SCIENCE BASED TARGETS

DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

Partner organizations

CDP · United Nations Global Compact · World Resources Institute · WWF

PATHWAYS TO NET-ZERO

SBTi Technical Summary

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About this technical summary

In July 2021, the SBTi announced plans to increase the minimum ambition of all new science-based targets (SBTs) from well-below 2°C to 1.5°C above pre-industrial levels. Since the SBTi was founded in 2015, near-term SBTs have been central to driving business climate action. As of October 2021, more than 2,000 companies have committed to setting near term targets in-line with SBTi guidance and criteria, with over 1,000 targets validated and two thirds of all approved targets being 1.5°C aligned. The SBTi's Net-Zero Standard, which has been informed by extensive public consultations, lays the groundwork for long-term SBTs that go further to steer the economy to net-zero by 2050.

This technical summary documents the SBTi's approach to determining 1.5ºC-aligned pathways for target-setting based on concepts from the SBTi's *Foundations of Science-based Target Setting* report, meetings with the SBTi's Scientific Advisory Group between 2020 and 2021, and feedback from the Net-Zero Standard stakeholder consultations.

About the SBTi

The Science Based Targets initiative mobilizes companies to set science-based targets and boost their competitive advantage in the transition to the low-carbon economy. It is a collaboration between CDP, the United Nations Global Compact, World Resources Institute (WRI) and the World Wide Fund for Nature (WWF), and one of the We Mean Business Coalition commitments. The initiative defines and promotes best practice in science-based target setting, offers resources and guidance to reduce barriers to adoption, and independently assesses and approves companies' targets.

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Abstract

Pathways used by the SBTi are determined based on a combination of science and principled judgements that aim to steer voluntary climate action and contribute to achieving the aims of the Paris Agreement and the Sustainable Development Goals (SDGs), reaching net-zero carbon dioxide (CO_2) emissions at the global level by 2050 and net-zero greenhouse gas (GHG) emissions in 2050 or later. Except for the forestry, land, and agriculture (FLAG) sectors and in specific cases of bioenergy use, these pathways are used to calculate emissions reduction targets that do not include CO_2 removal. In the SBTi's cross-sector pathway, which covers CO_2, methane (CH_4) and nitrous oxide (N_2O) emissions from energy supply, transport, industry, and buildings, emissions are reduced 42% by 2030 and 90% by 2050 from 2020 levels. Because pathways for each of these sectors are developed under projects with different advisory groups and timelines, sector-specific CO_2 budget ranges are established to ensure that an aggregate CO_2 budget is not exceeded. In the land sector, deforestation from internationally traded commodities—roughly a quarter of overall deforestation—is eliminated before 2030, total emissions from deforestation are eliminated by 2050, and agricultural CH_4 and N_2O emissions are reduced through a combination of strategies. Under these conditions, sector-specific pathways for the FLAG sectors are being developed through the SBTi's FLAG sector project. Overall, these pathways stay within the remaining carbon budget for at least a 50% likelihood of limiting warming to 1.5ºC, under the assumption of about 20-40 GT of cumulative CO_2 removal by 2050. In pathways currently offered by the SBTi, fluorinated gases and CH_4 emissions from landfill are not explicitly modelled due to lack of data but are still required to be covered by company SBTs where relevant.

1. Introduction

Mitigation pathways play a key role in setting science-based targets (SBTs) (**Figure 1**). For near-term SBTs covering a 5-10 year timeframe, mitigation pathways inform the rate of emissions reductions or emissions intensity reductions that are needed. For long-term SBTs with a target year as late as 2050, they inform the overall emissions reduction or convergence intensity that must be reached to be consistent with net-zero at the global or sector level. SBTs are emissions targets that do not include carbon dioxide (CO_2) removal, except for SBTs calculated with dedicated guidance for companies in the forestry, land, and agriculture (FLAG) sectors and in specific cases of bioenergy use.[1]

Pathways used by the SBTi are determined based on a combination of science and principled judgements that aim to steer voluntary climate action and contribute to achieving the aims of the Paris Agreement and the Sustainable Development Goals (SDGs), reaching net-zero CO_2 emissions at the global level by 2050 and net-zero greenhouse gas (GHG) emissions in 2050 or later. In accordance with concepts described in the SBTi's *Foundations of Science-based Target Setting* (2019) and principles introduced in *Foundations for Science-based Net-Zero Target Setting in the Corporate Sector* (2020), this document provides a detailed, up-to-date overview of how the SBTi determines 1.5ºC-aligned pathways for calculating SBTs.

This document focuses on global pathways due to the assumption that many companies set targets covering geographically diverse emissions sources and the justification that the SBTi's Sectoral Decarbonisation Approach, a method used to calculate intensity targets, implicitly accounts for some differences between countries in its target calculation formula (Krabbe et al., 2015). In certain cases, however, these assumptions may be insufficient, and the SBTi is exploring regional or country-level differentiation outside the scope of this document. Methods used to calculate company targets from mitigation pathways are also outside the scope of this document.

[1] The SBTi requires companies to include CO2 emissions from the combustion, processing, and distribution phase of bioenergy and the land-use emissions and removals associated with bioenergy feedstocks in the boundary of targets. In cases where biogenic removals exceed the magnitude of these reported emissions, the excess removals are not counted as progress toward achieving the target.

