TECHNICAL NOTE

METHODOLOGY UNDERPINNING THE STATE OF CLIMATE ACTION SERIES

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Technical notes document the research or analytical methodology underpinning a publication, interactive application, or tool.

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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, 2022a). Updated every year, 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 systemwide transformation into a set of actionable, 1.5°C-aligned mitigation targets primarily for 2030 and 2050, with associated indicators and datasets. Annual installments of the report then compare recent progress made toward (or away from) these mitigation targets 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 emissions and removing carbon from the atmosphere.

This technical note accompanies the *State of Climate Action* series. It describes our methods for identifying systems that must transform, translating these transformations into global mitigation targets for 2030 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, headed in the wrong direction, or insufficient data. Finally, it details how we identify critical barriers to change and enabling conditions that can support transformations, as well as limitations to our methodology. Many of the methods underpinning this series remain unchanged from *State of Climate Action 2021,* although we identify small adjustments throughout. This technical note, then, serves as a companion to *State of Climate Action 2022* and to subsequent annual State of Climate Action reports, with updates made where applicable.

1. Selection of Key Systems 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, greenhouse gas (GHG) emissions peak immediately or before 2025 at the latest, and then fall by a median of 43 percent from 2019 levels by 2030 (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 nearly all major systems—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 significant proportion of the carbon budget that we have already spent and residual GHG emissions that will likely prove difficult to eliminate (IPCC 2022). Each of these transformations entails reconfiguring a high-emitting system, 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, each of these systems must radically transform from one that releases dangerously high levels of GHGs to one that reduces atmospheric concentrations of GHGs while still delivering critical services to society that meet the needs of a growing population.

In the *State of Climate Action* series, we translate the far-reaching transformations needed to meet the Paris Agreement's 1.5°C global temperature goal into a more manageable set of critical shifts for each system that, taken together, can help overcome the deep-seated carbon lock-in common to these systems (Seto et al. 2016). Identifying these critical shifts for each system, 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 innumerable 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 system than to the transport system or vice versa) can be pursued to hold global warming to below 1.5°C. However, because the remaining GHG emissions budget is small, the degree of freedom to assign different weights to different systemwide transformations that must occur is relatively constrained, and the IPCC (2022) makes clear that, together, all systems will eventually have to dramatically lower emissions to limit global warming to 1.5°C. So, if a transformation across one system 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 system 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.[1] A good starting point in translating these needed systemwide transformations into a set of critical shifts is asking whether a system 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 low overshoot from Integrated Assessment Models (IAMs) included in IPCC (2018),[2] as well as recently published, peer-reviewed system-specific roadmaps that hold temperature rise to 1.5°C and bottom-up, sectoral estimates of 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 system's mitigation potential, as well as the specific shifts that collectively deliver that system's contribution to limiting global temperature rise to 1.5°C. For each system, 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 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 and 2050, as noted in Section 2.

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 the worst 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, 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 fuels 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 socio-technical 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

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]

Notes:
[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 system. 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 the long term (primarily 2050), each with an associated indicator (see Table A1, Appendix A).[3] The selected near-term targets can inform immediate action, particularly in the context of ratcheting up ambition and implementing enhanced nationally determined contributions during this decade, while mid-century targets[4] indicate the longer-term shifts 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 systems to qualitatively different, more sustainable ones, it does provide a snapshot of progress across each system 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 low overshoot from IAMs included in IPCC (2018); studies that conducted bottom-up modelling to identify system-specific mitigation pathways; and bottom-up assessments of both technical and cost-effective mitigation potential with environmental and social safeguards. Consequently, we present targets either as a single number or as a range of values. When applicable, we present a range of values to account for assumptions underlying distinct modelling approaches. The more and less ambitious bounds reflect varying degrees of trade-offs in decarbonization with other targets or systems and/or uncertainty in terms of technical and economic feasibility (CAT 2020b). Reaching the least-ambitious targets[5] across all systems will not likely be sufficient for achieving the Paris Agreement's 1.5°C global temperature goal. Consequently, only by achieving the more ambitious bound of some targets (e.g., phasing out coal as quickly as possible) will we create room for some systems to achieve their least-ambitious bounds where decarbonization is difficult and therefore slower.

It is critical to note here 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 industrial processes, while failure to sustainably increase crop yields could result in agricultural expansion across forests, spurring increases in deforestation.

2.1.1 Environmental & Social Safeguards and Economic Constraints

In selecting 1.5°C-aligned targets for inclusion in the *State of Climate Action* series, we employed various environmental and social safeguards where possible. Across power, buildings, industry, and transport, for example, we primarily adopted targets from modelled 1.5°C pathways from IAMs and bottom-up, system-specific studies that do not exceed environmental sustainability constraints identified by the IPCC for two land-based carbon removal strategies: bioenergy with carbon capture and storage (BECCS); and afforestation and reforestation (CAT 2020a). We similarly constrained our technological carbon dioxide removal (hereafter referred to as carbon removal) targets to include levels of BECCS that avoid unintended negative impacts on food security, biodiversity, and/or net emissions from land-use change associated with accessing biomass feedstocks (Fuss et al. 2018).[6] For BECCS, specifically, this limit is 5 gigatonnes of carbon dioxide per year ($GtCO_2$/yr) in 2050, while afforestation and reforestation is constrained to 3.6 $GtCO_2$/yr between 2050 and 2100.

We also limited dependence on carbon capture, utilization, and storage (CCUS) where possible. Today's CCUS systems can capture 90 percent of CO_2 emissions from a specific facility (IEA 2021a), and although future capture rates may increase, most CCUS systems even under the most idealized, theoretical conditions would still fall short of capturing 100 percent of CO_2 emissions (Brandl et al. 2021).[7] CCUS systems use additional water and energy (including causing upstream methane emissions through the use of natural gas) and increase operational expenses. Well-characterized and accessible geologic sequestration sites will also be needed to sequester captured CO_2. For industry, CCUS remains one of the best available options for lowering CO_2 emissions from high-heat processes and non-combustion processes (e.g., calcination in cement production), which may prove difficult to eliminate. Similarly, in transport, CCUS may play a role in the development of fuels, such as ammonia and hydrogen, for harder-to-abate forms of travel, including aviation and shipping. Carbon capture and storage also has a role in 1.5°C pathways, when combined with bioenergy or direct air capture, as a form of carbon removal. So, while we consider CC(U)S to be a viable option for industry and carbon removal, and to play an indirect role in transport, we do not consider it as an option for fossil fuel combustion in the power system.

Across forests and land, we worked to select targets that, if achieved, would not threaten food security, spur biodiversity loss, or undermine 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), which our reforestation target of 300 Mha does not exceed (Roe et al. 2021). 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 10 billion people (Searchinger et al. 2019, 2021).

Finally, we did not systematically consider cost in selecting our targets. We derived some targets from models that optimize for least-cost pathways (e.g., IEA 2021b; BloombergNEF 2021), while for others, we selected those that the literature considers cost-effective (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). Other targets, particularly those focused on mitigation across the global food system, 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.

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 System

2.3.1 Power

Decarbonizing power generation is essential to limiting global warming to 1.5˚C. This requires transforming the system from one that relies heavily on fossil fuels to produce electricity to another fundamentally different system that generates zero-carbon power. Transforming power will require both the immediate scale-up of renewables and the rapid phaseout of unabated coal, oil, and natural gas (IPCC 2022; IEA 2021b).[8] Together, these actions can dramatically reduce the carbon intensity of electricity generation.

To track progress made toward accelerating this systemwide transformation, we identified four key indicators of progress from 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, 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

TABLE 1 | Design of Power Indicators and Targets

INDICATOR	2030 TARGET	2050 TARGET	TARGET SOURCE	ADDITIONAL INFORMATION
Carbon intensity of electricity generation (gCO_2/kWh)	50–125	5–25 (2040) <0 (2050)	CAT 2020a	N/A
Share of zero-carbon sources in electricity generation (%)	74–92	87–100 (2040) 98–100 (2050)	CAT 2020a	In *State of Climate Action 2021*, we excluded nuclear power generation from this target and indicator due to political economy challenges, safety issues, concerns in relation to the nuclear fuel cycle (e.g., the disposal of nuclear waste), high economic cost, slow build times, and inflexibility (Boehm et al. 2021). However, we updated this target and indicator in 2022 to include nuclear power generation in an effort to remain neutral over the role of nuclear power in a future net-zero electricity system given that nuclear is a zero-carbon, low-emissions technology and makes up a small (<10%) share of power generation in most modelled 1.5°C pathways—see, for example, IPCC (2022), IEA (2021b), and IRENA (2021).
Share of unabated coal in electricity generation (%)	0–2.5	0 (2040) 0 (2050)	CAT 2020a	N/A
Share of unabated fossil gas in electricity generation (%)	17	5 (2040) 0 (2050)	Hare et al. 2021	N/A

Notes: gCO_2/kWh = grams of carbon dioxide per kilowatt-hour; N/A = not applicable. Achieving below zero-carbon intensity implies biomass power generation with carbon capture and storage. Our targets limit BECCS use to 5 $GtCO_2$ per year in 2050.

Source: Authors.

well as the scale-up of necessary zero-carbon power sources like renewables. While not included in the four target indicators for power, we also consider other key transformations needed in the sector in the enabling conditions section of the report, such as energy efficiency and demand management programs.

For each indicator, we adopted targets developed by Climate Action Tracker (CAT) in its *Paris Agreement Compatible Sectoral Benchmarks*: *Methods Report* (CAT 2020a), which employed a combination of top-down and bottom-up methods to establish near- and long-term power generation targets. To do so, CAT (2020a) first identified modelled sectoral pathways from *Global Warming of 1.5°C*: *An IPCC Special Report* (IPCC 2018), which included a total of 1,184 scenarios generated by 31 models. Each scenario represents a development pathway for the energy system at varying end points (e.g., final demand, mix of technologies deployed, speed of decarbonization) and at different spatial and temporal resolutions. CAT (2020a) then filtered these scenarios to include those that meet four conditions:

- Global warming is limited to 1.5°C with "no overshoot" or "low overshoot" (IPCC 2018).
- 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 electric).
- Scenarios have complete data and relatively high temporal resolution.

Just 11 pathways met these criteria. Critically, none of these modelled pathways consider an equitable distribution of costs and required action; rather, they indicate least-cost pathways to limiting global temperature rise to roughly 1.5°C with no or low overshoot. Achieving the global targets derived from these modelled pathways, then, implies that either substantial financial transfers are made among countries, that richer countries decarbonize more quickly than in the underlying models, or a combination of both (Bauer et al. 2020).

CAT (2020a) then combined their analysis of modelled pathways from IAMs with a bottom-up review of systemwide global modelling, including assessments of the feasibility and the cost of different technological features.[9] CAT (2020a) compared targets derived from this bottom-up review with those developed using the 1.5°C scenarios from IAMs (which served as an emission budget constraint) (CAT 2020a). This comparison helped ensure that, if any discrepancy existed among targets, those developed from the bottom-up approaches were more ambitious in achieving decarbonization more rapidly.

2.3.2 Buildings

Operational emissions in the buildings system 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 a zero-carbon buildings system (IPCC 2022). The materials used to construct and furnish buildings also contain substantial embodied emissions. We cover two of these materials—cement and steel—in this series' Industry section.

Two of the three[10] quantitative indicators and targets assessed in this report (see Table 2) directly track these components—carbon and energy intensity of building operations. We further subdivided each of these indicators into residential and commercial building types as the energy demand structure of each is different. We set another supporting target to capture progress made in accelerating the deep retrofitting rate of existing buildings, which will be required to achieve the other two targets. Constructing new low-carbon and zero-carbon buildings is also critical to achieving the intensity targets, but this was not included as an indicator in *State of Climate Action 2022* due to a lack of data and agreement in the literature on the timing of when all new buildings should be zero carbon.

CAT (2020a) relied on a bottom-up, sectoral model to develop quantitative targets for the buildings system. To verify these targets, CAT (2020a) then used modelled pathways from IAMs that meet four conditions:

- Global warming is limited to 1.5°C with "no overshoot" or "low overshoot" (IPCC 2018).
- 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 electric).
- Scenarios have complete data and relatively high temporal resolution.

Just 11 pathways met these criteria. CAT then cross-checked assumptions and results with national-level studies. Because these targets were developed using the same bottom-up, sectoral modelling exercise, they are internally consistent and therefore also dependent on one another. For instance, if energy intensity does not improve in line with its unique target, carbon intensity would need to improve at a faster rate to remain 1.5°C compatible. Similarly, the targeted retrofitting rate is required for sufficient replacement of technologies to achieve the reductions in energy and carbon intensities.

