SCIENCE BASED TARGETS
DRIVING AMBITIOUS CORPORATE CLIMATE ACTION

CORPORATE NET-ZERO STANDARD V2.0

Cross-Sector Pathway Documentation (Revision)

Version 2.2

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ABOUT SBTi

The Science Based Targets initiative (SBTi) is a corporate climate action organization that enables companies and financial institutions worldwide to play their part in combating the climate crisis.

We develop standards, tools, and guidance which allow companies to set greenhouse gas (GHG) emissions reductions targets in line with what is needed to keep global heating below catastrophic levels and reach Net-Zero by 2050 at latest.

The SBTi is incorporated as a UK charity, with a subsidiary SBTi Services Limited, which hosts our target validation services. Partner organizations who facilitated SBTi's growth and development are CDP, the United Nations Global Compact, the We Mean Business Coalition, the World Resources Institute (WRI), and the World Wide Fund for Nature (WWF).

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This Standard is issued by the Science Based Targets initiative (SBTi). Any feedback on SBTi Standards can be submitted to info@sciencebasedtargets.org for consideration of the SBTi.

[1] The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body for assessing the science related to climate change.

DOCUMENT HISTORY

Version	Release date	Updates on earlier version
1.0 Pathways to Net-Zero	October 2021	
2.0 Cross-sector pathway documentation	Draft shared internally with SBTi May 31 2024	• Updated principles of scenario selection • Updated set of scenarios included in cross-sector pathway • Updated quantitative synthesis methods used to derive cross-sector pathway from constituent scenarios • Updated benchmarks for target-setting using the Absolute Contraction Approach
2.1 Cross-sector pathway documentation	November 2024	• Disaggregation of residual emissions at the sector level
2.2 Cross-sector pathway documentation	March 2025	• Updates based on Technical Council feedback

ABSTRACT

This revised Technical Foundations document presents an update to the cross-sector pathway, which is used by the majority of companies setting targets validated by SBTi. The cross-sector pathway is derived from a selection of scenarios from the sixth assessment report (AR6) of the Intergovernmental Panel on Climate Change (IPCC), combined with a key scenario from gray literature. Six updated principles guide the selection of scenarios to be included; these principles address ambition, responsibility, scientific rigor, actionability, robustness, and transparency. The individual scenarios that were included in the cross-sector pathway illustrate a range of mitigation pathways that limit the global temperature rise to 1.5°C above pre-industrial levels. To improve the consistency of the cross-sector pathway with the most recent estimated emissions, we harmonized fossil CO_2 emissions in the filtered scenarios with realized emissions in the year 2022. A quantitative synthesis of the selected scenarios yields a pathway that describes a 41% reduction in gross fossil CO_2 emissions from energy and industrial processes between 2020 and 2030, and a 91% reduction between 2020 and 2050. In addition, when fossil emissions of methane (CH_4), nitrous oxide (N_2O), and other Kyoto green house gases (GHGs) are considered, the combined CO_2-equivalent pathway shows a 45% reduction between 2020 and 2030, and an 89% reduction between 2020 and 2050.[2] 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 8-34 Gt of cumulative novel CO_2 removal by 2050. This report supports a forthcoming update to SBTi's Corporate Net-Zero Standard, which will incorporate the updated pathway into target-setting criteria.

[2] For reference, the previous SBTi cross-sector pathway showed a 42% decrease in CO_2e between 2020 and 2030, and a 90% decrease in CO_2e between 2020 and 2050.

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1. INTRODUCTION

The Science Based Targets initiative (SBTi) drives ambitious climate action in the private sector by enabling organizations to set science-based emissions reduction targets. Central to SBTi's methodology for target setting is the use of climate mitigation scenarios or pathways. These pathways represent quantitative trajectories of GHG emissions over time and form the basis of science-based target setting for corporate entities. They define, for all of the economy or a portion of it, the emissions reductions that must be taken to limit global warming to a defined temperature goal. Through target-setting methods, companies set emissions reduction targets consistent with the underlying pathway, and therefore, with the corresponding temperature goal. While methods exist to set science-based targets using a carbon budget approach (e.g., Hadziosmanovic et al., 2022), the target-setting methods currently accepted by SBTi rely on emissions pathways that describe variations in the rate of emissions reductions over time (SBTi, 2019). The primary reason for using such pathway-based approaches is that they support the calculation of a 1.5°C-aligned reduction in emissions between any two points in time, thus accommodating variations among companies in the duration of their emissions target period.[3]

The global climate mitigation scenarios from which pathways are derived are developed in single-model and multi-model comparison studies. The research questions of these studies evolve over time, reflecting the changing climate policy debate and the progress in scientific understanding about the physical basis of climate change, its drivers, and any available response measures according to the Intergovernmental Panel on Climate Change (IPCC, 2022). It is important for SBTi to periodically review new scenarios in a robust and transparent manner, so that company targets validated by SBTi are up-to-date with the latest climate science while remaining consistent with SBTi's values and mission.

This Technical Foundations document revision presents an update of the cross-sector pathway that is used by the majority of companies setting targets validated by SBTi[4]. This pathway, first published in 2021 (SBTi, 2021), was determined by a combination of science and principled judgments. The pathway is used by companies in diverse sectors of the economy to set science-based targets using the cross-sector absolute reduction approach, also referred to as the Absolute Contraction Approach (ACA) (SBTi, 2019). The pathway defines the linear average reduction in absolute GHG emissions from energy and industrial processes, at a global level, that is required until 2050 to be consistent with a 50% chance of keeping global warming levels to 1.5°C by the end of this century. Importantly, SBTi's current target-setting criteria do not allow emission targets to include CO_2 removal, except for targets calculated via dedicated guidance for companies in the forestry, land, and agriculture (FLAG) sectors.

[3] SBTi's current criteria require companies to set near-term targets covering a minimum of five and a maximum of ten years (SBTi, 2023b).
[4] SBTi also offers sector-specific pathways for some sectors. See section 2 of this document, "Overview of pathways and which companies should use them".