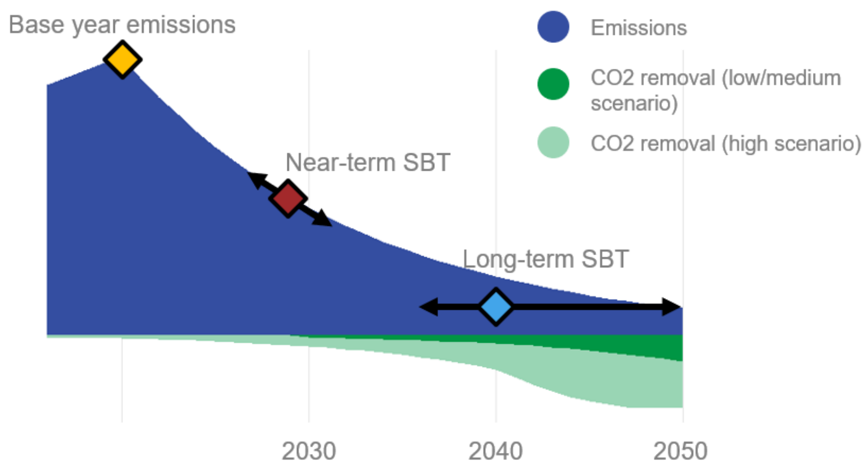

__Figure 1.__ Simplified illustration of how mitigation pathways are used to calculate near-term and long-term SBTs. In this diagram, emissions are based on the mixed sector pathway and CO_2 removal (not covered by most SBTs) is shown for comparison

2. How does the SBTi determine 1.5ºC-aligned pathways?

The SBTi reviews estimates of the remaining emissions budget, top-down mitigation scenarios, and sectoral studies to determine 1.5ºC-aligned pathways at the global and sectoral level. According to the IPCC, the remaining budget to limit global warming to 1.5ºC with a 50% probability is about 500 GT of CO_2 (IPCC, 2021). In top-down scenarios, annual CO_2 emissions are halved by around 2030 and reach net-zero by mid-century. Non-CO_2 GHGs such as nitrous oxide (N_2O) and methane (CH_4), which is a powerful but short-lived climate forcer, are also deeply reduced (IPCC, 2018). By comparison to top-down scenarios, most sectoral studies incorporate a wider range of mitigation options in greater detail but are more limited in temporal scope and range of emissions sources covered. In the climate action arena, where mitigation scenarios are increasingly used as a tool to steer voluntary climate action, it is important for sector pathways not to exceed the global emissions budget in aggregate when used for target-setting. An understanding of the synergies and trade-offs between different climate change mitigation pathways and sustainable development is also used to guide climate action.

In aggregate, 1.5ºC-aligned pathways used by the SBTi stay within the 500 GT carbon budget and reach net-zero CO_2 at the global level by 2050, under the assumption of at least 1-4 GT CO_2 removal per year by 2050. Within this framework, the SBTi developed a cross-sector emissions corridor that covers CO_2, CH_4, and N_2O emissions from energy supply, buildings, industry, and transport based on published studies and expert judgement (see **"4. How was the cross-sector pathway developed?"**). Based on the emissions corridor, the SBTi's cross-sector pathway reduces emissions at least 42% by 2030 and 90% by 2050 from 2020 levels before considering the impact of CO_2 removals. Outside the boundary of the cross-sector emissions corridor, deforestation from internationally traded commodities—roughly a quarter of overall deforestation—is eliminated before 2030, total emissions from deforestation are eliminated by 2050, and agricultural CH_4 and N_2O emissions are reduced through a combination of strategies. These profound emissions reductions across all sectors are complemented by swift action to scale-up CO_2 removal under conditions that resolve social and environmental concerns, while aiming to maximize storage durability (see **"5. What are total cumulative emissions and how much CO_2 removal is needed?"**).

The IEA (2021), *Net-Zero Roadmap*, and Roe et al. (2019), 'Contribution of the land sector to a 1.5ºC world,' studies have undergone rigorous peer review, incorporate detailed sectoral considerations, and utilize recent historical data. These studies are also consistent with delivering social and environmental benefits guided by the SDGs. Having informed the development of the SBTi cross-sector emissions corridor, these studies also define the upper bound of sectoral carbon budgets that must not be exceeded by target-setting pathways (see **"6. How is the carbon budget allocated to sectors?"**). Sector-specific pathways meeting this condition are typically developed under the SBTi's sector development process, which fosters stakeholder participation through convening an expert advisory group and inviting feedback through public consultations. Through the SBTi's sector development process, a wide range of studies are drawn from, and available pathways are improved upon with gap-filling, down-scaling, and other adjustments. The SBTi Research and Development Team may also incorporate new pathways without completing a full sector development process. Pathways are available or in development for a range of sectors (see **"3. Overview of pathways and which companies should use them"**), including those with significant emissions from forestry, land-use and agriculture (FLAG).

3. Overview of pathways and which companies should use them

The SBTi offers a cross-sector pathway and sector-specific pathways for SBT-setting. For most companies, the recommendation is to set absolute targets using the cross-sector pathway.

Using the cross-sector pathway, many companies set near-term SBTs that reduce emissions at a linear annual rate of 4.2% (e.g., 50% reduction from 2018 levels by 2030); however, some sector-specific pathways vary significantly from the cross-sector pathway in the near-term. More information on the 2020-2030 ambition of the cross-sector pathway, which covers a subset of global CO_2, CH_4, and N_2O emissions, is included in the section **"4. How was the cross-sector pathway developed?"** and "**S3. How do mitigation pathways compare to halving emissions by 2030?"**

In the long-term (e.g., 2050), emissions in the cross-sector pathway are reduced at least 90% and most sectors reduce CO_2 emissions 90% or more from 2020 levels. Consequently, for many companies, long-term SBTs will be equivalent to at least a 90% absolute reduction across scopes regardless of whether the cross-sector pathway or sector-specific pathways are used.