Critically, the targets that CAT (2020a) developed are not global; rather they are for the United States, the European Union, Brazil, India, China, and South Africa. But in the absence of targets derived from global data, we set global targets that span the target ranges of these individual countries for each building indicator.[11] More information about target and indicator design for each of these indicators is provided in Table 2.

TABLE 2 | Design of Buildings Indicators and Targets

INDICATOR	2030 TARGET	2050 TARGET	TARGET SOURCE	ADDITIONAL INFORMATION
Energy intensity of building operations (% of 2015 levels)	Commercial: 70–90 Residential: 70–80	Commercial: 50–85 Residential: 40–80	CAT 2020a	The range in target values reflects the range in reductions required for different countries, with their unique climates and existing infrastructure, that were included in CAT (2020a). When tracking progress of this indicator toward meeting its designated 2030 and 2050 targets, data that split floor area values between commercial and residential buildings were available for only one year (2017). The energy intensity indicator relies on having floor area data split by commercial and residential use. However, we could assess progress against the targets because the required reductions are similar for commercial and residential buildings. To assess energy intensity, we converted the energy intensity data and targets to an index that is referenced to the 2015 value. We then compared the combined trend for all buildings against the separate commercial and residential targets to calculate the required acceleration of the indicator (see more in Section 4). Framing the indicator in this way assumes that energy intensity improvements in residential and commercial buildings have developed in a similar manner.

Carbon intensity of building operations ($kgCO_2/m^2$)	Commercial: 15–21 Residential: 10–16	Commercial: 0 Residential: 0	CAT 2020a	The range in target values reflects the range in reductions required for different countries, with their unique climates and existing infrastructure, that were included in CAT (2020a). Targets for the carbon intensity indicator are different than those for energy intensity so the indexing approach described above doesn't work. Although emissions from the buildings sector were available for a longer time series, we were able to calculate the carbon intensity (emissions per floor area) for only the single year with floor area data (2017). Floor area data were available for a longer time series as an aggregate value, allowing us to calculate carbon intensity for all buildings together. This gave a carbon intensity trajectory for the whole system that we used as a proxy to evaluate the carbon intensity for the emissions intensity indicator. The carbon intensity targets assume that the power system targets for improvements in the emissions intensity of the grid are met.
Retrofitting rate of buildings (%/yr)	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 emissions 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).

Note: %/yr = percent per year; $kgCO_2/m^2$ = kilograms of carbon dioxide per square meter.
Source: Authors.

Due to benchmark and data availability, we focused exclusively on reducing buildings' energy-related emissions. However, additional areas of critical action related to buildings are material efficiency to avoid embodied emissions, reducing emissions of fluorinated gases from cooling in buildings, and waste avoidance and management. We partially cover embodied emissions in the Industry section of *State of Climate Action 2022*, with specific indicators on the production of cement and steel. For the same data limitation reasons, the 2022 report also omits analysis of growing floor area,[12] an indicator of the activity level in the buildings sector, for which Paris-aligned benchmarks are not available. *State of Climate Action 2022* omits analysis of the design of new zero-carbon buildings due to data limitation challenges as well.

2.3.3 Industry

Transforming the industry sector will require three key shifts (IPCC 2022; IRENA 2021; ETC 2021). First, although the mitigation potential of energy efficiency measures is limited in the industry system, adopting the best available technologies to improve efficiency could achieve some emissions reductions in the short term, while reducing the efforts needed by other shifts. Second, thermal energy demand in the industry system 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 system. Finally, because the industry system is responsible for a significant share of process emissions[13] and depends on high-temperature heat for some industrial processes, large-scale electrification pursued alongside the decarbonization of global energy supply is not sufficient to mitigate its emissions—new fuels, feedstocks, and technologies also need to be developed and commercialized.

We selected the industry system indicators and their respective targets (Table 3) with the aim of gauging overall progress across the system, as well as progress made in achieving the aforementioned required shifts. More specifically, for the second shift, we monitored the share of electricity in industry's final energy demand. We then tracked the first and third shifts through a closer look at the production of cement and steel[14]—two of the most difficult industrial subsectors to decarbonize, which together account for more than half of direct GHG emissions from the industrial system (ClimateWatch 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., electrification of medium-heat processes or adoption of new fuels). The report also tracks green hydrogen production 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 derived the targets used to measure progress in the industry system from two main sources: CAT (2020a) and IEA (2021b). CAT (2020a) used both top-down and bottom-up methods to establish targets for the share of electricity in the industry sector's final energy demand, carbon intensity of global cement production, and carbon intensity of global steel production.

For the share of electricity in the industrial sector's final energy demand, CAT relied on a top-down approach to develop the targets using IAM scenarios that meet four conditions:

- Global warming is limited to 1.5°C with "no overshoot" or "low overshoot" (IPCC 2018).
- 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 electric).
- Scenarios have complete data and relatively high temporal resolution.

Just 11 pathways met these criteria. Similar to the approach described for the CAT (2020a) targets in the power system, CAT derived this target from least-cost pathways, which do not consider equitable distribution of costs and required action.

Because IAMs provide less granularity and are thus limited in terms of their potential for defining sectoral benchmarks, CAT (2020a) established targets for the carbon intensities of cement and steel by using bottom-up, sectoral modelling tools and applying mitigation options that would enable full decarbonization of the sector as quickly as possible. Academic and gray literature on what is needed across the industry system to achieve compatibility with the Paris Agreement informed this modelling work, and CAT (2020a) compared the targets derived from this bottom-up, sectoral modelling with those from 1.5°C-compatible pathways modelled by IAMs that meet the sustainability criteria and data requirements outlined above to ensure that if there was any discrepancy, the targets taken from the 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. Also, the bottom-up modelling tools used to set targets are not based on a comprehensive economic analysis, but rather they prioritize the changes necessary to limit global warming to 1.5°C by mid-century from a technical feasibility perspective (CAT 2020a).

Finally, we sourced the green hydrogen production targets from IEA (2021b), which modelled 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 *State of Climate Action 2021* targets (Boehm et al. 2021), which were derived from Race to Zero (2021)—given its close alignment with the upper bound of IPCC Sixth Assessment Report estimates for 2050 (IPCC 2022).

TABLE 3 | Design of Industry Indicators and Targets

INDICATOR	2030 TARGET	2050 TARGET	TARGET SOURCE	ADDITIONAL INFORMATION
Share of electricity in the industry sector's final energy demand (%)	35	40–45 (2040) 50–55 (2050)	CAT 2020a	N/A
Carbon intensity of global cement production ($kgCO_2$/t cement)	360–370	55–90	CAT 2020a	N/A
Carbon intensity of global steel production ($kgCO_2$/t steel)	1,335–1,350	0–130	CAT 2020a	N/A
Green hydrogen production (Mt)	81	320	IEA 2021b	N/A

Note: $kgCO_2$/t = kilograms of carbon dioxide per tonne; Mt = million tonnes; N/A = not applicable.
Source: Authors.

An important change from the 2021 to the 2022 report is the exclusion of the number of low-carbon steel facilities indicator. Because of uncertainty around the frequency of updates made to the dataset used to track this indicator, the *Green Steel Tracker,* annual updates to the indicator cannot be ensured (Leadit 2021). Additionally, the other selected indicators for the industry system 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). The number of low-carbon steel facilities is therefore still mentioned in *State of Climate Action 2022*, but not maintained as an indicator of its own.

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 technology (BloombergNEF 2022). An often-used framework that helps organize the multiple solutions needed to achieve decarbonization is "avoid-shift-improve" (Dalkmann and Brannigan 2014). Under this approach, the sector should work toward *avoiding* the need to travel by using land-use and urban planning approaches that bring opportunities closer to citizens; *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-emission 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 how and whether 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 in this category.

We adopted three transport targets from CAT (2020a). Using a similar approach to the power system, CAT (2020a) filtered modelled pathways from IAMs to those scenarios that meet four conditions:

- Global warming is limited to 1.5°C with "no overshoot" or "low overshoot" (IPCC 2018).
- 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 electric).
- Scenarios have complete data and relatively high temporal resolution.

Just 11 pathways met these criteria. CAT (2020a) then used a combination of bottom-up modelling (e.g., for electric vehicles) and other independent peer-reviewed literature to finalize the more granular targets, comparing each target derived from this bottom-up analysis with 1.5°C-compatible pathways modelled by IAMs to ensure that, if there was any discrepancy, the targets derived from the bottom-up approaches were more ambitious in achieving decarbonization more rapidly. These pathways are defined on a least-cost pathway and do not consider equitable distribution of costs and required action.

We derived another four 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*, and the University Maritime Advisory Services' *A Strategy for the Transition to Zero-Emission Shipping* (IEA 2021b; MPP 2022; UMAS 2021). 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.

TABLE 4 | Design of Transport Indicators and Targets

INDICATOR	2030 TARGET	2050 TARGET	TARGET SOURCE(S)	ADDITIONAL INFORMATION
Share of kilometers traveled by passenger cars (%)	34–44	N/A	BloombergNEF 2021	To establish this 2030 target, we compared the bottom and top of the range for electric vehicle uptake (the sixth indicator in this table, in which electric vehicle penetration is 20–40 percent of global vehicle stock by 2030) against its projected BAU scenario (BloombergNEF 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 nonmotor vehicle modes will be either zero emissions (e.g., walking and cycling) or fully electrified (for motorized modes) by 2030.
Number of kilometers of rapid transit (metro, light-rail, and bus rapid transit) per 1 million inhabitants (in the top 50 emitting cities) (km/1 M inhabitants)	38	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 1,000,000 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 (in the top 50 emitting cities) (km/1,000 inhabitants)	2	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 modal share of cycling and availability of high-quality cycling infrastructure. Similar to above, we also selected the top 50 emitting cities from Moran et al. (2018) and used Open Street Maps 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 multi-use 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 Open Street Maps, especially when it comes to bike lanes built in earlier years (during the first decade of monitoring). In those cities with limited mapping activities, the mapping progress over the years might indicate more of how volunteers have contributed to the Open Street Maps, 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).
Carbon intensity of land-based passenger transport (gCO_2/pkm)	35–60	0	CAT 2020a	N/A
Share of electric vehicles in light-duty vehicle sales (%)	75–95	100 (2035)	CAT 2020a	N/A
Share of electric vehicles in the light-duty vehicle fleet (%)	20–40	85–100	CAT 2020a	N/A

Share of battery electric vehicles and fuel cell electric vehicles in bus sales (%)	60	100	IEA 2021b	N/A
Share of battery electric vehicles and fuel cell electric vehicles in medium- and heavy-duty vehicle sales (%)	30	99	IEA 2021b	N/A
Share of sustainable aviation fuels in global aviation fuel supply (%)	13–18	78–100	IEA 2021b; MPP 2022	N/A
Share of zero-emission fuels in maritime shipping fuel supply (%)	5–17	84–93	IEA 2021b; UMAS 2021	This indicator was updated from international shipping to all maritime shipping to keep in line with the updated targets.

Notes:. BAU = business as usual; EV = electric vehicle; gCO_2/pkm = grams of carbon dioxide per passenger kilometer; km = kilometer; M = million; N/A = not applicable.

[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 others (MCP 2017).

Source: Authors.

One indicator—the share of low-emission fuels in the transport system—was removed between the publication of *State of Climate Action 2021* and *State of Climate Action 2022*. We did so to reduce redundancy with the shipping and aviation indicators and because the only available dataset used in the 2021 report included primary biofuels. We excluded primary biofuels elsewhere in the 2022 report where possible because only a small amount of sustainable biomass is available for energy production in hard-to-abate sectors without jeopardizing the land and resources needed to feed a growing population (Searchinger et al. 2019).

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, as well as enhance carbon sequestration in the near term. Protecting, restoring, and sustainably managing these ecosystems represent the primary shifts needed for mitigation in this system (IPCC 2022).