2. OVERVIEW OF PATHWAYS AND WHICH COMPANIES SHOULD USE THEM

The SBTi offers a cross-sector pathway, described in this document, and sector-specific pathways for selected sectors. For most companies, the recommendation is to set absolute emissions targets using the cross-sector pathway.

Sector-specific pathways consistent with the 1.5°C temperature goal are available or in development for energy supply sectors, transport sectors, industry sectors including cement, steel, and chemicals, the buildings sector, and sectors with significant emissions from FLAG sectors. Companies in sectors where emissions are reduced significantly faster than the global average, like power generation, are required by SBTi to use the appropriate sector-specific pathway to set near-term SBTs. Additionally, companies with significant FLAG emissions are required to set SBTs using FLAG sector-specific pathways. FLAG (referred to as agriculture, forestry, and land use (AFOLU) in the IPCC AR6) is excluded from the cross-sector scenario envelope due to inconsistencies and gaps in how land-use sector removals are reported in the IPCC's AR6. These inconsistencies stem from differing methodologies used by modeling frameworks to account for land-based removals, such as afforestation and reforestation. Some scenarios report land removals as a combination of gross emissions and removals, while others define them relative to different baselines (Ganti et al., 2024; Smith et al., 2023). This is crucial for target setting in the FLAG sector, as the FLAG guidance may require separate emissions and removals accounting (SBTi, 2021).

Companies in all other sectors may use either the cross-sector pathway or sector-specific pathways to cover relevant emissions.

3. DESCRIPTION OF THE UPDATED CROSS-SECTOR PATHWAY

3.1 Background

SBTi's previous cross-sector pathway was derived from the ensemble of scenarios published with the Special Report on Global Warming of 1.5°C (SR1.5) (IPCC, 2018), in combination with five focal scenarios (SBTi, 2021). In this updated analysis, we draw from scenarios assessed in the recently published AR6 of the IPCC (IPCC, 2022). Compared to SR1.5, the expanded and updated scenario set contained in the AR6 builds on improved observational datasets to assess historical warming, as well as progress in scientific understanding of the response of the climate system to human-caused GHG emissions.

Since SR1.5, many new studies have added to the understanding of global mitigation pathways and associated emissions projections. These include several large-scale multi-model studies covering a range of scenarios consistent with limiting warming to 1.5°C, and studies based on individual models. Most multi-model studies aimed to explore different policy and societal questions associated with keeping the temperature goal of the Paris Agreement within reach. For instance, the climate outcomes descending from nationally determined contributions (NDCs), and the risk of temperature overshoot associated with a high reliance on negative emission technologies (Riahi et al., 2021; Roelfsema et al., 2020). Other studies used individual models to explore the link between mitigation and sustainable development, including the role of behavioral change and demand reduction (Bertram et al., 2018; Fujimori et al., 2020).

Whilst only a small number of these recent studies were already available in the SR1.5 scenarios database (Huppmann et al., 2018), a greater number were collected in the new AR6 scenario database (Byers et al., 2022). As a result, the number of scenarios categorized as limiting warming to 1.5°C with no or low overshoot[5] (category C1) is significantly larger in the AR6 database (97 C1 scenarios in the AR6 database versus 53 C1 scenarios in the SR1.5 database). This notwithstanding, AR6 scenarios show a slightly greater probability of exceeding 1.5°C in the year 2100: the median probability of staying below 1.5°C among scenarios in the C1 category was about 46% in the SR1.5 scenarios, but is 38% among the AR6 scenarios. In addition, AR6 scenarios on average show a later year of Net-Zero CO_2 emissions: while the median year of Net-Zero CO_2 emissions among the SR1.5 C1 scenarios was around 2051, this value has shifted to around 2055 in the AR6 C1 scenarios. The differences between the two databases in the year of Net-Zero emissions and the likelihood of staying within the 1.5°C temperature goal are predominantly due to revised, higher estimates of historical emissions (IPCC, 2023).

Despite these differences, SR1.5 and AR6 came to similar conclusions about the transformations required to limit warming to 1.5°C with no or limited overshoot, confirming that decisive mitigation efforts this decade will be crucial in determining whether we exceed this target by the early 2030s (Nicholls et al., 2022). The 97 scenarios in the C1 category of AR6 provide robust evidence that the 1.5°C temperature goal can be achieved with swift and transformative effort across all segments of the global economy.

3.2 Principles of scenario selection

The AR6 database contains 1,202 scenarios selected from multi-model and individual modeling studies. Together, these scenarios represent an ensemble of possible futures defined, among other factors, by a range of technological and socio-economic conditions. To navigate this complexity and to restrict the scenario space, we adopted six broad principles to guide our selection of scenarios informing the cross-sector pathway. The principles are designed to enable flexibility in assessment of emerging science while maintaining coherence with SBTi's values and mission, and inherit from overarching Principles for the Development of SBTi Standards and Technical Foundations (SBTi, forthcoming). Here, we used the principles to create strict criteria for scenario selection. The principles are outlined below, while the precise criteria applied to scenario selection are given in Table 1.

Ambitious: SBTi standards should drive action and transformative decarbonization in line with the ambition required to limit warming to 1.5°C. Ambition is the primary principle for pathway selection, as it relates directly to SBTi's primary goal of driving action in the private sector to reduce emissions. In this analysis, we began our scenario selection by including only scenarios in the AR6 database that limit warming to 1.5°C with a 50% or greater likelihood, with low or no overshoot of the 1.5°C temperature goal. Scenarios in this category (category C1) are the most ambitious scenarios assessed by the IPCC.

[5] In this category, "low overshoot" refers to scenarios that reach or exceed 1.5°C during the 21st century with a likelihood of 67% or less (up to about 0.12°C in terms of median warming above 1.5°C).