Sector-specific pathways are available or in development for energy supply sectors, transport sectors, industry sectors including cement and steel, the buildings sector, and sectors with significant FLAG emissions. Companies in sectors where emissions are reduced significantly faster than the global average, like power generation, are required to use the appropriate sector-specific pathway to set near-term SBTs. Additionally, companies in the FLAG sectors will be required to set SBTs using FLAG sector-specific pathways after the completion of sector guidance. Companies in all other sectors may use either the cross-sector pathway or sector-specific pathways to cover relevant emissions. The cross-sector pathway and pathways for energy supply, transport, industry, and buildings are used to calculate emissions reduction targets that do not include CO_2 removal. Pathways for the FLAG sectors may cover both emissions and removals.

4. How was the cross-sector pathway developed?

Companies in the power generation sector and FLAG sectors are required to set SBTs using sector-specific pathways (effective for FLAG sectors after the finalization of SBTi and GHG Protocol guidance). For all other companies, the cross-sector pathway (**Figure 2a**) is a one-size-fits-all pathway for SBTs. The cross-sector pathway covers all Kyoto Protocol GHG emissions except FLAG emissions, which are covered by separate FLAG sector pathways, and emissions from landfill waste and fluorinated gases, which are excluded from our calculation due to lack of data. Consequently, the cross-sector pathway reflects the main GHG emissions (CO_2, CH_4, and N_2O) from energy supply, transport, industry, and buildings. Where relevant, companies with emissions from landfill waste and fluorinated gases must still cover these emissions with SBTs calculated using the cross-sector pathway or a sector-specific pathway.

To develop the cross-sector pathway, we build on the approach described in SBTi (2019), *Foundations of Science-based Target Setting*, where top-down mitigation scenarios are filtered by probabilistic temperature outcome, emissions budget between the most recent year and net-zero, year of peak emissions, and qualitative criteria to construct a 1.5ºC-aligned "scenario envelope." The updated approach incorporates newer estimates of the remaining emissions budget and uses a more comprehensive scientific assessment, instead of filtering only top-down scenarios, to define the cross-sector GHG emissions corridor and pathway. Additionally, the boundary of the corridor has been updated to cover the main GHG emissions from energy supply, transport, industry, and buildings, as described above, instead of all GHG emissions. Lastly, and perhaps most importantly, the updated approach is also guided by consideration of the synergies and trade-offs between different mitigation pathways and SDGs, in-line with Guiding Principle 2 ('Transitioning to net-zero in line with global climate and sustainability goals') in SBTi (2020), *Foundations for Science-based Net-Zero Target Setting in the Corporate Sector.*

First, we disaggregated the remaining CO_2 budget into emissions corridors for energy and industrial process CO_2 emissions (herein referred to as the "cross-sector CO_2 emissions corridor," **Figure 2b**), deforestation and land-use change CO_2 emissions, and CO_2 removal based on a comparative assessment of top-down mitigation scenarios and sectoral studies, and principled judgements. Among other studies (see **"S1. Comparative analysis details"**), our assessment has included the following studies that include full coverage of energy and industrial processes CO_2 emissions:

- The interquartile range of 1.5ºC low/no overshoot scenarios from IPCC (2018), *Special Report on Global Warming of 1.5ºC* (SR15);
- P1 and P3, which were selected by the authors of SR15 as illustrative archetype scenarios used in the report;
- One Earth Climate Model (OECM), which is a model by the Institute for Sustainable Futures at University of Technology Sydney (UTS) with scenarios that reach net-zero by 2050 without overshooting 1.5ºC and with minimal reliance on CO_2 removal (Teske et al. 2020);
- NZE, which is the main scenario from the IEA (2021), *Net-Zero Roadmap*, and;
- Beyond 2°C Scenario (B2DS), which is a scenario from the IEA (2017), *Energy Technology Perspectives 2017*, that has been used by the SBTi to define well-below 2C SBTs since 2019.

In 2030, the cross-sector CO_2 emissions corridor is similar to the interquartile range of 1.5ºC low/no overshoot scenarios with an upper range similar to IEA B2DS, NZE, and P3; and a lower range similar to P1. In 2050, the corridor is similar to NZE, OECM, and P1, but considerably lower than the interquartile range of 1.5ºC low/no overshoot scenarios due to conservatively low assumptions of CO_2 removal availability (see **"5. What are total cumulative emissions and how much CO_2 removal is needed?"**) Studies have shown that many top-down scenarios use CO_2 removal at rates that are considered infeasible, which suggests that larger emissions reductions are needed to reach net-zero by 2050 than suggested by those scenarios (Vaughan & Gough, 2016; Warszawski et al., 2021). Additionally, the IPCC states that "pathways that feature low energy demand," like P1, "show the most pronounced synergies and the lowest number of trade-offs with respect to sustainable development and SDGs (very high confidence)" (Roy et al., 2018).

Next, to complete the cross-sector emissions corridor, energy-related N_2O emissions from the mean of 1.5ºC low/no overshoot scenarios and CH_4 emissions from NZE were added using 100-year global warming potentials from the IPCC Fifth Assessment Report (2014). Energy-related N_2O emissions are covered by top-down scenarios but are not covered by any of the sectoral studies between 2020 and 2050 in our review. Because these emissions are mainly caused by fossil fuel combustion and can be reduced in much the same way as energy-related CO_2 emissions, we judge energy-related N_2O emissions from the mean of 1.5ºC low/no overshoot scenarios to be consistent with the cross-sector emissions corridor in 2030 and a likely overestimate in 2050. (The magnitude of energy-related N_2O emissions in 2050—less than 0.25 Gt CO_2e—is small enough to ignore this likely overestimate.) By comparison to N_2O, a much larger share of CH_4 emissions occurs upstream of fossil fuel combustion. Thus, when combined with efforts to reduce fossil fuel use, interventions that specifically target upstream fossil fuel extraction and transportation can reduce energy-related CH_4 faster than energy-related CO_2 or N_2O in top-down scenarios. We judge NZE, which shows a 75% reduction in methane from fossil fuels between 2020-2030, to be consistent with the level of mitigation needed to limit warming to 1.5°C in the cross-sector emissions corridor.