Yet deriving targets for these measures from IAM modelled pathways that limit global temperature rise to 1.5°C with no or low overshoot—one of the primary approaches employed across energy-related systems (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 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 system'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 system's overall mitigation potential. Unlike IAMs, this approach 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 system 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. Additional safeguards are included 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 is considered cost-effective). Roe et al. (2021) noted that the upper end of this range, which represents the bottom-up, cost-effective estimate,[15] 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 and other ecosystems, specifically, delivers 48 percent of this cost-effective mitigation potential at 6.6 $GtCO_2e$/yr in 2050 (Roe et al. 2021). These findings are aligned with IPCC (2022), which similarly found that, at the same price, protecting, restoring, and sustainably managing these same 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). Further information on our methodology to develop the targets for each indicator is provided in Table 5. We excluded indicators and targets for improved forest management and improved fire management across grasslands due to data limitations in assessing their progress.[16] 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 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 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. 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).

TABLE 5 | Design of Land and Forest Indicators and Targets

INDICATOR	2030 TARGET	2050 TARGET	TARGET SOURCE(S)	ADDITIONAL INFORMATION ON TARGETS
Deforestation (Mha/yr)	1.9[a]	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. (2019)'s "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 percent reductions from the 2018 level (6.2 Mha, see *Use of Proxy Indicators* below). 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).

Reforestation (total Mha)	100[b]	300	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 about 100 Mha by 2030 and roughly 300 Mha[c] by 2050. 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 degradation (Mha/yr)	0	0	Griscom et al. 2017	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) derives this GHG emissions reduction estimate from Griscom et al. (2017)'s "maximum additional" mitigation potential for peatland degradation, which is estimated by assuming that all potential peatland degradation is avoided by 2030. In other words, the average annual historical rate of peatland degradation—0.78 Mha/yr from 1990 to 2008, as estimated by Griscom et al. (2017)—is reduced to zero by 2030. Absent more recent data on the global rate of peatland degradation, our area-based target is thus set to zero peatland degradation by 2030, following Griscom et al. (2017) in assuming a 10-year ramp-down period. 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 assume that these targets are still in line with 1.5°C pathways.

Peatland restoration (total Mha)	15	20	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 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 hold 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, 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 US$100/$tCO_2e$,[d] 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), which involves restoring nearly half of degraded peatlands—recently estimated at 46 Mha by Humpenöder et al. (2020)—by mid-century. Our target, then, represents an important starting point rather than a definitive goal for policymakers.

Mangrove loss (ha/yr)	4,900	N/A	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-up assumptions from Griscom et al. (2020), we set our target to achieve this reduction by 2030, resulting in a target for 2030 only (Griscom et al. 2020).
Mangrove restoration (total Mha)	0.24	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. The technical potential was 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, so much so that the world may have lost as much as 35% of mangrove forests globally. This target, therefore, likely represents the area of mangroves that, at a minimum, could be restored to achieve climate mitigation goals.

Notes: AFOLU = agriculture, forestry, and other land uses; CO_2 = carbon dioxide; $GtCO_2e$/yr = gigatonnes of carbon dioxide equivalent per year; ha/yr = hectares per year; Mha = million hectares; Mha/yr = million hectares per year; tCO_2e = tonnes of carbon dioxide equivalent.

[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 and 300 Mha by 2050 cover only approximately 86% 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, and rounded our 2030 target from 98 Mha to 100 Mha.

[d] 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.

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. 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)[17] 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 2021, tree cover loss by dominant driver (Curtis et al. 2018) updated to 2021, humid tropical primary forests (Turubanova et al. 2018), and tree cover loss due to fire (Tyukavina et al. 2022) updated to 2021. 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,[18] 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 resolution (10 kilometers; km), 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. 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 used a seven-year trendline from 2015 to 2021 to calculate the linear trendline, as changes to the methodology have been minimal since 2015.

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 woody vegetation that grew from a height of less than five meters (m) in 2000 to a height of greater than or equal to 5 m in 2020 or woody vegetation that experienced a height increase greater than or equal to 100 percent from 2000 to 2020.

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.[19] 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.

Mangrove Loss

To monitor mangrove loss globally (hectares per year; ha/yr), we used a dataset on tidal wetland change that estimates gross loss of tidal flats, tidal marshes, and mangroves from 1999 to 2019 (Murray et al. 2022). Murray et al. (2022) defined mangrove loss as the replacement of mangroves with non-intertidal ecosystems at the 30-m pixel scale, which includes both natural and human-caused losses, and using this definition, estimated mangrove loss for six three-year epochs. To convert these estimates to annual rates, we divided the gross loss by the number of years in each 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. More specifically, we derived our target from Roe et al. (2021), who focus on mitigation outcomes attributable to human activities, but by using the Murray et al. (2022) data, which include all losses, including those due to natural causes, we overestimate mangrove losses attributable to human activities. 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).

Another commonly used dataset on mangrove extent and change, Global Mangrove Watch, 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 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.

Mangrove Restoration

Murray et al. (2022) estimate gross 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 likely attributable to direct human interventions, such as mangrove planting and other restoration activities. Bunting et al. (2022) also note that the most commonly observed mangrove gains are due to natural processes, such as sedimentation around river estuaries. Because of these dynamics, we did not consider gross mangrove gain an adequate proxy for assessing the state of mangrove restoration, and we therefore categorized this indicator as insufficient data.

2.3.6 Food and Agriculture

Transforming the world's food system 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 soil carbon sequestration, as well as adding additional aboveground carbon via agroforestry and silvopasture systems, has the potential to reduce net agricultural emissions (Roe et al. 2021), although additional sequestration potential on working agricultural lands is likely limited (Poulton et al. 2018).

For each of these critical shifts, we primarily adopted targets established in *Creating a Sustainable Food Future* (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 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 simultaneously ends deforestation and achieves large-scale reforestation and peatland restoration as described in the *State of Climate Action* Forests and Land targets[20]

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.[21]

In total, this Breakthrough Technologies scenario includes more than 15 critical shifts—or 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 six critical shifts 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 percent of the mitigation potential identified in Searchinger et al. (2019) (Table 6).

We adopted targets for GHG emissions from agricultural production, ruminant meat productivity, and ruminant meat consumption in the Americas, Europe, and Oceania directly from Searchinger et al. (2019). Our target for crop yields initially came from Searchinger et al. (2019), but we updated it in the 2021 and 2022 reports to account for more recent crop demand forecasts for 2050 from Searchinger et al. (2021). We estimated a 2030 target for each by calculating the mean between the indicator's observed value in 2010 and the 2050 target. This created a linear pathway between 2010 (the observed value) and 2050 (the target value), creating a 2030 target at the midpoint. For this year's report, we removed on-farm energy use and peatland drainage from agricultural emissions to avoid double-counting with other sectors. Because of this, we adjusted our 2010 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.

Finally, we opted for more ambitious food loss and waste targets derived from Target 12.3 of the Sustainable Development Goals (UN 2015), which involve halving the rates of food loss and waste by 2030 instead of 2050. We opted 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, and this target was maintained to 2050.

A major caveat regarding the baseline and target values in this section is the reliance on historical data in FAOSTAT, the statistics service of the Food and Agriculture Organization of the United Nations. 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. 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 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. A specific limitation for the ruminant meat productivity indicator is that FAOSTAT does not differentiate pasturelands for ruminant meat production versus dairy production. As globally consistent datasets improve, it may become necessary in the future to re-estimate baseline and target values for these indicators.

TABLE 6 | Design of Food and Agriculture Indicators and Targets

INDICATOR	2030 TARGET	2050 TARGET	TARGET SOURCE(S)	ADDITIONAL INFORMATION
Agricultural production GHG emissions ($GtCO_2e/yr$)	4.6	3.6	Searchinger et al. 2019	Using additional outputs from the GlobAgri-WRR model, we further disaggregated this target by the primary sources of on-farm GHG emissions, including enteric fermentation, manure management, manure on pastures, soil fertilization, and rice cultivation, to illustrate the relative importance of each activity to climate change mitigation. This disaggregation is shown in the Food and Agriculture section of the 2022 report.
Crop yields (t/ha/yr)	7.8	9.6	Searchinger et al. 2019; Searchinger et al. 2021	N/A
Ruminant meat productivity (kg/ha/yr)	33	42	Searchinger et al. 2019	N/A
Share of food production lost (%)	7	7	UN 2015	N/A

Food waste (kg/capita/yr)	61	61	UN 2015	N/A
Ruminant meat consumption (kcal/capita/day)	79	60	Searchinger et al. 2019	While all other targets are global in scope, this goal focuses solely on lowering ruminant meat consumption in the high-consuming regions of the Americas, Europe, and Oceania for equity reasons. Other regions' consumption levels were below the 60-kilocalorie threshold in 2019 and, accordingly, were not included.

Note: GHG = greenhouse gas; $GtCO_2e/yr$ = gigatonnes of carbon dioxide per year; kcal/capita/day = kilocalories per capita per day; kg/capita/yr = kilograms per capita per year; kg/ha/yr = kilograms per hectare per year; N/A = not applicable.
Source: Authors.

2.3.7 Technological Carbon Removal

Lowering GHG emissions is 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 if we want to limit global warming to 1.5°C. We will also need to pull carbon dioxide out of the air to counterbalance GHG emissions that will prove difficult to mitigate in the coming decades (for example, from long-haul aviation, heavy industry, and agriculture) and to deal with excess CO_2 already in the atmosphere (NASEM 2019). 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., direct air capture), which we assess here. We recognize, however, that this current natural versus technological categorization is not definitive, 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 in the 2022 report, 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 direct air capture; biomass carbon removal and storage, including bioenergy with carbon capture and storage, or BECCS, and approaches that include pyrolysis or gasification of biomass; and mineralization, though development of future 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.

The 2030 and 2050 targets for this indicator are based on the range of modelled pathways that limit global temperature rise to 1.5°C (with no or low overshoot), as presented in IPCC (2018). We filtered these pathways to identify a subset of 20 that meet sustainability criteria based on Fuss et al. (2018) for biomass cultivation for carbon removal outlined in IPCC (2018). We used the median values for the 2030 and 2050 levels of technological carbon removal (i.e., from bioenergy with carbon capture and storage, direct air capture, and mineralization, which are the technologies incorporated into climate models) as 2030 and 2050 targets.

TABLE 7 | Design of Technological Carbon Removal Indicator and Target

INDICATOR	2030 TARGET	2050 TARGET	TARGET SOURCE(S)	ADDITIONAL INFORMATION
Technological carbon removal ($MtCO_2$/yr)	75	4,500	IPCC 2018; Fuss et al. 2018	N/A

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

While we used IPCC (2018) to establish 2030 and 2050 targets, we note that the more recent Sixth Assessment Report (IPCC 2022) includes additional scenarios that can provide a more nuanced understanding of carbon removal needs and how different scenarios for near-term emissions reduction can impact those needs. It indicates a range of estimates for technological carbon removal when net-zero CO_2 emissions and net-zero GHG emissions are reached in modelled pathways that limit warming to 1.5°C with no or limited overshoot (IPCC 2022). IPCC (2022) also notes several pathways that demonstrate the potential for less reliance on carbon removal technologies—to a level lower than this report's 2050 target[22]—through a greater emissions reduction in the near term. This can be achieved through increased resource efficiency, a shift toward more sustainable development (e.g., through reductions in inequality and poverty, more sustainable consumption patterns), or a faster and deeper transition to renewables. For example, a high renewables pathway points to the need for 2,400 million tonnes of carbon dioxide per year ($MtCO_2$/yr) of technological carbon removal in 2050 (IPCC 2022). While we have not yet comprehensively assessed the new IPCC Sixth Assessment Report scenarios, an initial review suggests that, once filtered for sustainability constraints, they may show less reliance on carbon removal technologies than our target for 2050. We will revisit this in *State of Climate Action 2023.*

Along these lines, other estimation methodologies can also come to lower technological carbon removal needs. The IPCC uses top-down climate models that optimize based on cost, which can result in an overreliance on future carbon removal due to assumed technology cost declines and cost declines of alternative technologies happening too slowly. An alternative, bottom-up methodology can also be used to estimate the amount of residual emissions that will need to be addressed with carbon removal. One estimate points to 1,500–3,100 $MtCO_2$/yr of carbon removal needed in the second half of the century to address portions of emissions from agriculture, aviation, shipping, and building heating (Bergman and Rinberg 2021). This estimate roughly aligns with the IPCC's pathways with more ambitious near-term action, also indicating the potential for lower amounts of carbon removal need than this report's target.

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 systemwide transformations covered in the *State of Climate Action* series. Indeed, to facilitate vast decarbonization across all systems, sufficient finance from both public and private sources must be made available, and investments in emissions-intensive practices and technologies must be disincentivized through carbon pricing mechanisms, removal of fossil fuel subsidies, and more.