Responsible: SBTi standards should incentivize a transition to Net-Zero that emphasizes low risk of adverse outcomes for broader sustainability goals. For pathways specifically, the principle of responsibility dictates that pathways should rest on drivers of climate mitigation that are conservative, emphasizing low risk of adverse outcomes for broader sustainability goals, including relevant Sustainable Development Goals (SDGs) and planetary boundaries. We addressed this principle through several criteria related to sustainability. First, within the C1 category, we excluded scenarios that exceeded the sustainability limits of bioenergy in primary energy consumption in any year before and by 2050. This threshold reflects current scientific consensus on the amount of bioenergy that can be sustainably produced while minimizing detrimental impacts on food production, livelihoods, and biodiversity (Frank et al., 2021). We excluded scenarios where large-scale bioenergy carbon capture and storage (BECCS) deployment poses risks to biodiversity, livelihoods, and carbon balance, often exceeding sustainability thresholds for land use as highlighted by recent IPCC reports and other literature (IPCC, 2023; Creutzig et al., 2021). To ensure alignment with precautionary limits, we applied a threshold of 3 $GtCO_2$ per year for BECCS deployment in any year between 2020 and 2050 (Warszawski et al., 2021).

With a similar rationale, we eliminated 18 scenarios that included more than 3.6 $GtCO_2$ sequestration per year via afforestation in 2050, reflecting the estimated upper limit of sustainable sequestration by this lever (Fuss et al., 2018).

Rigorous: SBTi standards should be informed by the best available science, as defined by international consensus bodies like the IPCC, and best practices in climate target setting and climate mitigation at the time of standard development. Our selection of scenarios from the AR6 database reflects the principle of scientific rigor, as we only included those that successfully passed the IPCC's rigorous vetting assessments. Our decision to include the Net Zero Emissions by 2050 Scenario in addition to the AR6 database, as described below (see “Final scenario set”), was driven both by the credibility of the International Energy Agency, which produced the scenario, and by documentation that described inclusive, deliberative, and rigorous procedures for scenario construction.

Actionable: SBTi standards should offer an actionable framework that provides organizations with clear, measurable, and achievable steps toward meeting their targets, thereby facilitating effective and immediate reductions in emissions. For pathways specifically, this principle dictates that pathways should be supported by climate mitigation scenarios that rest on credible narratives on how key socio-economic factors, such as population, economic growth, and rate of technological development, may evolve over time. We applied this principle primarily according to the deployment of key carbon storage technologies. We restricted scenarios according to the total amount of CO_2 captured and permanently stored in geological formations (CCS), eliminating 14 scenarios that featured a cumulative CCS capacity deployment higher than 214 $GtCO_2$ between 2010 and 2050. This restriction reflects broad concern over the plausibility and feasibility of large-scale CCS deployment along biophysical, infrastructural, and market-related lines (van de Ven et al., 2023).[6] We also ruled out scenarios exhibiting deployment of novel carbon dioxide removal (CDR) (i.e., removal of CO_2 via BECCS, direct air CCS, and enhanced weathering) greater

[6] This reflects a simplified assumption that 75% of the volume of oil and gas basins, and 25% of the volume of saline aquifers, could be deployed for CO2 storage. For more details about how this heuristic was derived, see supplementary material of Van de Ven et al. (2023).

than 2.3 Mt in the year 2020, representing their current yearly deployment level based on most recent estimates (Smith et al., 2023).

Robust: SBTi standards should be rigorous and impartial, safeguarding the independence of the standard-setting process, and enabling credible and evidence-based claims throughout the target-setting and implementation journey. For pathways, this principle necessitates that pathways should be internally consistent, and exhibiting coherent logic. We applied the principle of robustness in two ways: first, we examined scenarios that include mitigation through land sinks according to their compatibility with existing SBTi guidance for the land sector[7] (Anderson et al., 2022). While the cross-sector pathway is relevant for energy and industrial process emissions only, it is important that the scenarios underlying the pathway do not rely on the land sector for greater mitigation to meet the 1.5°C temperature goal than the existing SBTi pathway for FLAG can deliver. We implemented this restriction by calculating cumulative CO_2e emissions from AFOLU for each scenario over the 2020-2050 time period, and comparing this to the land-based emissions in the SBTi FLAG pathway. We eliminated two scenarios with smaller cumulative emissions from AFOLU than those in the SBTi FLAG pathway, thus ensuring that the scenarios included in the cross-sector pathway did not assume land-based mitigation at amounts higher than the SBTi FLAG pathway (SBTi, 2022).[8] We applied no constraint on the upper limit of land-based emissions.

We also addressed consistency with sector-specific pathways offered by SBTi by including the International Energy Agency's (IEA) Net Zero Emissions by 2050 scenario in our analysis. This scenario currently serves as SBTi's basis for evaluating sectoral emissions budgets (SBTi, 2021).

Transparent: SBTi standards should make all relevant information publicly available, and be documented in a way that supports balanced, multi-stakeholder involvement in their construction and use. This principle implies that SBTi standards must rest on methods, scenarios, and positions that are transparently documented, including explicit statements of assumptions. As such, we selected scenarios for inclusion in the cross-sector pathway only if the underlying scenario data were publicly available. We also served the transparency principle in this document by making code sufficient to reproduce calculation of the cross-sector pathway publicly available (see "Code and data availability" below). We have also included the definitions and descriptions of the variables retrieved from the AR6 scenarios (see "Description of Variables" below).

Upon applying the principles-driven filtering criteria to the C1 scenarios category of the AR6, 19 scenarios were found to meet these criteria, originating primarily from three main model families. The number of scenarios satisfying each filter is shown in Table 1; a complete list of scenarios and models excluded and retained from the C1 category of the AR6 database appears in supplementary Tables S1-S8. The median of filtered scenarios showed gross fossil CO_2 emissions near the bottom of the interquartile range of C1 scenarios (Figure 1).

[7] The SBTi FLAG pathway is based on the summary of land-based mitigation potential in 1.5°C scenarios described by Roe et al. (2019).
[8] The SBTi FLAG pathway may be updated in the course of regular revisions to the FLAG guidance, following the Standard Operating Procedures for Development of SBTi Standards (SBTi, 2023c).

