1.5°C global warming by up to about 0.1°C and for up to several decades" (IPCC 2022). The report also notes that "scenarios in this category are found to have simultaneous likelihood to limit peak global warming to 2°C throughout the 21^{st} century of close to and more than 90%" (IPCC 2022).

2. Given the nature of links among systems, moving more slowly in one system may in some cases make it harder to move faster in another; for example, electric vehicle uptake in the transport system cannot adequately decarbonize the system until the carbon intensity of the power system declines.

3. Targets derived from the IPCC's Sixth Assessment Report will continue to be incorporated more comprehensively into future iterations of the *State of Climate Action* series.

4. As an example, to monitor a shift toward zero-carbon power uptake, we set targets to increase the share of zero-carbon sources in electricity generation to 88–91 percent by 2030, 96 percent by 2035, and 99–100 percent by 2050; the indicator associated with this shift is "share of zero-carbon sources in electricity generation (%)." In general, we rounded all targets to two significant figures. However, we deviated from this approach in several instances in which rounding lost nuance.

5. For some indicators (e.g., the phaseout of coal in electricity generation), the long-term shift needs to be achieved before 2050; in these instances, we also identified a 2040 target.

6. Because some of our targets call for reductions (e.g., in the share of unabated fossil gas in electricity generation), the lower bound of a target range is not always the less ambitious bound.

7. Many IAMs still do not represent DACCS at all, nor do they represent low-temperature direct air capture technology, which offers the most promising route for DACCS deployment. Pathways with more DACCS deployment tend to rely less heavily on BECCS. We applied a less stringent threshold for BECCS, based on the assessment that DACCS potential is likely underestimated in most IAM scenarios. However, we did not consider BECCS a perfect proxy for other technological carbon removal options because of the different land and energy system implications (e.g., BECCS produces energy while DACCS uses energy, so they cannot be seen as interchangeable from a modelling perspective). As modelers strive to represent a wider range of carbon removal technologies in IAMs, this approach could evolve to include specific filters for individual carbon removal technologies. However, given pervasive uncertainty around the feasibility of large-scale carbon removal technologies, the most robust strategy remains to cut GHG emissions as fast as possible to minimize reliance on these nascent innovations.

8. Grant et al. (2021) used expert interviews to determine limits for A/R of 3.6 $GtCO_2$/yr in 2050 and 5.3 $GtCO_2$/yr in 2100. We filtered pathways so that the average A/R deployment over 2050–2100 doesn't exceed the average of these two limits (4.4 $GtCO_2$/yr).

9. It is important to distinguish between CCS used for emissions reductions (e.g., from fossil fuel combustion and in industrial applications) and technological carbon dioxide removal applications that rely on geological CO_2 storage. In the former, CCS reduces fossil fuel or industrial process emissions, although in many cases there are alternative decarbonization options that could do so more cheaply and/or sustainably. In the latter, the net effect of capturing and storing CO_2 in geological storage is a removal, or negative emission, which is important for ultimately lowering atmospheric CO_2 concentrations. There are two main types of carbon dioxide removal in this category. DACCS involves capturing the CO_2 that's already in the atmosphere, rather than from an emissions source. BECCS involves the application of CCS technology to a bioenergy facility, meaning that biogenic CO_2 is captured and stored. Since CO_2 is drawn down as the bioenergy feedstocks grow, BECCS can also lead to removals.

10. An exception is a variation on CCUS—the Allam Cycle—which is in development and involves combustion of natural gas in a high oxygen environment. It would theoretically be able to capture 100 percent of direct emissions from natural gas combustion and has been demonstrated at a 50-megawatt scale, but not yet at a large scale (Yellen 2020).

11. *Unabated use of fossil fuels* refers to the consumption of fossil resources without measures to abate associated CO_2 emissions with carbon capture and storage.

12. Only a very small amount of global power is produced by oil, so this report series prioritizes monitoring the phaseout of coal and unabated fossil gas.

13. Zero-carbon power is defined as generation by solar, wind, hydropower, nuclear, geothermal, marine, and biomass technologies, all of which generate negligible CO_2 during their operational cycles. In addition to tracking progress toward targets for the share of all zero-carbon sources in electricity generation, the 2024 update introduces an additional indicator to track the uptake of wind and solar power in particular, as both are projected to contribute the largest shares of electricity in the future zero-carbon power mix. .