In the *State of Climate Action* series, we examined six indicators, each with 2030 and 2050 targets (Table 8) for insight into how finance can unlock greater climate action.[23] We used a variety of methodological approaches to design 2030 and 2050 targets for each indicator. Because the design of our total climate finance targets, as well as those for public and private climate finance targets for 2030 and 2050, aggregated information from multiple sources and requires a lengthy methodological explanation, we provide an in-depth explanation in Box 2. Justification for the target design for all other indicators is described in Table 8.

TABLE 8. DESIGN OF FINANCE INDICATORS AND TARGETS

INDICATOR	2030 TARGET	2050 TARGET	TARGET SOURCE(S)	ADDITIONAL INFORMATION
Global total climate finance (trillion US$/yr)	5.2	5.1	IPCC 2018, 2022; IEA 2021b; OECD 2017; UNEP 2021a, 2021b	See Box 2 for an overview of how we used these sources to design our targets.
Global public climate finance (trillion $/yr)	1.31–2.61	1.29–2.57	Buchner et al. 2021; IPCC 2018	See Box 2 for an overview of how we used these sources to design our targets.
Global private climate finance (trillion $/yr)	2.61–3.92	2.57–3.86	Buchner et al. 2021; IPCC 2018	See Box 2 for an overview of how we used these sources to design our targets.
Share of global emissions under mandatory corporate climate risk disclosure (%)	75	75	N/A	We designed the targets for 2030 and 2050 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).
Median carbon price in jurisdictions with pricing systems (2015 $/t$CO_2$e)	170–290	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 U.S. dollars (IPCC 2022).

Total public financing for fossil fuels (billion $/yr)	0	0	IEA 2021b; IPCC 2022; G20 2009; G7 2016	The IEA's net-zero roadmap to achieve 1.5°C 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 fossil fuel subsidies, 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). 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.

Note: COP26 = 26th Conference of the Parties to the United Nations Framework Convention on Climate Change; GHG = greenhouse gas; G7 = Group of Seven; G20 = Group of 20; IEA = International Energy Agency; N/A = not applicable; tCO_2e = tonnes of carbon dioxide equivalent; US$/yr = US dollars per year.

Source: Authors.

BOX 2 | Methodology for Designing Global Targets for Total Climate Finance, Public Climate Finance, 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.

Accurately projecting total climate financing needs is challenging due to a continually improving understanding of climate science, rapidly falling 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 needs in IPCC (2018):[d]

- 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 U.S. dollars.[e]
- The IPCC's Sixth Assessment Report compilation of sector studies to determine average annual mitigation financing found needs until 2030 of $2.4 to $4.8 trillion per year, in 2015 U.S. dollars, covering the energy, transport, and AFOLU sectors under a mixture of 1.5°C and 2°C scenarios.[f] We subtracted the AFOLU figures ($0.1–$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).
- 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 U.S. dollars.[g]
- 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 U.S. dollars.[h]

We adjusted all nominal figures to 2020 U.S. 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 estimates 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 U.S. dollars.[i]
- UNEP estimates 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 U.S. dollars from the original 2016 estimates,[k] which 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, 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 correspond 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 goal 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 2050. See Table B2.1 for a breakdown of these totals.

TABLE B2.1 | Estimated Annual Climate Investment Needs (trillion US$)

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		**$4.80**	**$5.22**	**$5.05**	**$5.14**

Note: N/A = not applicable.

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 *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.

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 use 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" (UNFCC 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 for 2030, 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 1 and 3 years for most indicators, but over 10 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 require 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

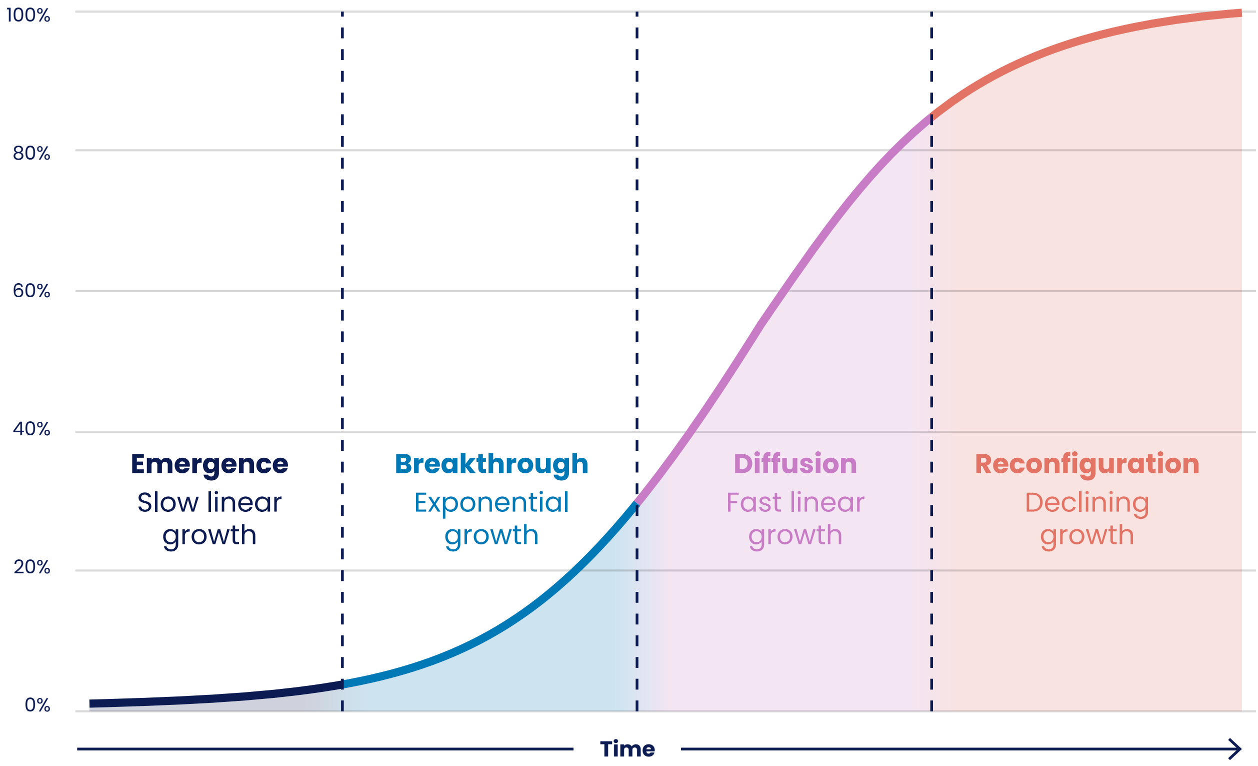
In this section, we provide an overview of our methodology for assessing global progress of all indicators toward their near-term targets. We first provide background on why some indicators may follow nonlinear paths. We then explain the methods we used to determine whether indicators are on track to meeting their 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 way is to assume that growth continues at its current rate of change following a purely linear trajectory, and, indeed, this was an effective method for some indicators. However, it is unlikely that all indicators will follow a linear path. For example, the adoption of new technologies has often followed a rough S-curve trajectory (Figure 1). At the emergence stage of an S-curve, progress is linear and quite slow. Then, once a breakthrough is achieved, it accelerates exponentially. This exponential growth continues until the technology reaches its maximum speed of uptake. This is the steepest part of the curve, which is linear again, but growing at a much faster rate. Most of the diffusion—when the technology becomes integrated as the status quo—occurs during this stage. Finally, as the technology approaches a saturation point, growth gradually slows once again. 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 system).

A tipping point—defined broadly as a critical threshold beyond which a system reorganizes often abruptly or irreversibly (IPCC 2022)—can also be conceptualized as the inflection point on an S-curve. Reaching this threshold often allows a new technology to achieve a breakthrough and accelerate on its S-curve path. 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 small changes in

FIGURE 1 | Illustration of an S-Curve



Source: Adapted by the authors from Boehm et al. (2021) and Grubb et al. (2021).

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

Once tipping points are crossed, self-amplifying feedbacks 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 distribute the high costs of improvements across a wider customer base. 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). These reinforcing feedbacks spur adoption and help new innovations supplant existing technologies (Victor et al. 2019).

Widespread adoption of new technologies, in turn, can 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 3). 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 by assuming that future uptake will follow a linear trajectory (Abramczyk et al. 2017; Mersmann et al. 2014; Trancik 2014).

BOX 3 | 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 system, for instance, a few early movers, including Denmark, Germany, Spain, and California, implemented policy portfolios that supported deployment of solar and wind energy technologies. Other 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 between interconnected systems, as illustrated in Figure B3.1. 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. The world is moving closer to such a tipping point. 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 B3.1. UPWARD CASCADE OF POSITIVE TIPPING POINTS

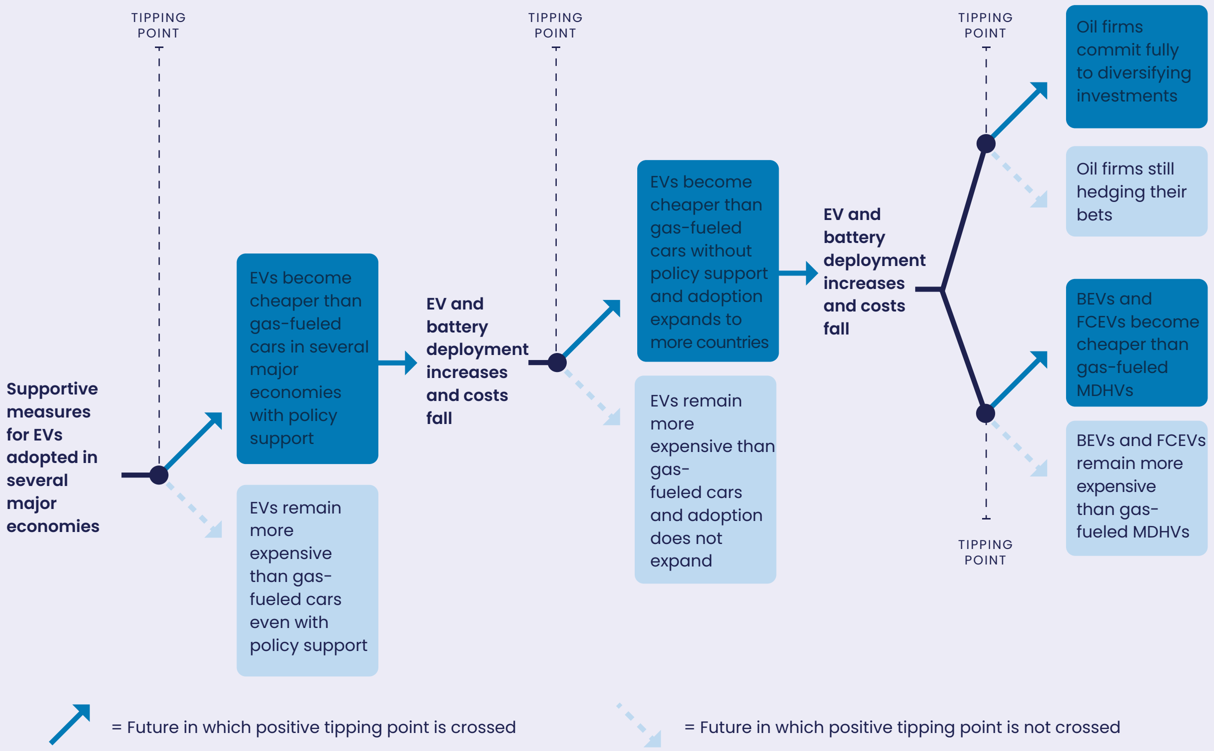


Figure note: BEV = battery electric vehicle; EV = electric vehicle; FCEV = fuel cell electric vehicle; MDHVs = medium- and heavy-duty vehicles.