Table 1. Filtering criteria applied to the AR6 scenario database, and the number and percentage of C1 scenarios satisfying each individual criterion. When applied together, 16 scenarios satisfied all criteria. Scenarios in the C1 category are the most ambitious scenarios assessed by the IPCC and exhibit low or no overshoot of the 1.5°C temperature goal.

Filtering criterion	Value	Reference	Num. (%) of C1 scenarios meeting criterion
Maximum primary energy from bioenergy in any year between 2010-2050	<100 EJ	Frank et al., 2021	30 (31%)
Maximum CO_2 removed via BECCS in any year between 2010-2050	<3 Gt CO_2	Warszawski et al., 2021	35 (36%)
Maximum CO_2 removed via afforestation in 2050	<3.6 Gt CO_2	Fuss et al., 2018	80 (82%)
Total cumulative CO_2 permanently stored in geological deposits, 2010-2050	<214 Gt CO_2	van de Ven et al., 2023	83 (86%)
Maximum CO_2 removed via novel CDR in 2020	<2.3 Mt CO_2	Smith et al., 2023	92 (95%)
Total cumulative AFOLU emissions, 2020-2050	>-99.54 Gt CO_2e	SBTi, 2022	95 (98%)

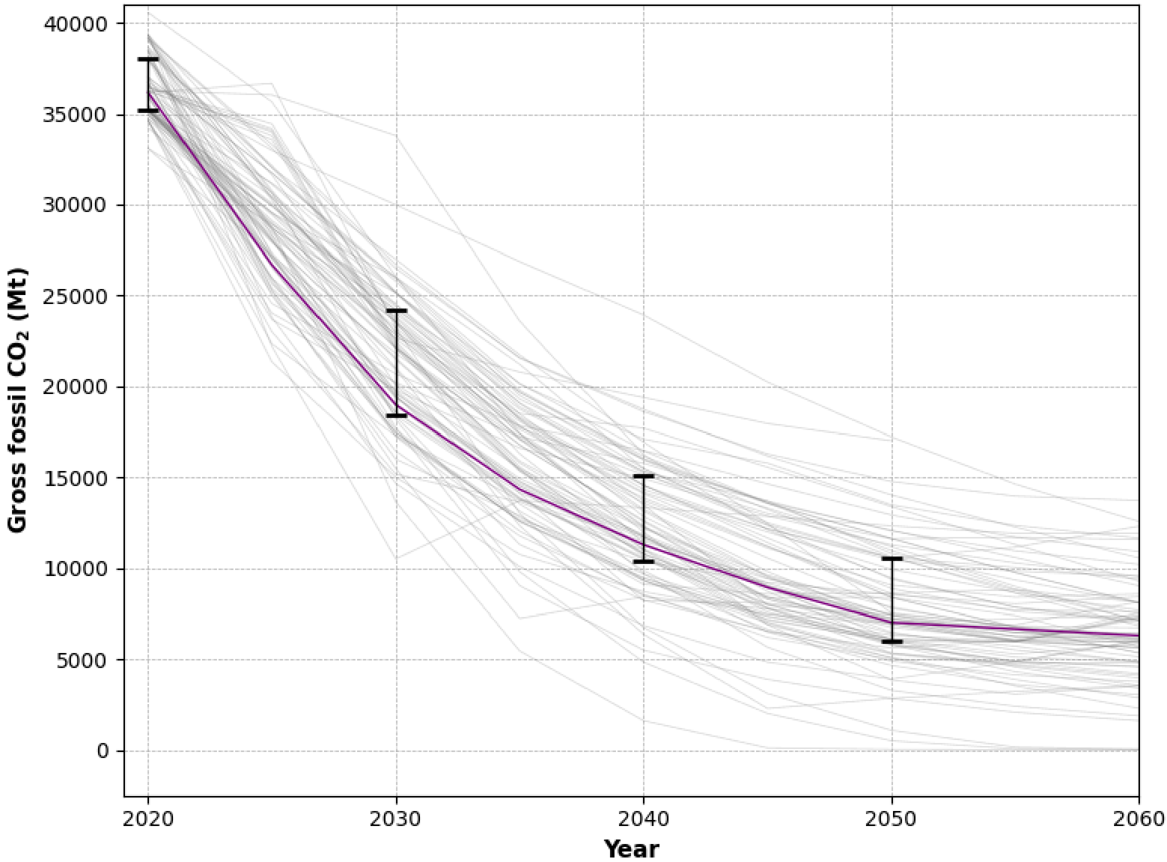

Figure 1. Gross CO_2 emissions from energy and industrial processes in selected scenarios from the AR6 database. All C1 scenarios are shown in gray. The purple line shows the median of filtered scenarios after applying the filtering criteria listed in Table 1. Error bars show the interquartile range of all C1 scenarios.

3.3. Final scenario set

In addition to the scenarios selected from the AR6 database according to the principles described above (see "Principles of scenario selection"), we considered the IEA Net Zero Emissions by 2050 Scenario (NZE) in the scenario set used to generate gross fossil CO_2 emissions in the cross-sector pathway. The IEA NZE is an important institutional scenario from the gray literature. Our choice to add this scenario to the filtered scenario set serves three main purposes: 1) to align the cross-sector pathway with the highest credible ambition to reduce emissions; 2) to maintain consistency of the cross-sector pathway with sector-specific pathways offered by SBTi; and 3) to contextualize the cross-sector pathway among prominent and highly credible scenarios.

The NZE, originally published by the IEA in 2021, is a normative, policy-driven roadmap that sets out a pathway to reach Net-Zero energy-related and industrial process CO_2 by 2050. The scenario is characterized by a 2020-2050 cumulative net CO_2 budget of around 500 Gt and is aligned with a 50% chance of limiting warming to 1.5°C by 2100 (as reported by IEA). In addition to the overarching goal of reaching Net-Zero CO_2 in the energy sector by 2050, the NZE also includes relevant sustainable development metrics, including universal energy access by 2030 and a major reduction in air pollution. To accomplish this, primary mitigation levers in the NZE include rapid uptake of efficient technologies and increased materials recycling. The NZE also includes strong reliance on behavioral changes such as modal shifts for passenger and freight transport, energy demand in buildings, and end use energy efficiency measures. These behavioral shifts place NZE below the interquartile range of C1 scenarios in terms of final energy demand in 2050 (Figure 2). The NZE scenario is unique among many in that it does not explicitly model the land sector. For this analysis, we used data from the 2023 update of the NZE scenario (IEA, 2023).