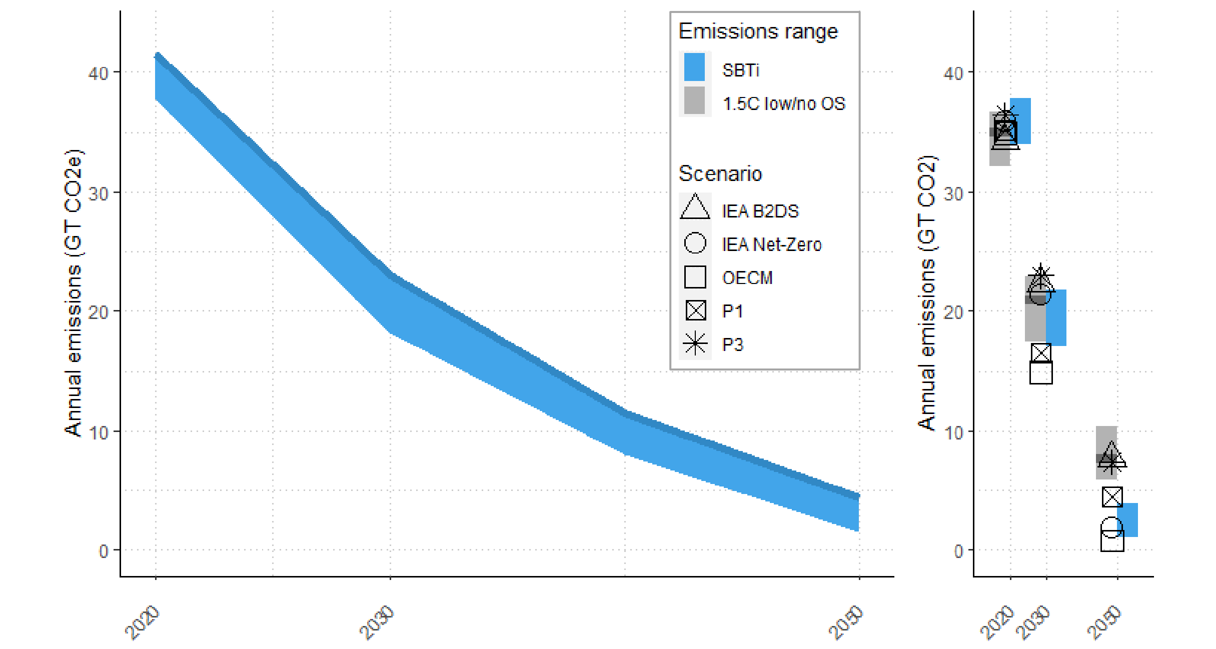

Figure 2. *SBTi emissions corridors (light blue) for **a.** cross-sector GHG emissions and **b.** CO_2 only with comparison to the median (dark grey line) and interquartile range of 1.5ºC low/no overshoot scenarios (grey bars) and individual scenarios (black icons). GHG emissions from forestry, land-use, and agriculture; landfill waste; and fluorinated gases are excluded from both corridors. The SBTi's cross-sector emissions pathway (dark blue line), used to define the minimum ambition of many SBTs, is based on the upper bound of the cross-sector GHG emissions corridor*

5. What are total cumulative emissions and how much CO_2 removal is needed?

Between 2020 and 2050, the energy and industrial processes CO_2 emissions corridor results in cumulative CO_2 emissions of 450-480 GT CO_2. This spread results mainly from different mitigation choices across pathways within the corridor. Deforestation from internationally traded commodities—roughly a quarter of overall deforestation—is eliminated by 2030 and total emissions from deforestation are eliminated by 2050, resulting in cumulative CO_2 emissions of around 55 +/- 15 GT CO_2. This uncertainty results from the uncertainty in baseline annual deforestation-related emissions, which we calculate to be 5.7 GT CO_2 (+/- 2.2 GT CO_2) based on land-use change (LUC) CO_2 emissions in 2019 multiplied by the estimated proportion of LUC emissions from deforestation (Friedlingstein et al., 2020; Houghton & Nassikas, 2017). Under the assumption of about 20-40 GT of cumulative CO_2 removal by 2050—challenging but within the range of Roe et al. (2019) and NZE before 2050—the 1.5ºC budget is conserved without overshoot.

SBTi emissions corridors presume that transformative political steps will be taken to rapidly reduce global emissions. We believe that COP26 is an unmissable opportunity for governments to step up action by committing to achieve economy-wide net-zero emissions as soon as possible, strengthening their NDCs and 2030 targets, and laying out policies to achieve these targets. However, if more forceful policies fail to materialize, the 1.5ºC target could quickly fall out of reach without increasingly speculative and potentially harmful amounts of CO_2 removal (Dooley & Kartha, 2018; Lade et al., 2020; Strefler et al., 2018). As a risk avoidance measure, many experts suggest that steps should be taken to advance rapid emissions reductions (e.g., near and long-term SBTs) *and* prepare for scenarios where much larger, speculative amounts of CO_2 removal are needed (Fuss et al., 2018; Lin, 2019).