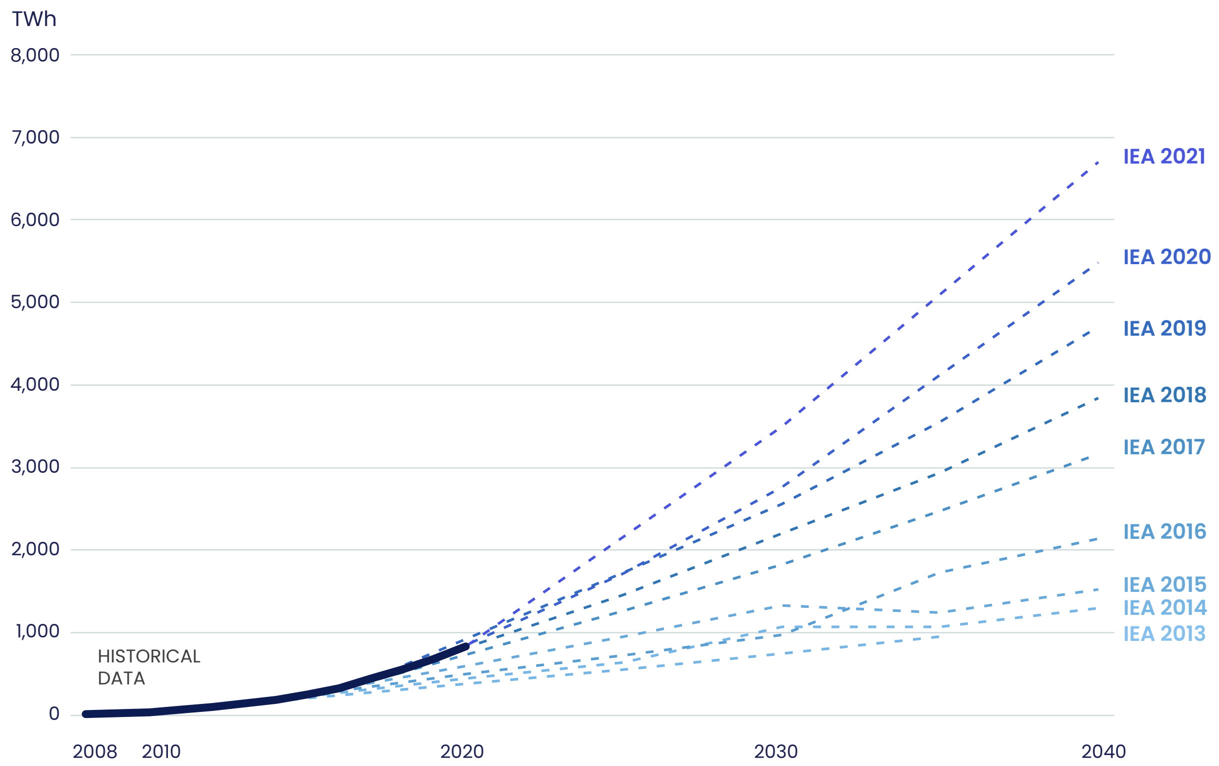
Figure source: Reproduced from Boehm et al. (2021), who adapted the figure from Sharpe and Lenton (2021).

Notes:
a. Sterl et al. 2017; Eckhouse 2020.
b. Sharpe and Lenton 2021.

It is important to note here that, in addition to technology adoption, social and political forces can also contribute to or hinder nonlinear change (F.C. Moore et al. 2022). Our assessment of recent progress made toward near-term targets does 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.

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 has historically assumed that future growth in solar photovoltaic (PV) generation would be largely linear, but it has had to repeatedly increase these forecasts as growth in solar PV has accelerated (Figure 2). 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. Other institutions have similarly underestimated the path of solar and wind, such as the U.S. Energy Information Administration in its *Annual Energy Outlook* (Saha and Jaeger 2020). Even if it is likely that most technologies will not follow linear growth, it is very difficult to pinpoint which nonlinear path they are likely to follow, which is one reason projections stick to roughly linear assumptions. Linear assumptions often suffice for short-term projections, but longer-term projections should consider the potential for systems change and nonlinear growth.

FIGURE 2 | The International Energy Agency's Stated Policy Scenarios Have Not Accounted for the Possibility of Rapid, Nonlinear Growth in Solar Photovoltaics



Note: IEA = International Energy Agency; PV = photovoltaic; tWh = terawatt-hour (10^{12} watt-hours).

Source: Reproduced from Boehm et al. (2021), and authors' analysis of *World Energy Outlook* reports from 2013 to 2021, all of which can be accessed through IEA (2021d).

4.2 Methodology to Assess Global Progress

To assess global progress made toward 1.5°C-compatible targets for all indicators, including those that may roughly follow an S-curve trajectory, we followed three steps for each indicator:

Step 1: Determine whether exponential change is unlikely, likely, or possible.

Step 2: Calculate an acceleration factor by comparing a linear trendline based on the most recent 5 years of historical data (or 10 years of historical data for indicators in the Forests and Land section) with the average annual rate of change needed to achieve an indicator's 2030 target. Using this acceleration factor, we sorted the indicator into a category of progress. An acceleration factor of 0–1 means the indicator is "on track," whereas 1–2 is "off track," >2 is "well off track," and <0 is "wrong direction." The final category is insufficient data, in cases where we were not able to calculate an acceleration factor.

Step 3: Adjust the category of progress where appropriate.

- If exponential change is unlikely for the indicator, we used the category determined by the acceleration factor.
- If exponential change is possible for the indicator, we used this category but noted that change may occur faster than expected.
- If exponential change is likely for the indicator, we consulted the literature and experts to determine if the category should be adjusted.

In the following sections, we explain each of these steps in detail.

Step 1: Determine Each Indicator's Potential for Nonlinear Change

We first evaluated the likelihood that each indicator will experience exponential change[24] and placed indicators into one of three categories based on our understanding of the literature and consultations with experts:

Exponential change 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).

Exponential change 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 following S-curve dynamics, though it is not guaranteed that they will do so. These technologies are innovative, often displacing incumbent technologies (e.g., renewable energy, electric vehicles, green hydrogen).

Exponential change possible: Finally, we identified indicators that do not fall neatly within the first two categories, with most tracking technology adoption indirectly (e.g., those focused on carbon intensity). While many factors, such as increases in resource efficiency, may impact future changes in these indicators, adoption of zero- or low-emission technologies will likely also have an impact on their future trajectories. Thus, although these indicators have generally experienced linear growth in the past, they could experience some unknown form of nonlinear, exponential change in the coming decades if the nonlinear aspects grow 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-emission power, which is expected to be nonlinear. If the nonlinear growth in zero-emission 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 Indicator Categorizations

Exponential Change 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	Share of kilometers traveled by passenger cars	Changes in this indicator are based on behavior change, not technology adoption.
	Number of kilometers of rapid transit (metro, light-rail, and bus rapid transit) per 1 M inhabitants (in the top 50 emitting cities)	Changes in these indicators are not based on innovative technology adoption.
	Number of kilometers of high-quality bike lanes per 1,000 inhabitants (in the top 50 emitting cities)	
Forests and land	Deforestation	Changes in forests and land use are based on changes in activities, behavior, and other incremental processes, not technology adoption.
	Reforestation	
	Peatland degradation	
	Peatland restoration	
	Mangrove loss	
	Mangrove restoration	
Food and agriculture	Agricultural production GHG emissions	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.
	Crop yields	
	Ruminant meat productivity	
	Share of food production lost	
	Food waste	
	Ruminant meat consumption	
Finance	Global total climate finance	Changes in finance flows and policy are based on public and private policies and action, not technology adoption.
	Global public climate finance	
	Global private climate finance	
	Share of global emissions under mandatory corporate climate risk disclosure	
	Median carbon price in jurisdictions with pricing systems	
	Total public financing for fossil fuels	

Exponential Change 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 battery electric vehicles and fuel cell electric vehicles in bus sales	
	Share of battery electric vehicles and fuel cell electric vehicles in medium- and heavy-duty vehicle sales	
	Share of sustainable aviation fuels in global aviation fuel supply	
	Share of zero-emission fuels in maritime shipping fuel supply	

Exponential Change Possible

SECTOR	INDICATOR	EXPLANATION
Power	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.
	Share of unabated 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	
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.

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.
Transport	Carbon intensity of land-based passenger transport	Changes in this indicator depend on both low-carbon technologies like EVs, as well as innovations or changes in behavior that improve the energy efficiency of existing vehicles.
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: EV = electric vehicle; GHG = greenhouse gas; M = million.

Step 2: Assessment of Progress Based on Acceleration Factors

For indicators with sufficient historical data, we calculated a linear trendline, also known as a line of best fit, based on the most recent 5 years of historical data. For several indicators, most notably those in the forests and land system, we calculated a linear trendline based on more years of historical data to account for natural interannual variability.[25] 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 last year's report, 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.[26] 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 4). 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.[27]

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[28] by the average annual rate of change derived from the historical five-year trendline. 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, tenfold, or twentyfold, for example, to meet 2030 targets.[29] We then used these acceleration factors to assign our indicators one of five categories of progress:

- **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.
- **Off track**. The historical rate of change is heading in the right direction at a promising yet insufficient pace. Indicators with acceleration factors between 1 and 2 fall into this category.

- **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. Indicators with acceleration factors of greater than or equal to 2 fall into this category.[30]
- **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., share of electricity in the industry sector's final energy demand), 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 note that progress must accelerate from 2030 to 2050 to stay aligned with efforts to limit global temperature rise to 1.5°C.

BOX 4 | 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 report. For some indicators, these changes are likely temporary, as there is little evidence that they have spurred structural changes 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 initial evidence for 2021 suggests that emissions in the sector have 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 included this value in our linear trendline calculations unless the latest science indicates that this change was temporary (e.g., we are already seeing a rebound in the data). In these instances, we showed the 2020 value, but excluded it from our linear trendline calculations and categorizations of progress. The removal of the 2020 value is noted where applicable.

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

Step 3: Additional Adjustments for "Exponential Change Likely" Indicators

For indicators that are "exponential change unlikely," we used the linear trendline and associated acceleration factors to assign categories of progress. For indicators that are categorized as "exponential change possible," we also used the linear trendline and associated acceleration factors to assign categories of progress, but it is critical to note that these linear trendlines form a baseline, or floor, for action needed to achieve 1.5°C-aligned targets. If nonlinear change begins, progress may unfold at significantly faster rates than expected and the gap between the existing rate of change and required action will shrink.

However, for indicators categorized as "exponential change likely," adoption of new technologies will likely spur rapid, nonlinear change in the coming decades, and future trajectories of growth may resemble an S-curve. For these indicators, acceleration factors based on linear trendlines likely underestimate the pace of future change, as well as overestimate the gap in required action to reach the global targets. Therefore, we used the acceleration factor method as only a starting point for our evaluation of "exponential change likely" indicators, and then, if needed, we adjusted the categorization to account for exponential change based on our qualitative research of the literature and expert consultations.

Ultimately, determining whether "exponential change likely" indicators are on track or not carries considerable uncertainties. 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 new 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.

Below, we explain the steps we took for "exponential change likely" indicators:

1. Use the acceleration factor based on the linear trendline as a starting point to categorize the indicator.

2. Consider what stage of an S-curve the indicator is in:

- *Emergence.* In this stage, the rate of adoption is slow and still fairly linear. Indicators in this stage will almost always be "well off track" based on the linear trendline. However, when categorizing an indicator's progress, we also considered whether a breakthrough is near, which would mean that it would outperform the linear trendline.
- *Breakthrough.* In this stage, change is exponential. When categorizing the progress for indicators in this stage, we took into consideration that they will usually outperform the linear trendline.
- *Diffusion.* In this stage, the rate of adoption has reached its maximum steepness. Growth is linear but fast. When categorizing progress for indicators in this stage, we considered that they are likely to approximately follow the linear trendline for a while, but will eventually underperform against the linear trendline.
- *Reconfiguration.* In this stage, growth is declining as it approaches the saturation point. When categorizing progress for indicators in this stage, we considered that they are likely to underperform against the linear trendline.

3. Review the literature and consult with experts to consider nonlinear growth:

- *Additional literature.* For some indicators, existing literature evaluating their progress already employs a range of methodologies to consider nonlinear change. This could be in the academic peer-reviewed literature or the gray literature. For example, we reviewed current policy projections from institutions like BloombergNEF that consider more than just linear growth in their forecasts. We reviewed these studies and reports to assess the likelihood that each indicator's future growth will outperform what is suggested by the linear trendline, weighing the results based on the methods' rigor and the extent to which consensus exists across sources. We also evaluated whether the literature finds that recent rates of change need to increase by less than two times (off track) or by greater than two times (well off track), if the targets in the literature align with ours, or if we were able to compare the literature's projections to our targets. The literature is particularly important when considering technology-specific indicators that do not have enough data to show the rate of historical growth because they are so nascent. If the literature shows that the development of these technologies is advancing quickly, even in the pre-deployment stage, we can reasonably say the indicator is progressing in the right direction but is "well off track" at a minimum, noting that nonlinear change is possible.
- *Expert consultations.* System experts around the world review each *State of Climate Action* report, commenting on the extent to which they agree with our assessment of each indicator's progress. We took these comments into consideration when categorizing progress.