To identify relevant scenarios from outside the AR6 database that should be reviewed for inclusion in the pathway, we first reviewed institutional scenarios that are highly prominent in the gray literature. We consulted with internal and external advisory groups to identify candidate scenarios. We reviewed each scenario for adherence to the principles and filtering criteria described in section 3.2.

Figure 2 shows how the IEA NZE scenario and the median of filtered scenarios from the AR6 database compare to the interquartile range of AR6 C1 scenarios in terms of key mitigation drivers.

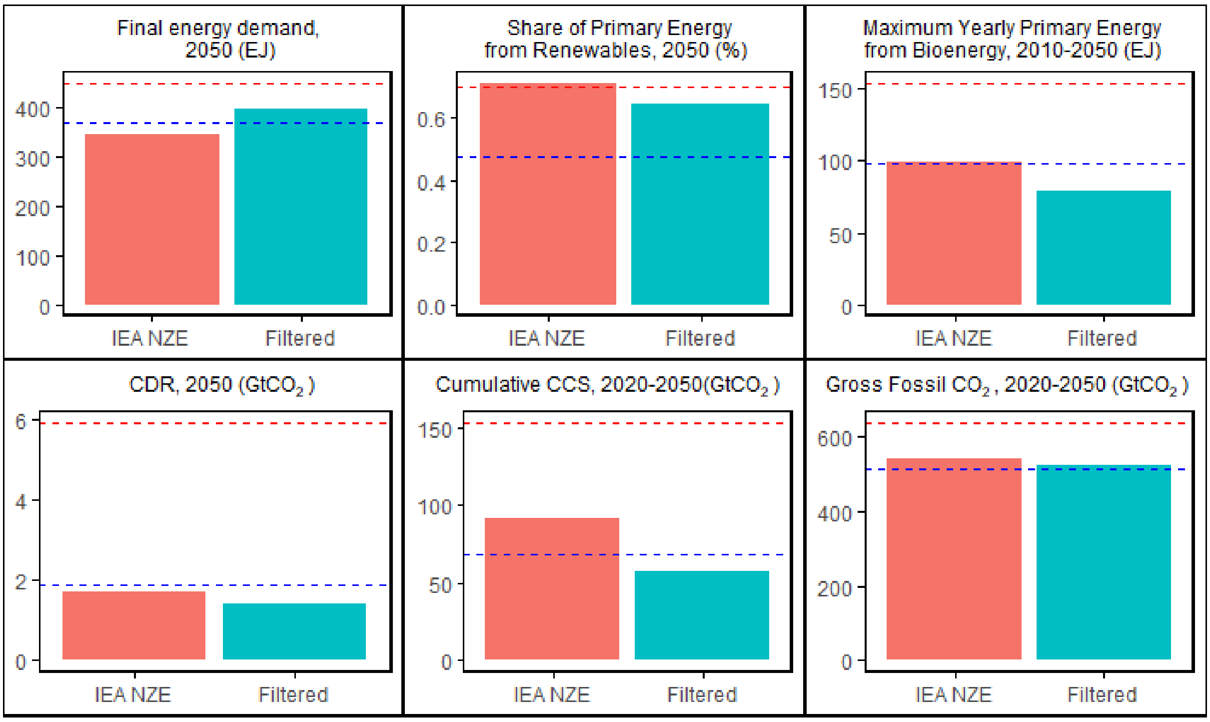

Figure 2. Summary of key scenario characteristics among scenarios included in the cross-sector pathway. The "filtered" scenario refers to the median of filtered C1 scenarios from the AR6 database. Dashed lines show the 25th (blue) and 75th (red) percentile of values across the 97 C1 scenarios in the AR6 database.

3.4. Quantitative synthesis methods

3.4.1 Harmonization with recent historical emissions

All published scenarios depict a possible modeled future from a set of starting conditions that represent a snapshot in time. Meanwhile, as time passes, the modeled initial conditions may grow increasingly out of synchronization with realized or actual historical emissions. All of the filtered scenarios drawn from the AR6 scenarios database were published between 2018 and 2021 (see "Supplementary Information" for a table of filtered scenarios); many of the scenarios include steep modeled reductions in emissions between 2020 and 2025. In reality, global emissions of most GHGs have risen since 2020; global emissions of fossil CO_2 rose from approximately 36 Gt in 2022 to 37 Gt in 2023, according to recent empirical estimates (Forster et al., 2024).

Most of the 19 filtered scenarios report emissions in five-year increments. However, when 2023 emissions are calculated from the scenarios via interpolation, all scenarios show projected fossil CO_2 emissions in 2023 that are lower than actual empirical emissions for that year (37 Gt; Forster et al., 2024). Modeled emissions in 2023 range from 446 Mt to 9.9 Gt below actual emissions (with an average of 7.3 Gt lower than actual emissions) (Figure 3).

To improve the consistency of the cross-sector pathway with the most recent estimated emissions, we harmonized fossil CO_2 emissions in the filtered scenarios with realized emissions in the year 2023 from Forster et al. (2024), using a harmonization algorithm similar to that which was used for the AR6 report. We used the aneris package (Gidden et al., 2018), implementing a budget-invariant harmonization method. This means that the harmonization algorithm adjusted projected emissions of fossil CO_2 to match historical emissions in 2023 while maintaining the same cumulative emissions budget of the original scenario. We implemented the harmonization to conserve cumulative emissions through 2050, despite the fact that temperature alignment of model outputs are typically assessed over a time period extending to 2100, because this is the period covered by short- and long-term science-based targets. We did not harmonize non-CO_2 GHGs due to a lack of data for these gasses. Figure 3 shows the impact of harmonization on the 19 filtered scenarios.