6. How is the carbon budget allocated to sectors?

NZE and Roe et al. (2019) are used to derive carbon budget allocation across sectors for the maximum remaining budget of 500 GT CO_2. In other words, these studies define the upper bound of sectoral carbon budgets that must not be exceeded by target-setting pathways. Under the FLAG sector project, sector-specific pathways meeting this condition are being developed based on a combination of Roe et al. (2019) and updated commodity-specific pathways from Smith et al. (2016), 'Science based GHG Emissions targets for agriculture and forestry commodities.' These pathways will cover CH_4 and N_2O emissions, as well as CO_2 emissions from deforestation, land-use, and land-use change. For the energy supply, transport, industry, and buildings sectors, sector-specific pathways are being developed under projects with different advisory groups and timelines. For these sectors, we have estimated a lower bound on sectoral carbon budgets based on a review of relevant studies, in addition to defining an upper bound from NZE. Budget ranges for these sectors (third column of **Table 1**) are intended to establish a clear set of guardrails for new sector-based research, roadmaps, and collaborations across the climate action landscape. Using these budget ranges, we also show each sector's share of the 2020-2050 energy and industrial processes CO_2 budget relative to its share in 2019 (fourth column of **Table 1**). This normalised metric makes it easier to assess the relative size of each sector's remaining CO_2 budget and to compare sectoral carbon budget allocation across different scenarios (**Figure 3**). Outside the scope of this document, sector-by-sector comparisons that focus on emissions intensity and sector-specific mitigation levers are also being conducted to inform the usage and development of sector-specific pathways.

Sector	2019 CO_2 emissions (GT CO_2)	2020-2050 CO_2 budget used by the SBTi to assess 1.5°C pathways (GT CO_2)	Share of 2020-2050 energy and industrial processes CO_2 budget relative to sector's share in 2019 (%)
Energy supply	**15.3**	**115-146**	**59-75**
Electricity and heat	13.8	102-133	58-76
Transport	**8.3**	**100-129**	**95-123**
Road transport	6.1	73-91	92-117
Maritime transport	0.9	12-16	101-143
Aviation	1.0	15-19	110-147
Industry	**8.9**	**134-153**	**116-135**
Iron and steel	2.5	20-40	62-126
Cement	2.5	35-41	109-131
Chemicals	1.3	13-26	73-153
Buildings	**3.0**	**30-41**	**75-107**
Residential buildings	2.0	20-30	74-117
Service buildings	1.0	10-11	76-89
Cross-sector total (CO_2 only)	**35.5**	**450-480**	**-**

Table 1. *2020-2050 CO_2 emissions budgets used by the SBTi for the energy supply, transportation, industry, and buildings sectors. Budgets cover direct emissions only (i.e., scope 1) but when setting SBTs, companies must set targets that also cover indirect emissions (i.e., scopes 2 and 3). Due to expected mitigation trade-offs across sectors, the lower bound of "Total" CO_2 emissions is higher than aggregating the lower bound of all sectors. 2019 CO_2 emissions data are sourced from IEA (2021). Sector-specific pathways in-line with the budget ranges in this table do not automatically qualify for use by the SBTi.*

All sectors require tremendous near-term and long-term mitigation efforts to comply with SBTi budgets; yet each sector faces unique mitigation challenges, demands, and opportunities that affect the size of its remaining budget. SBTi budget variance can be large for sectors like aviation, iron & steel, and chemicals where both projected sectoral growth under a business-as-usual scenario and mitigation potential from reduced demand are high. In the buildings sector, different energy demand pathways can also lead to budget variance. Many scenarios that purposefully incorporate demand-side mitigation require "massive policy support and investment" (IEA 2021), but the amount of demand-side mitigation still varies substantially across scenarios, reflecting different modeling philosophies and societal views. One such view would be that unessential energy-intensive business models and services, however defined, should be immediately regulated and phased-out; while a contrasting view would be that doing so is politically infeasible or undesirable. The upper bound of SBTi sector budget ranges, NZE, seems to fall somewhere in the middle.

In addition to reflecting demand-side factors, SBTi budget variance can also reflect energy supply-side differences like primary energy mix, fuel cost assumptions, nuclear availability, and constraints on bioenergy.