4. Decide whether to adjust the category of progress. We defaulted to keeping the indicator in its original category, but if we found compelling evidence that it should be changed, we updated its category of progress and explained why.

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

For indicators that are "exponential change likely" and have at least one historical data point, we presented S-curves as dotted lines in the graphs 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, but also 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; this may not be the case in reality, however. Another limitation is that when we drew S-curves, we made sure the target years were aligned with 1.5°C. However, we did not check 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.

5. Selection of Enabling Conditions for Climate Action

To support global efforts to achieve 1.5°C-aligned targets for 2030 and 2050, each *State of Climate Action* report identifies enabling conditions that can help overcome barriers to transformational change. To inform our selection, we first reviewed the academic literature on transition, transformation, and systems change theory as it relates to global environmental change research. We also assessed case studies of historical transitions of sociotechnical systems (e.g., power, transport, industry) and transformations of social-ecological systems (e.g., management of forests and wetlands). Although the specific factors supporting systems change ranged widely across the literature, we identified several common enabling conditions, including innovations, regulations and incentives, strong institutions, leadership from key change agents, and shifts in behavior and social norms (Table 10). While we presented these categories of enabling conditions as discrete from one another, we also recognize that, in reality, these supportive measures may fall into more than one category.

TABLE 10 | Enabling Conditions for Climate Action

CATEGORIES OF ENABLING CONDITIONS	EXAMPLES OF SPECIFIC ENABLING CONDITIONS	DESCRIPTION
Innovations in technology, practices, and approaches	Development and adoption of complementary technologies	Innovations, which broadly encompass new technologies, practices, and approaches, often offer solutions to seemingly intractable challenges. Investments in research and development, support for research networks and consortiums, and universal access to education provide a strong foundation for innovation. Similarly, creating protected spaces for experimentation, pilot projects, and small-scale demonstrations facilitates learning that can lead to improvements in performance and reductions in cost. Developing complementary technologies (e.g., batteries and charging infrastructure for electric vehicles) can also boost functionality and support widespread adoption of innovations.
	Investments in research and development	
	Research networks and consortiums	
	Education, knowledge sharing, and capacity building	
	Experimentation, pilot projects, demonstrations, and other early application niches	

Regulations and incentives	Economic incentives, such as subsidies and public procurement; economic disincentives, such as subsidies reform, taxes, and financial penalties	By establishing standards, quotas, bans, or other "command-and-control" regulations, governments can not only mandate specific changes but also create a stable regulatory environment, often cited as a prerequisite for private sector decarbonization. Using noneconomic or market-based instruments to create incentives (or disincentives) can also shape action from companies, nonprofit organizations, and individuals—and, in some contexts, may be more politically feasible than command-and-control regulations. For subsidies in particular, revenues must be raised to cover these costs, and the mechanisms to do so will also vary by system and region.
	Noneconomic incentives, including removal of bureaucratic hurdles, measures that spotlight good or bad behavior to influence reputations, transitional support to affected communities, or transferring ownership of natural resources to local communities	
	Quotas, bans, regulations, and performance standards	
Strong institutions	Establishment of international conventions, agreements, and institutions	Establishing new institutions or strengthening existing ones can ensure that the policies designed to reduce greenhouse gas emissions are effectively implemented. These institutions can enforce laws, monitor compliance with regulations, and penalize those who break the rules. Creating more transparent, participatory decision-making processes at all levels of government can also help reconfigure unequal power dynamics and enable marginalized communities—those who have often suffered from business-as-usual actions and who generally have the most to gain from transitions to new systems—to steer transformations to a net-zero future.
	Creation of national ministries, agencies, or interagency taskforces	
	Changes in governance, such as more participatory, transparent decision-making processes or natural resource management	
	Efforts to strengthen existing institutions by, for example, increasing staff, funds, or technological resources	
Leadership from change agents	Leadership from national and subnational policymakers, such as setting ambitious targets	Successful transitions often depend on sustained, engaged leadership from a wide range of actors who envision new futures, develop roadmaps for change, initiate actions, and build coalitions of those willing to help implement these plans. While these champions may lead governments, companies, and nonprofit organizations, they need not always sit at the helm of an institution. Civil society organizations, as well as social movements, can effectively pressure those in power to accelerate transitions, and beneficiaries of these changes play an important role in resisting attempts to return to business as usual. Diverse, multistakeholder coalitions that bring these champions together can be a powerful force for change, unifying disparate efforts; pooling resources; and counterbalancing well-organized, influential incumbents.
	Leadership from the private sector, such as establishing ambitious climate commitments and adopting good practices to implement them	
	Diverse, multistakeholder coalitions	
	Beneficiaries of transitions	
	Civil society movements	

Behavior change and shifts in social norms	Changes in behavior Shifts in social norms and cultural values	Through educational initiatives, public awareness campaigns, information disclosure, or targeted stakeholder engagement, agents of change can make a clear, compelling case for transitions, explain the consequences of inaction, and identify concrete steps that individuals can take to help collectively accelerate transitions. They can build consensus for a shared vision of the future, as well as prime people for behavior change interventions. As social norms begin to shift, so too will the policies communities support, the goods and services they demand, and their consumption patterns.

Sources: Enabling conditions were identified from a synthesis of the following studies: Chapin et al. 2010; Few et al. 2017; Folke et al. 2010; Geels et al. 2017a; Geels and Schot 2007; Hölscher et al. 2018; ICAT 2020; Levin et al. 2012; M.-L. Moore et al. 2014; Olsson et al. 2004; Otto et al. 2020; O'Brien and Sygna 2013; Patterson et al. 2017; Reyers et al. 2018; Sharpe and Lenton 2021; Sterl et al. 2017; Victor et al. 2019; Westley et al. 2011; Levin et al. 2020; Bergek et al. 2008; Hekkert et al. 2007.

Exogenous changes, including both shocks (e.g., economic recessions, conflicts, pandemics) and slower-onset events (e.g., demographic shifts) can also create windows of opportunity for transformation by destabilizing existing systems. These external forces, for example, can focus public attention on reducing previously unseen risks, motivate policymakers to adopt niche innovations to address new crises, or create space for leaders who support transforming existing systems to win elections. However, such shocks can also spur backlash against change, further entrenching existing systems. Given that such crises are often immediate, unforeseen, and disruptive, we excluded them from our assessment of underlying conditions that enable climate change mitigation.

After determining a common set of factors supporting systems change, we then reviewed the academic literature—as well as peer-reviewed, well-cited papers published by independent research institutions, United Nations agencies, and high-level sectoral coalitions (e.g., Energy Transitions Commission, High Level Panel for a Sustainable Ocean Economy)—to systematically identify critical barriers to transformational change within each system, as well as key enabling conditions across these five overarching categories that may help decision-makers surmount such obstacles to achieve 2030 and 2050 targets aligned with limiting global warming to 1.5°C.

To identify these system-specific barriers and enabling conditions, we paired keywords detailed in Table 11 with phrases from the five overarching categories of enabling conditions: innovation, regulations and incentives, strong institutions, leadership from key change agents, and shifts in behavior and social norms. While many of the papers that we identified during this process also summarize key barriers to change, we conducted an additional search to supplement these findings by combining the keywords identified in Table 11 with "barriers," "challenges," and "obstacles."

We conducted these literature reviews in English and constrained the dates of our searches from 2015 to 2022. For some targets and indicators (e.g., protecting and restoring ecosystems), however, analysis of this recent body of literature suggested that several highly cited and seminal papers were published prior to 2015. In such instances, we included those studies in our review. Repositories used include Google Scholar and EBSCO. We also searched for recent publications directly from the websites of independent research institutions, United Nations agencies, and high-level sectoral coalitions. We acknowledge that because we conducted our literature review in English, there is a potential bias toward knowledge generated by those in the Global North.

TABLE 11. | Keywords Used in Search to Identify Barriers to and Enabling Conditions for Transformational Change

INDICATOR	KEYWORDS
Power	
Carbon intensity of electricity generation (gCO_2/kWh)	Carbon intensity of electricity generation; emissions intensity of electricity generation
Share of zero-carbon sources in electricity generation (%)	Renewable electricity generation; solar power; wind power
Share of unabated coal in electricity generation (%)	Coal-fired power; coal phaseout in electricity generation
Share of unabated fossil gas in electricity generation (%)	Gas-fired power; fossil gas electricity generation; gas phaseout in electricity generation
Buildings	
Energy intensity of building operations (% of 2015 levels)	Renewable energy for heating; carbon intensity of buildings
Carbon intensity of building operations ($kgCO_2/m^2$)	Energy efficiency of buildings; building envelope improvements; near-zero buildings
Retrofitting rate of buildings (%/yr)	Retrofitting rate; deep retrofitting of buildings
Industry	
Share of electricity in the industry sector's final energy demand (%)	Electrification; high heat; medium heat; low heat; industry; decarbonization
Carbon intensity of global cement production ($kgCO_2/t$ cement)	Novel cement; alternative binders; low-carbon cement; CCS; CCU; decarbonization; concrete; industry
Carbon intensity of global steel production ($kgCO_2/t$ steel)	Low-carbon steel; scrap steel; electric arc furnace; hydrogen-based steel; direct reduced iron; CCS; CCU; decarbonization; blast furnace; industry
Green hydrogen production (Mt)	Green hydrogen; electrolyzer; electrolysis; price
Transport	
Share of kilometers traveled by passenger cars (%)	Modal split; modal share; passenger vehicles; public transit; walk; bicycle; passenger kilometers traveled
Number of kilometers of rapid transit (metro, light-rail, and bus rapid transit) per 1 M inhabitants (in the top 50 emitting cities) (km/1 M inhabitants)	Transport electrification; e-fuels/green hydrogen research; advanced biofuels; modal shift behavior change
Number of kilometers of high-quality bike lanes per 1,000 inhabitants (in the top 50 emitting cities) (km/1,000 inhabitants)	Electric vehicle; zero-emissions vehicle; EV incentives; lithium-ion battery
Carbon intensity of land-based passenger transport (gCO_2/pkm)	Electric vehicle stock; electric vehicle fleet; ICE vehicle phaseout
Share of electric vehicles in light-duty vehicle sales (%)	Zero-emission buses; transit electrification and decarbonization; barriers; BEV and FCEV incentives; enabling infrastructure

Share of electric vehicles in the light-duty vehicle fleet (%)	Zero-emission trucks and commercial vehicles; fleet electrification and decarbonization; barriers; BEV and FCEV incentives; enabling infrastructure
Share of battery electric vehicles and fuel cell electric vehicles in bus sales (%)	Aviation; sustainable aviation fuel; biofuel; jet fuel
Share of battery electric vehicles and fuel cell electric vehicles in medium- and heavy-duty vehicle sales (%)	Shipping; international shipping; zero-emission fuels; drivers; enablers; ammonia; hydrogen; decarbonization
Share of sustainable aviation fuels in global aviation fuel supply (%)	Rapid transit; rapid transit ratio; people near transit; transit access
Share of zero-emission fuels in maritime shipping fuel supply (%)	High-quality bike lanes; bike infrastructure; biking access; people near bikeways
Forests and Land	
Deforestation (Mha/yr)	Reducing deforestation; deforestation; forest loss; protecting forests; forest conservation; nature-based solutions; natural climate solutions
Reforestation (total Mha)	Reforestation; forest landscape restoration; forest restoration; forest conservation; nature-based solutions; natural climate solutions
Peatland degradation (Mha/yr)	Peatland degradation; peatland loss; peatland protection; peatland conservation; mires degradation; mires loss; mires protection; mires conservation; fens degradation; fens loss; fens protection; fens conservation; nature-based solutions; natural climate solutions
Peatland restoration (total Mha)	Peatland restoration; peatland rewetting; peatland conservation; mires restoration; mires rewetting; mires conservation; fens restoration; fens rewetting; fens conservation; nature-based solutions; natural climate solutions
Mangrove loss (ha/yr)	Mangrove loss; mangrove conversion; mangrove deforestation; mangrove protection; mangrove conservation; coastal wetlands loss; coastal wetlands conservation; coastal wetlands protection; nature-based solutions; natural climate solutions
Mangrove restoration (total Mha)	Mangrove restoration; mangrove rehabilitation; mangrove conservation; coastal wetlands restoration; coastal wetlands conservation; nature-based solutions; natural climate solutions
Food and Agriculture	
Agricultural production GHG emissions ($GtCO_2e$/yr)	GHG emissions; agricultural production; climate-smart agriculture
Crop yields (t/ha/yr)	Sustainable crop yield intensification; sustainable increases in crop productivity; low-emission crop yield gains; crop production
Ruminant meat productivity (kg/ha/yr)	Sustainable livestock intensification; sustainable increases in meat productivity; sustainable increases in dairy; livestock production