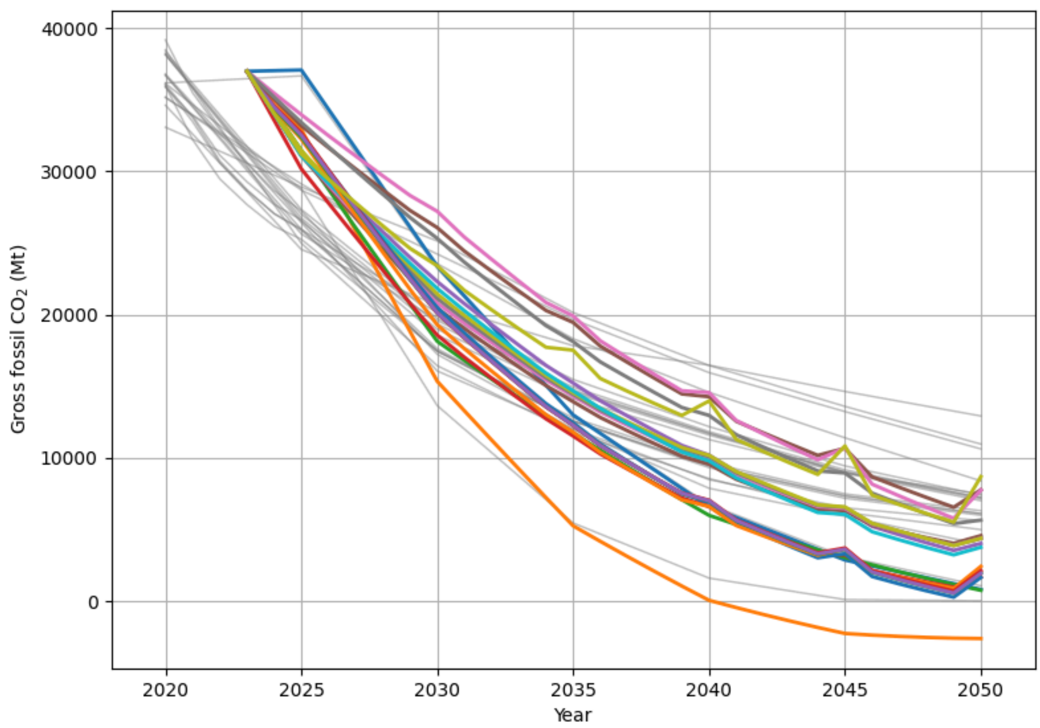

Figure 3. Impact of harmonization with historical emissions on scenarios from the AR6 database. The filtered scenarios from the AR6 database (shown in gray) were harmonized with estimated empirical emissions, constrained to maintain total cumulative emissions for each scenario during the period of 2023-2050. Harmonized scenarios, which were used to construct the cross-sector pathway, are shown in colored lines.

Our methodology for calculating the pathway from the scenarios described above was aimed at ensuring consistency with SBTi's target-setting guidance. First, under current guidance, companies with significant land-based emissions must use the sector-specific guidance and pathway for FLAG (Anderson et al., 2022). Therefore, the relevant emissions boundary for the cross-sector pathway excludes emissions from AFOLU. In addition, according to the mitigation hierarchy defined in the SBTi Corporate Net-Zero Standard (SBTi, 2023a), companies cannot count removals outside their value chains towards achieving their near-term and long-term targets. It follows that the cross-sector pathway must describe reductions in gross emissions, not including CDR.

Reflecting this application context, we resolved the gross emissions from the energy and industrial process which is reported as net flux in the AR6. We first calculated gross fossil CO_2 for each scenario by taking the sum of energy and industrial process CO_2 (following harmonization with recent historical emissions, as described above) and CDR, according to the variables reported by each scenario. In the AR6 database, for example, CDR is reported in the variables describing Direct Air Capture (DAC), BECCS, and enhanced weathering; the IEA NZE scenario reports net fossil CO_2 and CDR using a slightly different variable scheme, but data published for the scenario support calculation of gross fossil CO_2. This calculation method ensured that CO_2 emissions synthesized across scenarios in the next step reflected emissions from energy and industrial processes only, and did not include any emissions from FLAG.

After calculating gross fossil CO_2 from each scenario, we determined the gross fossil CO_2 for the cross-sector pathway by taking the median of the 20 scenarios (comprising 19 scenarios from the AR6 database, and the NZE scenario) at each modeled timestep.

The current SBTi guidance (SBTi, 2023b) mandates that companies include up to six GHGs additional to CO_2 in their targets, namely methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3), and requires them to report emission inventories and targets exclusively in terms of CO_2-equivalent. Recent experimental findings have suggested potential benefits in addressing these GHGs separately (Bjørn et al., 2023). Consequently, we have calculated distinct pathways for each of these gasses,[9] as well as a combined CO_2-equivalent pathway. Our decision to report separate pathways for each gas is aimed at facilitating the potential for future revisions to SBTi criteria, pending further research.

We estimated non-CO_2 GHGs using only the AR6 database, because the IEA NZE scenario does not report these gasses. Additionally, we summarized the non-CO_2 GHGs from the AR6 database by taking the median of all C1 scenarios without filtering because models differ greatly in their estimates of these gasses and are, therefore, highly susceptible to bias through restriction of sample size. While this methodological choice introduces some inconsistency into the pathway because different gasses are summarized from different scenarios, we judge the inconsistency to be small because CO_2 comprises the majority of total CO_2e in the combined pathway through 2050.

After summarizing single-gas pathways for gross fossil emissions of the six Kyoto Protocol gasses, we converted all non-CO_2 gasses to CO_2-equivalent, using GWP100 values from the Sixth Assessment Report (IPCC, 2021), and added these to the gross fossil CO_2 pathway to estimate gross fossil CO_2e. For application in target setting using the ACA, we calculated emissions reduction benchmarks for each individual gas and for the combined

[9] Note that the AR6 database reports all Kyoto Protocol gasses listed above, except for NF3.

CO_2e pathway as a percent reduction from 2020 levels in each five-year time period between 2020 and 2050.