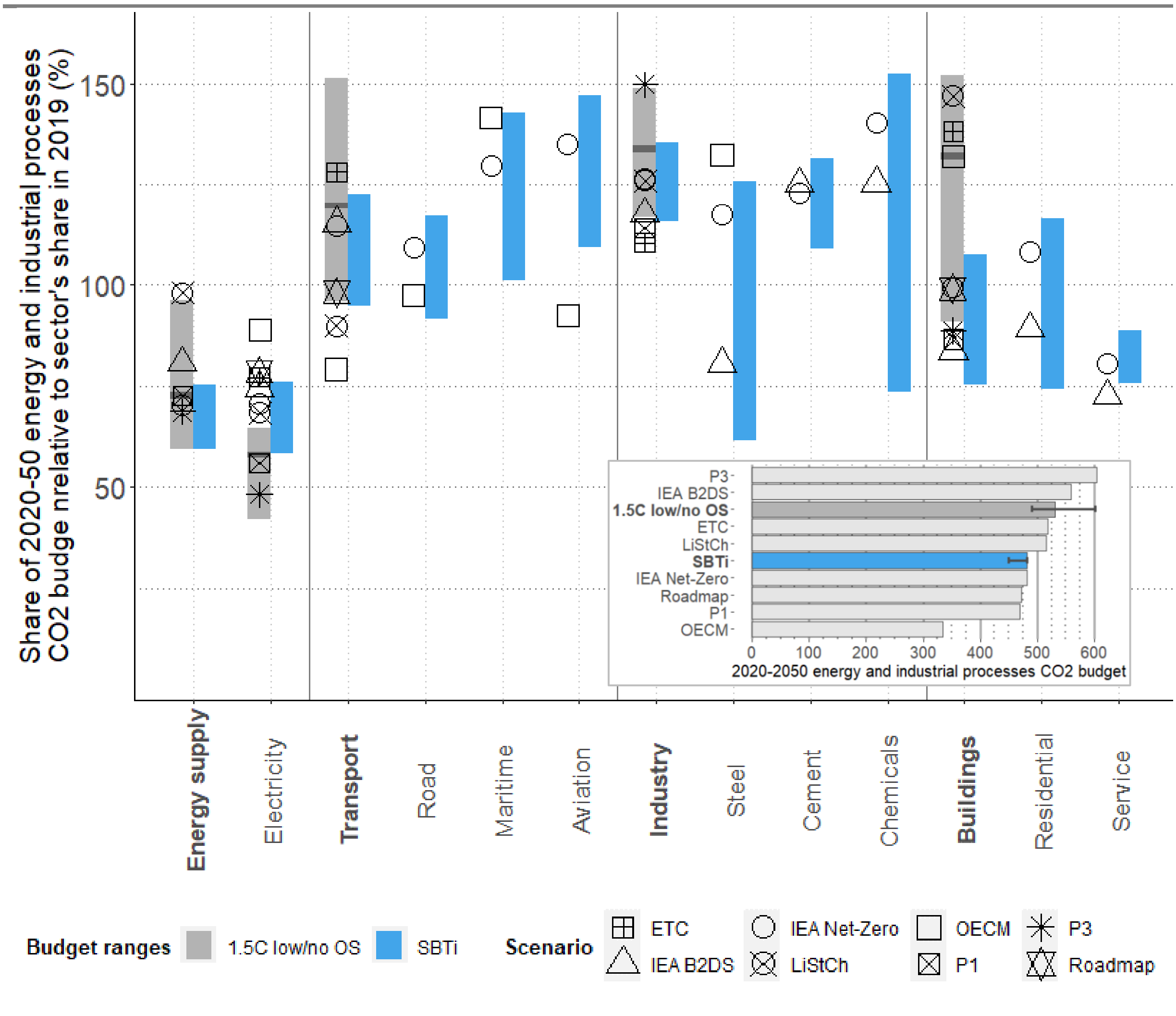

Figure 3. ***a.*** *Share of 2020-2050 energy and industrial processes CO_2 budget by sector relative to share of energy and industrial processes in 2019 for SBTi 1.5°C pathways (blue bars) with comparison to the median (dark grey line) and interquartile range of 1.5ºC low/no overshoot scenarios (grey bars) and individual scenarios (black icons).* ***b.*** *Size of 2020-2050 energy and industrial processes CO_2 budget by scenario. For 1.5°C low/no OS scenarios, median is shown by the grey bar and interquartile range is shown by the error bar. For SBTi, the upper budget range is shown by the blue bar and the full budget range shown by the error bar. Sector budgets cover direct CO_2 emissions from fossil fuel combustion and industrial processes*

Appendix 1. Comparative analysis details

Comparative analysis design

The SBTi conducted an in-depth comparative analysis to inform its 1.5°C-aligned pathway approach. Our comparative analysis differentiates between top-down mitigation scenarios, which are derived from integrated assessment models (IAMs), and hybrid scenarios, which are intended to achieve goals in a specific way, calculated with sub-global models, back-casting, and/or detailed sector roadmaps. (In this technical summary, the terms "hybrid scenario" and "sectoral study" are used interchangeably.) The results of our analysis are focused on four top-down scenarios and five hybrid scenarios. Details on each scenario are included in the section below.

Our comparison focused on annual emissions in 2020, 2030, and 2050, as well as 2020-2050 cumulative emissions, in absolute and normalized terms across different sectors in all nine scenarios.

Because these nine scenarios are associated with distinct narratives, assumptions, and modeling approaches, we did not aim to quantify trends or correlations across the scenarios. Rather, a comparison of data from the scenarios was used holistically and iteratively to inform the upper and lower bounds of nested emissions corridors and emissions budgets for different sectors. Complete data from our comparative analysis will be published as an accompaniment to this Technical Summary.

Pathway descriptions

Top-down scenarios, which are derived from global IAMs

- 1.5ºC low/no overshoot scenarios from IPCC (2018), *Special Report on Global Warming of 1.5ºC* (SR15), are top-down scenarios with a 50% probability of limiting end-of-century warming to 1.5ºC with less than 0.1C overshoot (Rogelj, Shindell, et al., 2018). For each scenario variable assessed, the interquartile range is calculated using the same methodology as SR15 to exclude scenario duplicates that would bias ranges towards a single study except using release 2.0 of the dataset (Huppman et al., 2019).

- P1 and P3 were selected by the authors of SR15 as two of the four illustrative archetype scenarios used in the report (Rogelj, Shindell, et al., 2018). P3 is a scenario resulting in peak warming of 1.61C in 2051 that uses "middle-of-the-road" (SSP2) socioeconomic assumptions (Rogelj, Popp, et al., 2018). P1 is a scenario resulting in peak warming of 1.53C in 2048 that uses the same SSP2 socioeconomic assumptions as P3 except social, business and technological innovations result in lower energy demand (Grubler et al., 2018). P1 and P3 are top-down scenarios that were produced using different variants of the MESSAGE-GLOBIAM IAM, which includes a coupled energy system and land-use model. P1 and P3 are both included in the Warszawski et al. (2019) filtered scenario corridor, which aims to differentiate between mitigation scenarios that rely on "speculative" levels of mitigation from one or more levers from those that face a lesser challenge to feasibility.