14. Targets for commercial and residential buildings are combined into one indicator for carbon intensity of buildings and one indicator for energy intensity of buildings.

15. The buildings targets for energy intensity and carbon intensity were updated in 2023 to follow methods identified in CAT (2023) for two reasons. First, although residential and commercial buildings have different energy use patterns and therefore tracking them separately would be more appropriate, no historical data are available to track them separately. However, there are historical data available to track residential and commercial buildings together, so we updated our targets to enable this. Second, we based our original global targets on an analysis of seven countries, while we developed our new targets at the global level.

16. Targets for retrofitting and new zero-carbon buildings, however, did not need to be updated, as they remain valid for achieving the energy and carbon intensity targets. Further, they are consistent with other analyses published since we set the original targets (e.g., IEA 2021b; WGBC n.d.).

17. The target range for each country's retrofitting rate spans a low and high energy demand scenario. Both scenarios include some energy efficiency improvements, but the low demand scenario includes retrofitting to a more stringent energy use level that minimizes demand on the power grid. The global targets used in the *State of Climate Action* reports are based on these same scenarios and encompass the reduction ranges of all countries included in that study.

18. The IEA expects the floor area worldwide to increase 75 percent between 2020 and 2050, of which 80 percent is expected to be in emerging markets and developing economies (IEA 2021b).

19. *Process emissions* refer to GHG emissions occurring during industrial processes (e.g., cement production) due to chemical reactions (other than fuel combustion) involved in creating industrial products.

20. Subsequent annual *State of Climate Action* reports may focus on different subsectors (e.g., aluminum, chemicals, pulp, paper) while continuing to track indicators for cement and steel.

21. Roe et al. (2021) define *cost effective* as those measures that cost up to \$100/tCO_2e.

22. Although the Food and Agriculture Organization of the United Nations collects and publishes national-level statistics on the area of managed forests every five years, there are currently no global datasets that comprehensively and consistently map managed forests. Similarly, no such datasets exist for grasslands. Due to these data limitations, *State of Climate Action 2022* and *2023* exclude targets for two land use, land-use change, and forestry mitigation wedges in Roe et al. (2021): improved forest management and avoided GHG emissions from grassland fires. As data become available, subsequent *State of Climate Action* reports will include targets for both of these land-based mitigation measures.

23. We define tree cover loss as the complete removal or mortality of tree cover in a 30-meter-by-30-meter pixel, whereby tree cover is woody vegetation at least five meters in height with a tree canopy density greater than 30 percent at the 30-meter pixel scale.

24. The Tyukavina et al. (2022) data identify tree loss where fire was the direct driver of loss for each 30-meter loss pixel mapped by Hansen et al. (2013). This does not include loss where trees were removed prior to burning (e.g., burning felled trees to clear land for agriculture). It may include wildfires, escaped fires from human activities, and intentionally set fires, among others (Tyukavina et al. 2022).

25. Although the study time period covers the years 1990–2019, the land cover data used to assess change in the study cover only the period from 1993 to 2018. Therefore, we included only the years for which change in drainage area is estimated for the study.

26. Reforestation is defined as the conversion of non-forested lands to forests in areas where forests historically occurred. This excludes afforestation in non-forest biomes, forest growth related to harvesting cycles in areas that are already established plantations, or restoration of non-forested landscapes.

27. This 4 $GtCO_2e$/yr target from Searchinger et al. (2019) is based on the concept of equal sharing across global economic sectors. The latest projections from IPCC (2022) show that GHG emissions from all human sources are on a course to reach about 70 $GtCO_2e$/yr by 2050 (according to the current policies scenario, or C7). Reaching 20 $GtCO_2e$ in 2050, the amount of allowable GHG emissions for a 2°C pathway (C7 in the IPCC report), would require a 70 percent reduction compared with projected 2050 levels. If the agriculture system, including land-use change, also reduces its projected emissions under our principal business-as-usual scenario (15 $GtCO_2e$) by 70 percent, emissions from agriculture plus land-use change would need to decline to 4.5 $GtCO_2e$. A 1.5°C pathway, in which total emissions are closer to 9 $GtCO_2e$/yr in 2050 (C1 in IPCC 2022), would require emissions from agriculture plus land-use change to decline to 2.5 $GtCO_2e$. Because land-use change emissions must not only reach but go below zero, achieving net reforestation, a target of 4 $GtCO_2e$/yr for agricultural production emissions remains aligned with a 1.5°C pathway, assuming the world simultaneously ends deforestation and achieves large-scale reforestation as described in the Land and Forest targets. This target also aligns with the 1.5°C scenarios in IPCC (2018), where agriculture non-CO_2 emissions were 3.9–6.8 $GtCO_2e$/yr in 2050 (Roe et al. 2019).