3.5. Results: updated cross-sector pathway

The quantitative synthesis of scenarios yielded cross-sector benchmarks for gross fossil CO_2, five non-CO_2 GHGs, and a combined CO_2-equivalent pathway. A summary of the cross-sector pathway is shown in Table 1.

Table 2. Summary of the updated cross-sector pathway for key GHG emissions from energy and industrial processes. Note that the pathway reflects reductions in energy and industrial process emissions only, and does not include reductions in emissions from FLAG. Companies with significant FLAG emissions are required to set targets using the dedicated FLAG pathway (SBTi, 2022).

Greenhouse gas	2020 - 2030 (%)	2020 - 2035 (%)	2020 - 2040 (%)	2020 - 2045 (%)	2020 - 2050 (%)
Gross fossil CO_2	41 [34-43]	60 [58-65]	76 [71-81]	85 [81-90]	91 [87-95]
Fossil CH_4	61 [45-68]	68 [56-79]	71 [63-79]	76 [67-84]	80 [69-82]
Fossil N_2O	34 [-2-49]	46 [15-57]	50 [21-62]	57 [24-68]	61 [27-70]
Hydrofluorocarbons (HFCs)	80 [44-80]	86 [43-86]	92 [47-92]	91 [54-91]	91 [61-91]
Perfluorocarbons (PFCs)	73 [70-75]	77 [77-77]	81 [81-81]	84 [84-85]	87 [87-88]
Sulfur hexafluoride (SF_6)	60 [46-60]	62 [44-62]	64 [41-64]	67 [42-67]	69 [38-70]
CO_2e (all gasses combined)	45 [35-48]	62 [57-68]	75 [69-80]	84 [78-89]	89 [83-93]

We use the median of the modeled 2020 values from the scenarios for non-CO_2 gasses, while the historical value for fossil CO_2 is taken from Foster et al. (2024). The results are presented as the median percentage reduction along with the interquartile range (25th-75th) across the scenarios.

Because the cross-sector pathway is derived from a synthesis of multiple scenarios, it does not reflect a single storyline about how mitigation should be achieved. The comparison of important scenario drivers shown above demonstrates that there are multiple paths to limit warming to 1.5°C. However, some broad implications emerge from the scenarios taken collectively. In general, there is a strong consensus in the literature that attainment of the 1.5°C temperature goal is not possible without meeting significant challenges along at least one of the dimensions of renewables scale-up, atmospheric CDR deployment, and behavioral change to reduce final energy demand (Warszawski et al., 2021). Of these dimensions, and because of the principles outlined in this document, the cross-sector pathway leans most heavily on the deployment of renewable energy, placing relatively less emphasis on CDR scale-up and reduction in final energy demand.

Between 2020 and 2050, the energy and industrial processes CO_2 emissions corridor of the cross-sector pathway results in cumulative CO_2 emissions of around 450 $GtCO_2$. The cumulative novel CDR within this period is around 8-34 $GtCO_2$. The cross-sector pathway implies very high renewables deployment. Taking the average across scenarios in the final scenario set, the pathway implies 40% of primary energy from renewable sources in 2030, and 65% of primary energy from renewables in 2050. These levels are near the 75th percentile of C1 scenarios in the AR6 database (Figure 2). Further, considering our principled limitation on the deployment of bioenergy, the bulk of this deployment must come from non-bioenergy renewable sources (including solar, wind, geothermal, solar thermal, and ocean energy). The cross-sector pathway, therefore, implies a large scale-up of non-bioenergy renewable energy sources, in stark contrast to the expected deployment of these resources under current policies: under the IEA's Stated Policies scenario, non-bioenergy renewables are forecast to represent only a 9% share of primary energy in 2030, and reach 18% in 2050 (IEA, 2023).

The deployment of CDR and CCS implied by the cross-sector pathway is very low among the assessed scenarios, equal to 0.9-2.7 $GtCO_2$/yr of annual removals by CDR and 2.1-5.6 Gt CO_2/yr captured from combustion and industrial process emissions, and permanently stored via CCS in 2050. These conservative estimates are just below the interquartile range of C1 scenarios from AR6 (Figure 2), reflecting our choice to emphasize mitigation pathways with low reliance on the capture and storage of CO_2.

A reduction in final energy demand is a prominent mitigation lever among several scenarios included in the cross-sector pathway, most notably the NZE scenario; the final energy demand in 2050 across scenarios included in the cross-sector pathway is 396 EJ. This is below the median value of all C1 scenarios and represents a significantly less challenging reduction in energy demand than ambitious demand-driven mitigation scenarios found in the literature (Grubler et al., 2018; Millward-Hopkins et al., 2020). However, recent empirical analysis has questioned the viability of energy demand reduction levels displayed by Integrated Assessment Models, highlighting the strong potential conflict with sustainable development goals (Semieniuk et al., 2021).

As discussed in Chapter 5 of the AR6 third working group report, individual annual energy consumption currently ranges globally from under 5 GJ to over 200 GJ per capita (IPCC, 2022), in stark contrast to energy requirements for decent living (13 to 18.4 GJ per person per year; Millward-Hopkins et al., 2020). Thus, the implementation of a reduction in final energy demand as a mitigation strategy in a way that is consistent with the principle of responsibility depends on regional differentiation in energy demand trajectories: to protect minimum levels of essential goods service delivery in developing regions, behavioral change to reduce demand must be concentrated in developed economies. The minimum global energy access in the cross-sector pathway is estimated at 26–51 GJ per person, per year, between 2020 and 2050. Though these values are above the minimum requirements for decent living (Millward-Hopkins et al., 2020), they only represent a global aggregate and do not account for regional disparities. Ensuring equitable energy transitions requires prioritizing energy access improvements in low-consuming regions while addressing overconsumption in high-consuming regions.