- LifeStyleChange (LiStCh) is a scenario from van Vuuren et al. (2018), "Alternative pathways to the 1.5 °C target reduce the need for negative emission technologies," that explores the impact of lifestyle change as a prioritized mitigation lever to reduce the need for CO_2 removal to meet the Paris climate target. In addition to standard mitigation options that are explored by top-down models, LiStCh includes less meat-intensive diet (conforming to health recommendations), less CO_2-intensive transport modes (following the current modal split in Japan), less intensive use of heating and cooling (change of 1C in heating and cooling reference levels) and a reduction in the use of several domestic appliances. LiStCh was produced using the IMAGE-3 model. Like P1 and P3, it is included in the Warszawski et al. (2019) filtered scenario corridor.

- One Earth Climate Model (OECM) is a model by the Institute for Sustainable Futures at University of Technology Sydney (UTS) with scenarios that reach net-zero by 2050 without overshooting 1.5ºC and with minimal reliance on CO_2 removal (Teske et al., 2020). As such, OECM demonstrates more aggressive gross emissions reductions than scenarios where more CO_2 removal is used—especially BECCS. Updated sector pathways from OECM commissioned by the Net-Zero Asset Owners Alliance were published in 2020 following several rounds of review and feedback from groups including the SBTi. New sector pathways are under development. Both completed and draft pathways are included in this comparative assessment.

Hybrid scenarios, which are intended to achieve a goal in a specific way that are calculated with sub-global models, backcasting and/or detailed sector roadmaps

- NZE is the main scenario from the IEA (2021), *Net-Zero Roadmap*. It charts a pathway for the world to achieve net-zero CO_2 emissions from energy and industrial processes by 2050 – consistent with around a 50% chance of limiting long-term warming to 1.5ºC with no overshoot. It also aims to ensure that energy-related and industrial process CO_2 emissions to 2030 and aligned with 1.5ºC scenarios with no or low overshoot. Cumulative net CO_2 emissions from energy and industrial processes in this scenario are limited to about 460 GT CO_2 between 2020 and 2050. Methane emissions from fossil fuel extraction and transport are also deeply reduced. NZE aims to deliver sustainable development including universal energy access by 2030, major reductions in air pollution and pollution-related deaths, and job creation.

  Mitigation scenarios produced by the IEA incorporate top-down modelling and information from bottom-up sectoral studies. While they are more limited in scope than top-down IPCC scenarios, they include a much greater degree of technological and geographic resolution.

- The “Beyond 2°C Scenario” (B2DS) is a scenario from the IEA (2017), *Energy Technology Perspectives 2017.* It was described by the IEA as a scenario where “technology improvements and deployment are pushed to their maximum practicable limits across the energy system in order to achieve net-zero emissions by 2060 and to stay net zero or below thereafter.” Cumulative net CO_2 emissions from energy and industrial processes in this scenario are limited to about 750 GT CO_2 between 2015 and 2100 (and about 530 GT CO_2 between 2020 and 2050).

  Sector pathways from B2DS have been used by the SBTi to define well-below 2C SBTs since 2018. By comparison to B2DS, sector pathways in NZE reflect (1) the influence of a smaller CO_2 budget on mitigation, and (2) the opposing influence of delayed action, which may affect how mitigation is balanced across sectors and time.

- Exponential Roadmap is a scenario that explores how the “carbon law,” which aims to reduce CO_2 emissions by half each decade (Rockström et al., 2017), can be implemented across all sectors of the global economy to limit climate change to 1.5°C above pre-industrial levels with a specific focus on the decade leading up to 2030 (Falk et al., 2019). The Exponential Roadmap highlights 36 solutions and includes clear action steps for businesses, cities, and policymakers.

- Roe et al. (2019) is a review study that aggregated top down IAM models (from the IAM and SSP databases) with bottom up studies such as Griscom et al. (2017) to assess mitigation in the land sector for a 1.5 C future. The study includes a “roadmap” for the land sector divided into seven main mitigation wedges. The roadmap seeks to align with other international commitments and policies, in addition to the Paris Agreement, including the Sustainable Development Goals (SDG) 2, 6, 12, 14 and 15, the New York Declaration on Forests (NYDF) goals 1 and 5, and the United Nations Convention on Biological Diversity (UNCBD) Aichi Targets 5 and 15.

- The Energy Transitions Commission (ETC) is a global coalition of leaders from across the energy landscape committed to achieving net-zero emissions by mid-century, in line with limiting global warming to well below 2°C and ideally to 1.5°C (Energy Transitions Commission, 2021b). ETC produces transition roadmaps, as well as recommendations and tools to inform the implementation of those roadmaps, using detailed bottom-up analyses. For analyses in this report, we use updated data from “Scenario B,” which reflects mitigation from energy efficiency, supply-side decarbonisation, and material, obtained directly from ETC (personal communication, October 26, 2021) based on ETC (Energy Transitions Commission, 2021a), *Reaching climate objectives: The role of carbon dioxide removals (ETC Consultation Paper).*

Appendix 2. Planned updates after the publication of the IPCC 6th Assessment Report: Mitigation of Climate Change

After the release of the IPCC *6th Assessment Report: Mitigation of Climate Change* in March 2022, we will assess whether updates are needed to the cross-sector pathway or sector emissions budgets used by the SBTi to assess 1.5°C-alignment. These assessments will include an evaluation of non-CO2 GHGs and mitigation assumptions for the FLAG sector. Changes to the cross-sector pathway, if needed, will be introduced in early 2023. If changes are needed to 1.5°C-aligned sector emissions budgets used by the SBTi, new budgets will become effective for sector projects in 2023. In that case, 1.5°C-aligned sector pathways developed before the end of 2022 will continue to be used by the SBTi unless replacement or retirement is deemed necessary by the SBTi. Sector-specific projects may also use AR6 to conduct analyses on non-CO2 GHG mitigation under the scope of each project.