28. For more on the GlobAgri-WRR model, scenario assumptions, and the global-level targets, see Box 2-1 and Table 32-1 in Searchinger et al. (2019).

29. We added GHG emissions intensity of agricultural production as a new indicator to *State of Climate Action 2023*. See Appendix A for more information.

30. For *State of Climate Action 2022,* we removed on-farm energy use and peatland drainage from agricultural GHG emissions to avoid double-counting with other sectors. Because of this, we adjusted our 2017 observed value and changed the emissions targets from a 21 percent reduction in 2030 and 38 percent reduction in 2050 to 22 percent and 39 percent reductions, respectively. Subsequent installments follow this precedent.

31. To minimize unintended negative impacts on food security, biodiversity, and/or net emissions from land-use change associated with accessing biomass feedstocks, we constrained BECCS deployment to an average of 5 gigatonnes of carbon dioxide per year ($GtCO_2$/yr) from 2040 to 2060 (Fuss et al. 2018; IPCC 2018).

32. Together, these targets reflect the magnitude of need across all systems examined in the *State of Climate Action* series, but don't necessarily add up the individual costs of achieving each target in the report.

33. While discussed in the context of low-carbon technologies, this self-amplifying feedback loop is not inherently positive. Private sector institutions that expand their market shares, deepen their political influence, and amass the resources needed to petition for more supportive policies do not always use their power for the public good. Some may leverage their influence to advance their own interests that are at odds with societal goals (e.g., tampering innovation of other low-carbon technologies, advocating for less restrictive regulations across other environmental harms, petitioning for policies that protect their profit margins). Governments have a critical role to play in effectively regulating the private sector on behalf of the public and in service to societal goals.

34. While the other forests and land indicators used a 10-year trendline, for our deforestation indicator we calculated an 8-year trendline using data from 2015 to 2022 due to temporal inconsistencies in the data before and after 2015 (Weisse and Potapov 2021).

35. For example, this change in methods means that instead of subtracting the 2020 data point from the 2015 data point to assess the most recent five years of historical progress, we included data from 2016, 2017, 2018, 2019, and 2020 in our linear trendline projections. However, for some indicators with data limitations, we reverted to the method for assessing progress used in Boehm et al. (2021). Deviations from our standard methods are noted accordingly.

36. For indicators that did not have at least five years of historical data, we reverted to the methods from *State of Climate Action 2021* if applicable and noted it accordingly.

37. Note that for the indicators with targets presented as a range, we assessed progress based on the midpoint of that range—that is, we compared the historical rates of change to the rates of change required to reach the midpoint. One exception is the median carbon price in jurisdictions with emissions pricing systems indicator; here, we calculated the acceleration factor required from a midpoint of \$220/tCO_2e within the 2030 range, as determined by IPCC (2022).

38. For acceleration factors between 1 and 2, we rounded to the tenth place (e.g., 1.2 times); for acceleration factors between 2 and 3, we rounded to the nearest half number (e.g., 2.5 times); for acceleration factors between 3 and 10, we rounded to the nearest whole number (e.g., 7 times); and for acceleration factors higher than 10, we noted them as >10. In our reports prior to 2022, all acceleration factors under 10 were rounded to the tenth place (e.g., 7.4), which was too high a level of precision for the data available. Rounding to the nearest whole number is clearer and provides equivalent information about the pace of change needed.

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Systems Change Lab aims to drive change at the pace and scale needed to tackle some of the world's greatest challenges: limiting global warming to 1.5 degrees C, halting biodiversity loss and building a just and equitable economy. Convened by World Resources Institute and the Bezos Earth Fund, Systems Change Lab supports the UN Climate Change High-Level Champions and works with key partners and funders including Climate Action Tracker (a project of Climate Analytics and NewClimate Institute), ClimateWorks Foundation, Global Environment Facility, Just Climate, Mission Possible Partnership, Systemiq, University of Exeter and the University of Tokyo's Center for Global Commons, among others. Systems Change Lab is a component of the Global Commons Alliance.

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