Share of food production lost (%)	Food loss and waste; reducing GHG emissions from food loss and waste; food wastage
Food waste (kg/capita/yr)	Food loss and waste; reducing GHG emissions from food loss and waste; food wastage
Ruminant meat consumption (kcal/capita/day)	Ruminant meat consumption; shifting diets; sustainable diets; low-emission diets; beef consumption; plant-based diets
Technological Carbon Removal	
Technological carbon removal ($MtCO_2$/yr)	Carbon removal scale-up; carbon removal policies; direct air capture (DAC); bioenergy with carbon capture and storage (BECCS); carbon mineralization
Finance	
Global total climate finance (trillion US$/yr)	Public climate finance; government investment climate; climate investment; scaling climate finance; increase climate finance; private climate finance; private investment climate; mobilize private climate finance; private climate finance mobilization
Global public climate finance (trillion $/yr)	Public climate finance; government investment climate; climate investment; scaling climate finance; increase climate finance
Global private climate finance (trillion $/yr)	Private climate finance; private investment climate; climate investment; scaling climate finance; increase climate finance; mobilize private climate finance; private climate finance mobilization
Share of global emissions under mandatory corporate climate risk disclosure (%)	Corporate climate risks; corporate climate risk disclosure; climate-related financial disclosures; climate risk reporting
Median carbon price in jurisdictions with pricing systems (2015 US$/t CO_2e)	Carbon pricing; carbon tax; emissions pricing; emissions tax; emissions trading schemes; carbon-pricing policy
Total public financing for fossil fuels (trillion $/yr)	Fossil fuel subsidy; fossil fuel subsidy phaseout; end fossil fuel subsidies; fossil fuel production subsides; fossil fuel consumption subsidies; public finance fossil fuel

Note: %/yr = percent per year; BEV = battery electric vehicle; CCS = carbon capture and storage; CCU = carbon capture and utilization; EV = electric vehicle; FCEV = fuel cell electric vehicle; gCO_2/kWh = grams of carbon dioxide per kilowatt-hour; gCO_2/pkm = grams of carbon dioxide per passenger kilometer; GHG = greenhouse gas; $GtCO_2e$/yr = gigatonnes of carbon dioxide equivalent per year; ha/yr = hectares per year; ICE = internal combustion engine; kcal/capita/day = kilocalories per capita per day; $kgCO_2/m^2$ = kilograms of carbon dioxide per square meter; $kgCO_2$/t = kilograms of carbon dioxide per tonne; kg/capita/yr = kilograms per capita per year; kg/ha/yr = kilograms per hectare per year; km = kilometer; M = million; Mha = million hectares; Mha/yr = million hectares per year; Mt = million tonnes; $MtCO_2$/yr = million tonnes of carbon dioxide per year; t/ha/yr = tonnes per hectare per year; US$/tCO2e = US dollars per tonne of carbon dioxide equivalent.

The enabling conditions we selected are by no means exhaustive in terms of illustrating the complex set of factors that can support global efforts to overcome key barriers to transformational change and achieve each target. However, the ones we highlight in each report either have proved effective in catalyzing and sustaining past transitions (e.g., in forest landscape restoration) or, for those transitions that are just beginning (e.g., the transition to green hydrogen), represent a subset of recommended interventions prioritized in the literature.

6. 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.

6.1 Constraints in Aggregating Targets

As described in Section 3, we selected near- and long-term targets for all systems from a variety of underlying sources and methodological approaches. Each of these targets were either

- directly extracted or adapted from modelled pathways that limit global warming to 1.5°C with no or low overshoot; recently published peer-reviewed, system-specific roadmaps that limit temperature rise to 1.5°C; or bottom-up sectoral estimates of mitigation potential; or
- constructed by the authors using top-down or bottom-up methods with 1.5°C-alignment as the priority constraint.

This aggregation technique allowed us to track progress toward targets across diverse systems, drawing on high-quality 1.5°C-aligned modelling and mitigation potential estimations that already exist for each system.

However, a key limitation of this report series is that, 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 low overshoot. Similarly, because the targets explored in this report do not cover every shift needed to transform all global systems, the collective mitigation potential of all targets together may also fall short of limiting global temperature rise to 1.5°C. 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 system.

Finally, because we took the approach of aggregating individual 1.5°C-aligned targets across each system, we cannot robustly account for interaction effects that likely occur among systems. 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 when all targets are aggregated.

6.2 Lack of Prioritization of Shifts or Indicators

Systems change requires a complex web of transformations. This introduces limitations in the way that the findings of the *State of Climate Action* reports can be interpreted.

We did not evaluate which critical shifts and indicators are more important than others in terms of limiting global temperature rise to 1.5°C. Prioritization is difficult in part because these systems are interdependent. For example, an increase in the use of renewable electricity in the power system will enable emissions reductions in other systems like transport and industry, which must shift so that a greater proportion of their energy use is electric.

The critical shifts and indicators in this report are a complicated network of hierarchies, interconnections, and overlaps, so it is impossible to map out and communicate all these relationships. Likewise, we did not fully consider trade-offs among targets when there were multiple pathways to reach a goal or there were goals that conflicted with each other. It is important to note here that some systems have more indicators than others; this simply means that there are more discrete transformations to pay attention to.

With this as context, simply summing the number of shifts that are on or off track cannot provide a complete picture of progress. If two out of five indicators in a particular system are on track to meet their 2030 targets, it does not mean that that system is 40 percent on track. Instead, progress must be evaluated in a more holistic way.

6.3 Inherent Uncertainty of Future Projections

Assessing whether an indicator is on track to reach its targets comes with inherent uncertainties given the possibility of nonlinear change.

Even at the outset, classifying indicators as “exponential change unlikely,” “exponential change likely,” or “exponential change possible” is subjective. While we have criteria to determine which indicators fit into which category, the decisions are not always clear cut and are ultimately finalized by author judgment. The terms “unlikely,” “possible,” and “likely” do not refer to specific likelihood percentiles, as they do in other forums like IPCC reports. Instead, they are categories assigned by the authors based on the nature of the indicator (i.e., whether the indicator is based on technology adoption fully, partially, or not at all).

For "exponential change 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 tracked 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 maximum growth rate of the indicator will be at the steepest part of the S-curve, which is ultimately the most important factor in determining whether an indicator will be able to reach its specified targets. This is why we used author judgment based on a variety of factors to determine whether "exponential change likely" indicators are on track or not. And, as described in Section 5, when we present S-curves in this report, they are only illustrations of potential pathways to reach indicator targets, not predictions. To achieve this illustrative pathway, the technology would have to reach a high maximum growth rate and overcome any obstacles that limit or cause a ceiling to growth.

For the "exponential change possible" indicators, many of these same limitations also apply. Moreover, even for the "exponential unlikely" indicators, there is still some nonquantifiable 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 Section 4. 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.

6.4 Incomplete Consideration of Biodiversity and Equity

Because many of the systems 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 systems.

Additionally, the enabling conditions we identified were specifically chosen to support global efforts to achieve climate mitigation targets; however, if implemented, these measures can also have implications for biodiversity, equity, and human health, among other societal goals, and these impacts will likely vary by context. Although we did not systematically evaluate these effects for each enabling condition selected, we do provide illustrative examples of instances in which these enabling conditions can help or hinder efforts to protect nature, reduce inequality, or improve other sustainable development outcomes.

6.5 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, economic, and financial 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 system that will contribute to transformations in the other systems, 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 goal. These include the following:

- Ensuring good governance at all levels of decision-making 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 key systems—if we are to avoid the worst climate impacts.

6.6 Data Limitations

A lack of high-quality, consistently updated, and publicly available data constrains our assessment of global progress across several systems. For some indicators, data are patchy, and continuous time series of annual data are not available. While the data that are available do provide some indication of progress, they do 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 "exponential change unlikely" and "exponential change 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 systems, and rather focused on those that we could quantitatively monitor. Indicators without quantitative targets and 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, and 2022

Table A1. Comparison of Targets across State of Climate Action Reports

TARGETS AND INDICATORS LEBLING ET AL. (2020) (2020 REPORT)	TARGETS AND INDICATORS BOEHM ET AL. (2021) (2021 REPORT)	TARGETS AND INDICATORS BOEHM ET AL. (2022) (2022 REPORT)
Power		
Reduce the carbon intensity of electricity generation to 50–125 gCO_2/kWh by 2030 and to below zero[a] in 2050.	Target and indicator are the same.	Target and indicator are the same.
Increase the share of renewables in electricity generation to 55–90% by 2030 and to 98–100% by 2050.	Target and indicator are the same.	Increase the share of zero-carbon sources in electricity generation to 74–92% by 2030 and to 98–100% by 2050. We changed our 2022 indicator to measure all "zero-carbon sources" in electricity generation (including nuclear power)—nuclear power was excluded from the definition of "renewables" in 2020 and 2021. This increase in scope accounts for the increased 2030 targets in our 2022 report.
Reduce the share of unabated coal in electricity generation to 0–2.5% by 2030 and to 0% by 2050.	Target and indicator are the same.	Target and indicator are the same.
N/A	N/A	Reduce the share of unabated fossil gas in electricity generation to 17% by 2030 and to 0% by 2050. This target and indicator are new in 2022.
Buildings		
Decrease the energy intensity of residential building operations in key countries and regions by 20–30% by 2030 and by 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 by 15–50% by 2050, relative to 2015.	Target and indicator are the same.	Target and indicator are the same.

Reduce the carbon intensity of operations in select regions by 45–65% in residential buildings and by 65–75% in commercial buildings by 2030, relative to 2015; reach near zero carbon intensity globally by 2050.	Target and indicator are the same.	Target and indicator are the same.
Increase buildings' retrofitting rate to 2.5–3.5% annually by 2030 and to 3.5% annually by 2040; ensure that all buildings are well-insulated and fitted with zero-carbon technologies by 2050.	Target and indicator are the same.	Increase the annual global deep 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.
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.	Target and indicator are the same.	Target and indicator are the same.
Reduce the carbon intensity of global cement production to 360–370 $kgCO_2$/t of cement by 2030 and 55–90 $kgCO_2$/t of cement by 2050, with an aspirational target to achieve 0 $kgCO_2$/t of cement by 2050.	Target and indicator are the same.	Target and indicator are the same.
Reduce the carbon intensity of global steel production to 1,335–1,350 $kgCO_2$/t of steel by 2030 and 0–130 $kgCO_2$/t of steel by 2050.	Target and indicator are the same.	Target and indicator are the same.
N/A	Build and operate 20 low-carbon commercial steel facilities, with 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 system 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	Boost green hydrogen production capacity to 0.23–3.5 Mt (25 GW cumulative electrolyzer capacity) by 2026 and to 500–800 Mt (2,630–20,000 GW cumulative electrolyzer capacity) by 2050.	Increase green hydrogen production to 81 Mt by 2030 and to 320 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).

Transport		
N/A	Reduce the percentage of kilometers traveled by passenger cars to 4-14% below business-as-usual levels by 2030. This target and indicator were new in 2021.	Target and indicator are the same.
N/A	N/A	Double rapid transit infrastructure by 2030, relative to 2021. This target and indicator are new in 2022.
N/A	N/A	Install 2 kilometers of high-quality, safe bike lanes per 1,000 inhabitants in urban areas by 2030. This target and indicator are new in 2022.
Reduce the carbon intensity of land-based passenger transport to 35–60 gCO_2/pkm by 2030 and reach near zero by 2050.	Target and indicator are the same.	Target and indicator are the same.
Increase the sale of EVs as a percentage of all new car sales to 45–100% in 2030, and 95–100% by 2050.	Increase the share of EVs in total annual LDV sales to 75–95% by 2030 and to 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. (2017), and Climate Transparency (2020).	Target and indicator are the same.
Expand the share of EVs to account for 20–40% of the total LDV fleet by 2030 and 85–100% by 2050.	Target and indicator are the same.	Target and indicator are the same.
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.	Boost the share of BEVs and FCEVs to 60% of annual global bus sales by 2030 and to 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.