Appendix 3. How do pathways used by the SBTi compare to halving emissions by 2030?

Section C1 from the IPCC SR15 Summary for Policymakers is frequently cited to highlight the importance of near-term emissions reductions. It states “In model pathways with no or limited overshoot of 1.5°C, global net anthropogenic CO_2 emissions decline by about 45% from 2010 levels by 2030 (40–60% interquartile range), reaching net zero around 2050 (2045–2055 interquartile range)” (IPCC, 2018).

In aggregate, SBTi pathways reduce CO_2 emissions at least 40% from 2010 levels and 45% from 2019 levels by 2030. By comparison to C1, the 5% difference is mainly caused by how top-down models calculate AFOLU CO_2 emissions, which is inconsistent with GHG emissions inventory accounting methods used by companies. To a lesser extent, it also reflects differences in the mix of mitigation options included in boundary of SBTi pathways; for example, bioenergy carbon capture and storage (BECCS) is not included in the boundary of SBTi pathways and SBTi pathways often include a greater role for demand-side mitigation options than top-down pathways.

In SBTi pathways, different sectors reduce absolute emissions by different amounts, which are compared to model pathways with no or limited overshoot of 1.5°C below:

- Gross CO_2 emissions from energy, transport, industry, and buildings, as covered by the cross-sector pathway and sector-specific pathways used by the SBTi, are reduced by an amount consistent with model pathways with no or limited overshoot of 1.5°C. In pathways used by the SBTi, these emissions are reduced at least 40% from 2019 levels by 2030. In model pathways with no or limited overshoot of 1.5°C, these emissions are reduced an average of 40% (33%-50% interquartile range) from 2019 levels by 2030;

- FLAG sector pathways used by the SBTi are consistent with Roe et al., (2019), which is roughly equivalent to the level of mitigation in model pathways with no or limited overshoot of 1.5°C in 2030. Using the FLAG sector pathway, deforestation in company value chains is eliminated before 2030. Land-sector mitigation covering a large share of avoided deforestation and nature restoration is also needed outside of company value chains.

  In model pathways with no or limited overshoot of 1.5°C, net AFOLU CO_2 emissions are reduced an average of 100% (90-120% interquartile range) from 2019 levels by 2030. Top-down models calculate AFOLU CO_2 emissions differently from GHG inventory accounting methods, which allocate deforestation emissions over 20 years following a deforestation event, making a 1:1 comparison of the emissions reduction in SBTi pathways and top-down pathways inaccurate (IPCC, 2003; World Resources Institute and WBCSD, 2014);

- Model pathways with no or limited overshoot of 1.5°C also include an average of 0.4 GT CO_2/year of bioenergy carbon capture and storage (BECCS) (0-1 interquartile range) in 2030. No pathways currently used by the SBTi include CO_2 removal with geologic storage in the pathway boundary.

Halving gross CO_2 emissions every decade is also supported by the “carbon law,” which describes a scenario-informed roadmap to achieve the goals of the Paris Agreement (Rockström et al., 2017). As a planning instrument intended to drive institutional alignment and mitigation breakthroughs, the carbon law is a heuristic tool that can be used to steer mitigation for any sector.

Using the mixed pathway, companies reduce GHG emissions (including non-CO_2 GHGs) at a linear annual rate of 4.2% between the base year and target year. Differences in the choice of company base year, target year, and level of emissions reduction already achieved affect each company target uniquely; but in many cases, targets are consistent with halving emissions over the course of a decade, and in all cases, targets calculated using the mixed sector pathway reduce emissions at a rate that is close to the carbon law.

With the exception of cement, all 1.5°C-aligned sector pathway that are currently available (power) or planned for immediate release (buildings) reduce scope 1+2 emissions more than 50% by 2030. Other 1.5°C-aligned sector pathways will be reviewed on a sector-by-sector basis.

Appendix 4. Methodological notes on Figure 2

Several adjustments were made to scenario data to improve comparability

<u>All scenarios</u>

- Scenario variables from a single scenario were in some cases added or subtracted to derive new variables not included in reported data. For example, gross energy and industrial process CO_2 emissions was calculated for NZE based on the sum of net CO_2 emissions and CO_2 removal reported in scenario data

- For scenarios that incorporate actual emissions data for historic years, 2019 data is used in place of 2020

- Except where otherwise noted, 2020-2050 cumulative budgets were calculated by interpolating emissions data over 5-year or 10-year timesteps based on data availbility

OECM

- Where sector emissions in 2019 varied more than 20% from NZE values, cumulative CO_2 emissions for the sector were calculated based on a pathway normalized to 2019 base year data from NZE

Exponential Roadmap

- To calculate budgets, data for 2030 were compiled from Falk et al. (2020) and data for 2040 and 2050 were estimated by applying the “carbon law” – a key principle underlying the report that specifies for all sectors to halve emissions every 10 years

1.5°C low/no overshoot scenarios, P1, P3, and LiStCh

- Because direct process emissions from industry are not available in publicly available data for these scenarios, process emissions were added based on the mean of a no-CCS scenario and a high-CCS scenario. The no-CCS scenario assumes that process emissions from industry are twice as high as process emissions from cement (2020-2050) in the OECM pathway based on the proportion of industry direct emissions from cement calculated in AR5 (Fischedick et al., 2014). The high-CCS scenario is identical to the no-CCS scenario until 2035 and then reduces process emissions 80% at a linear rate between 2035 and 2050.

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