N/A	Increase the share of BEVs and FCEVs to 8% of global annual MHDV sales by 2025 and to 100% in leading markets by 2040. This target and indicator were new in 2021.	Increase the share of BEVs and FCEVs to 30% of global annual MHDV sales by 2030 and to 99% by 2050. The target for the medium- and heavy-duty vehicles indicator was changed 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.
Raise the share of low-emission fuels in the transport sector to 15% by 2030 and to 70–95% by 2050	Target and indicator are the same.	This target and indicator were removed in 2022.
N/A	Increase sustainable aviation fuels' share of global aviation fuel supply to 10% by 2030 and to 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 to 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.
N/A	Raise zero-emission fuel's share of international shipping fuel to 5% by 2030 and to 100% by 2050. This target and indicator were new in 2021.	Raise the share of zero-emission fuels in maritime shipping fuel supply to 5–17% by 2030 and to 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.

Forests and Land		
Reduce deforestation by 70% by 2030 and by 95% by 2050, relative to 2019.	Reduce the rate of deforestation by 70% by 2030 and by 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 globally to 1.9 Mha/yr by 2030 and to 0.31 Mha/yr by 2050. While our 2030 and 2050 targets still represent a 70% decrease in deforestation 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.
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 remain unchanged from 2020, this year's 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 a total of 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 section, 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).

Cumulative carbon removal to reach 7.5 $GtCO_2$ by 2030 and 75 $GtCO_2$ by 2050 above the 2018 level.	Remove 3.0 $GtCO_2$ annually through reforestation by 2030 and 7.8 $GtCO_2$ annually by 2050. Carbon removal from the reforestation indicator and targets were updated from the 2020 report, using more recent estimates of annual carbon sequestration potential per hectare for forest regrowth from Cook-Patton et al. (2020). This report also translated cumulative targets from Lebling et al. (2020) into annual benchmarks.	To ensure that our indicators are discrete from one another, we removed this indicator and its associated target because it has a direct relationship with our reforestation indicator and target.
N/A	Reduce the degradation and destruction of peatlands by 70% by 2030 and by 95% by 2050, relative to 2018. This target and indicator were new in 2021.	Reduce the annual rate of peatland degradation globally to 0 Mha/yr by 2030, with no additional degradation 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 the avoidable rate of peatland degradation associated with the "maximum additional mitigation potential" estimated in Griscom et al. (2017).
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 a total of 20 Mha of degraded peatlands between 2020 and 2050, reaching 15 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 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 current uncertainties in estimating the amount of peatland restoration that's feasible, particularly at costs of up to $100/$tCO_2$e. We used the bottom-up, cost-effective mitigation potentials from Roe et al. (2021) for most targets in the Forests and Land section, which collectively are in line with pathways that limit global warming to 1.5°C, including the 14 $GtCO_2$e/yr mitigation target established in Roe et al. (2019).

N/A	Reduce the conversion of coastal wetlands by 70% by 2030 and by 95% by 2050, relative to 2018. This target and indicator were new in 2021.	Reduce the annual rate of gross mangrove loss globally to 4,900 ha/yr by 2030. 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 section, 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).
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 a total of 0.24 Mha of mangrove forests 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 section, 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).
Food and Agriculture		
Reduce global GHG emissions from agricultural production by 22% by 2030 and 39% by 2050, relative to 2017.	Target and indicator are the same.	Target and indicator are the same. For this year's report, we removed "drained organic soils" (peatland emissions) from total direct agricultural emissions to avoid double-counting with the Forests and Land section.

Increase crop yields by 13% by 2030 and by 38% by 2050, relative to 2017.	Increase crop yields by 18% by 2030 and by 45% by 2050, relative to 2017. The target was updated from 2020 to be consistent with Searchinger et al. (2021). The indicator remained unchanged.	Target and indicator are the same.
Increase ruminant meat productivity per hectare by 27% by 2030 and 58% by 2050, relative to 2017.	Target and indicator are the same.	Target and indicator are the same.
Reduce food loss and waste by 25% by 2030 and by 50% by 2050, relative to 2017.	Reduce the share of food production lost by 50 percent by 2030, relative to 2016, and maintain these reductions through 2050. In 2021, we separated targets out 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.	Target and indicator are the same.
	Reduce per capita food waste by 50% by 2030 and maintain these reductions through 2050, relative to 2019.	Target and indicator are the same.
Limit increase in ruminant meat consumption to 5% above the 2017 level by 2030 and 6% above the 2017 level by 2050.	Reduce daily per capita ruminant meat consumption to 79 kilocalories by 2030 and to 60 kilocalories by 2050 across high-consuming regions (the Americas, Europe, and Oceania). Target is 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.	Target and indicator are the same.

Technological Carbon Removal		
N/A	Increase annual technological carbon removal rates to 75 $MtCO_2$ /yr by 2030 and to 4,500 $MtCO_2$ / yr by 2050. This target and indicator were new in 2021.	Target and indicator are the same.
Finance		
N/A	Increase total climate finance flows to US$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. This year, we updated these targets to include energy finance needs that were presented in IPCC (2022). We also adjusted all numbers for inflation to 2020 U.S. dollars. The addition of IPCC (2022) values shifted the 2030 value above the value for 2050, which is consistent with IEA 2021b.
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 $1.31–2.61 trillion per year by 2030 and $1.29–2.57 trillion per year by 2050. Last year, we fixed global public climate finance at 25 percent of total global climate finance. This year, we present a range of 25 percent – 50 percent of total global climate finance.
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 $2.61–3.92 trillion per year by 2030 and $2.57–3.86 trillion per year by 2050. Last year, we fixed global private climate finance at 75 percent of total global climate finance. This year, we present a range of 50 percent – 75 percent of total global climate finance.
N/A	Jurisdictions representing three-quarters of global emissions mandate TCFD-aligned climate risk reporting and 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 Task Force on Climate-Related Financial Disclosures' 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 mandatory 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.

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. For Boehm et al. (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 U.S. 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 U.S. dollars. For the 2022 report, we updated the target to use these new prices from the IPCC Sixth Assessment Report.
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.	Target and indicator are the same.

Note: BEV = battery electric vehicle; EV = electric vehicle; FAO = Food and Agriculture Organization of the United Nations; FCEV = fuel cell electric vehicle; gCO_2/kWh = grams of carbon dioxide per kilowatt-hour; gCO_2/pkm = grams of carbon dioxide per passenger kilometer; GHG = greenhouse gas; GtCO_2e/yr = gigatons of carbon dioxide equivalent per year; GW = gigawatt; G7 = Group of Seven; ha/yr = hectares per year; IEA = International Energy Agency; IPCC = Intergovernmental Panel on Climate Change; kcal/capita/day = kilocalories per capita per day; kgCO_2/t = kilograms of carbon dioxide per tonne; km = kilometer; LDV = light-duty vehicle; Mha = million hectares; Mha/yr = million hectares per year; MHDVs = medium- and heavy-duty vehicles; Mt = million tonnes; MtCO_2 = million tonnes of carbon dioxide; N/A = not applicable; SDG = Sustainable Development Goal; TCFD = Task Force on Climate-Related Financial Disclosures; tCO_2 = tonnes of carbon dioxide; tCO_2e = tonnes of carbon dioxide equivalent.

[a]: Achieving below zero-carbon intensity implies biomass power generation with carbon capture and storage. Our targets limit BECCS use to 5 GtCO_2 per year in 2050.

ENDNOTES

1. 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 emissions intensity of the power system declines.

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

3. 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 74–92 percent by 2030 and to 98–100 percent by 2050; the indicator associated with this shift is "share of zero-carbon sources in electricity generation (%)." In general, we round all targets to two significant figures. However, we deviate from this approach in several instances in which rounding loses nuance.

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

5. Because some of our targets call for reductions (e.g., phaseout of coal), the lower bound of a target range is not always the less ambitious bound.

6. Biomass for bioenergy with carbon capture and storage (BECCS) must be sourced in a way that avoids unintended negative impacts. For example, clearing forested land to grow biomass for BECCS would reduce the forest carbon sink, and that lost carbon sequestration would need to be included in net GHG calculations; using agricultural land for BECCS feedstocks could reduce land available for food production and threaten food security; planting large areas of feedstocks could have negative impacts on biodiversity and ecosystems. Use of waste biomass can help avoid these challenges, but lifecycle calculations (including emissions from accessing and transporting biomass) are still needed to ensure there is a net benefit to the climate.

7. 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).

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

9. Bottom-up models are usually based on energy system models that focus on the individual combinations of technologies to satisfy a given demand and can include temporal and spatial dimensions.

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

11. A target range for each country 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.

12. 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).

13. 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.

14. 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.

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

16. 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* does not include 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.

17. 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.

18. 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).

19. 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.

20. 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 Gt CO_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).

21. 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).

22. Future installments of the *State of Climate Action* report will use targets based on the most recent IPCC scenarios filtered for sustainability criteria.

23. 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.

24. Note that we use the term "exponential" instead of "S-curve" for communication purposes because it is a more commonly known term. Not all stages of an S-curve are exponential.

25. While the other Forests and Land indicators used a ten-year trendline, for our deforestation indicator we calculated a seven-year trendline using data from 2015 to 2021 due to temporal inconsistencies in the data before and after 2015 (Weisse and Potapov 2021).

26. 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 previous method for assessing progress in Boehm et al. (2021). Deviations from our standard methods are noted accordingly.

27. Note that on the graphs within the *State of Climate Action* reports, the 5-year trendline (or 10-year trendline) won't necessarily line up perfectly with the most recent year of data if that year is different from the overall linear trend.

28. 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 with 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).

29. 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 we noted acceleration factors higher than 10 as >10. In previous reports, 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.

30. In a change from the 2021 report, we no longer have a "stagnant" category. Indicators that were classified as stagnant in last year's report are now placed in the well off-track or wrong direction category based on the linear trendline.

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ABOUT SYSTEMS CHANGE LAB

Systems Change Lab monitors, learns from, and mobilizes action toward the transformational shifts necessary to protect both people and the planet. Convened by World Resources Institute and Bezos Earth Fund, Systems Change Lab supports the United Nations Climate Change High-Level Champions and works with key partners and funders including Climate Action Tracker, 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.

ABOUT OUR PARTNERS

The United Nations Climate Change High-Level Champions

The United Nations Climate Change High-Level Champions for COP26 and COP27—Mahmoud Mohieldin and Nigel Topping—build on the legacy of their predecessors to engage with nonstate actors and activate the "ambition loop" with national governments. Their work is fundamentally designed to encourage a collaborative shift across all of society towards a decarbonized economy, so that we can all thrive in a healthy, resilient, zero-carbon world. Mahmoud and Nigel have convened a team to help them deliver on this work through flagship campaigns, targeted stakeholder engagement, and leadership in systems transformation.

Climate Action Tracker

The Climate Action Tracker (CAT) is an independent research project that tracks government climate action and measures it against the globally agreed Paris Agreement goal of limiting warming to 1.5˚C. A collaboration of two organizations, Climate Analytics and NewClimate Institute, the CAT has been providing this independent analysis to policymakers since 2009.

Climate Analytics

Climate Analytics is a non-profit institute leading research on climate science and policy in relation to the 1.5ºC limit in the Paris Agreement. It has offices in Germany, the United States, Togo, Australia, Nepal, and Trinidad and Tobago.

NewClimate Institute

NewClimate Institute is a non-profit institute established in 2014. NewClimate Institute supports research and implementation of action against climate change around the globe, covering the topics of international climate negotiations, tracking climate action, climate and development, climate finance, and carbon market mechanisms. NewClimate Institute aims at connecting up-to-date research with real world decision-making processes.

ClimateWorks Foundation

ClimateWorks Foundation is a global platform for philanthropy to innovate and accelerate climate solutions that scale. We deliver global programs and services that equip philanthropy with the knowledge, networks, and solutions to drive climate progress. Since 2008, ClimateWorks Foundation has granted over $1.3 billion to more than 600 grantees in over 50 countries.

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Bezos Earth Fund is Jeff Bezos's $10 billion commitment to fund scientists, activists, NGOs, and other actors that will drive climate and nature solutions. By allocating funds creatively, wisely, and boldly, the Bezos Earth Fund has the potential for transformative influence in this decisive decade. Funds will be fully allocated by 2030—the date by which the United Nations' Sustainable Development Goals must be achieved.

World Resources Institute

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge: Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision: We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.