4. WHICH SECTORS WILL HAVE RESIDUAL EMISSIONS IN 2050?

The scenario envelope encompassed by the cross-sector pathway and the IEA NZE delineates the allowable emissions trajectories for each sector to achieve global net-zero targets. These pathways establish that despite stringent economy-wide mitigation actions, some emissions still persist in 2050 and need to be removed to achieve the global Net-Zero target. The cross-sector pathway projects that Energy and Industrial CO_2 emissions will be reduced by 91% by 2050, leading to residual CO_2 emissions of 3 $GtCO_2$ at the global level (equal to 9% of 2020 global emission levels), mainly originating primarily from the transportation and industrial sectors. Notably the electricity and heat sector are expected to be completely decarbonized by 2050, with minimum gross CO2 emissions (equal to 95% and 99% reduction by 2040 and 2050 respectively[10]) which are counterbalanced by BECCS to power technologies. Differing sectoral residual emissions at the Net-Zero year reflects unique technological constraints and mitigation potential, which affects the pace of decarbonization (Buck et al., 2023). We derive the residual emissions from the Net-Zero benchmarks established for each sector-specific standard (SBTi, 2024). These benchmarks are quantified through detailed modeling of sectoral mitigation potentials, incorporating technological readiness levels, cost-effectiveness assessments, and system-level constraints. This sectoral differentiation ensures that residual emissions are rooted in a technically robust framework, capturing the difficult-to-abate emissions within each sector. Consequently, these benchmarks also inform the design of targeted carbon removal strategies required to neutralize residual emissions and achieve a scientifically-consistent pathway to global Net-Zero.

Table 3. 2050 sector-specific residual levels of gross CO_2 emissions for electricity and heat, buildings, transportation, and industry sectors. Note that the emission data reflects direct emissions only (scope 1), though companies setting science-based targets must include indirect emissions (scopes 2 and 3).

Sectoral disaggregation	Sub sector	Residual emissions in 2050 ($MtCO_2$)	% share of global gross CO_2 emissions in 2020
Electricity and heat	N/A	99	0.28%
Buildings	N/A	171	0.48%
Transportation	Aviation	210	0.6%
	Shipping	122	0.35%
	Passenger car	85	0.24%
	Truck	198	0.57%

[10] According to the IEA NZE 2023, the electricity and heat reaches net-zero about a decade later compared to the IEA NZE 2021 pathway, which has been adopted by the SBTi in the SBTi Pathway to Net Zero report.

Sectoral disaggregation	Sub sector	Residual emissions in 2050 ($MtCO_2$)	% share of global gross CO_2 emissions in 2020
Industry	Cement	133	0.38%
	Chemical	66	0.19%
	Iron and Steel	220	0.66%
	Aluminum	8	0.02%
Total across all sectors		1308	~4%

5. LIMITATIONS

The scenarios from the IPCC's AR6 relies heavily on mitigation pathways based on Integrated Assessment Models (IAMs). While IAMs serve as valuable tools for understanding the complex interactions within the energy-economy-land-climate system, they exhibit limitations that can impact their accuracy and ability to effectively guide climate policy decisions. IAM models overlook or simplify critical elements within these complex systems. For instance, IAMs may not accurately capture the full extent of economic outcomes resulting from climate change or fully account for the economic benefits associated with mitigation strategies. Additionally, concerns exist regarding the accurate reflection of the potential for rapid technological advancements and to adequately address distributional impacts of climate change and associated policies (IPCC, 2022). The reliance on long-term projections introduces unavoidable uncertainties. Forecasting over extended periods, such as a century, requires a wide range of potential future developments, making it challenging to accurately predict factors like economic growth, technological innovation, and societal responses to climate change. IAMs prioritize quantitative, system-level transformations with less focus on the underlying social and cultural shifts necessary for achieving those transformations. While IAMs can effectively model changes in areas such as energy systems or land use, they often struggle to capture the intricate social and institutional changes required to support and sustain those transformations. Consequently, aspects such as potential extreme climate impacts and the disruptive nature of technological advancements, both capable of significantly altering societal structures, may not be fully represented within existing frameworks (IPCC, 2022).

Equity considerations are not explicitly required in IPCC's scenario assessment. This criterion omission has implications on residual emissions, particularly in the context of historical emissions, burden-sharing, and climate justice. In quantitative terms, regions with high historical emissions might still have substantial residual emissions, while countries with lower historical emissions are disproportionately assigned a more stringent mitigation burden (IPCC, 2022).

Recognizing these limitations, the SBTi will update pathways as new scientific evidence, technological advancements, and insights into societal and economic dynamics emerge. This iterative process ensures that the pathways remain robust, scientifically grounded, and aligned with evolving knowledge. By incorporating improvements in modeling techniques, better understanding of climate impacts, and the potential for disruptive technologies, these updates aim to enhance the relevance and reliability of pathways in guiding effective climate action and policy development.

The cross-sector pathway is derived from global pathways due to the assumption that many companies set targets covering geographically diverse emissions sources. Despite the scientific rigor followed in this analysis, there are certain cases whereby this assumption may be insufficient because the global pathway approach does not account for regional differentiation in emissions reduction. While the SBTi's Sectoral Decarbonization Approach (SDA) accounts for regional-level differences in its estimations, more specific regional analysis could provide a clearer picture of how decarbonization efforts should be distributed across different countries in line with equity considerations. The SBTi is actively exploring such regional or country-level pathways, but these are beyond the scope of this document. Methods used to calculate company targets which integrate regional and equity principles and pathways are also currently being explored, but this topic is also outside the scope of this document.

6. CODE AND DATA AVAILABILITY

All of the scenario data used in this analysis are publicly available from the cited sources. Code to reproduce calculation of the cross-sector pathway from published data is available in this repository: https://github.com/sbti-de/revised-cross-sector

7. SUPPLEMENTARY INFORMATION

This supplementary section provides a narrative of the scenarios assessed in the IPCC's AR6, detailing the rationale behind the sustainability criteria that shape the filtered scenario set used to estimate the cross-sector pathway. We also show the excluded scenarios that failed to meet the sustainability thresholds and other set constraints.

7.1 Rationale on constraints of sustainability factors in the cross-sector pathway

These sustainability criteria were used to refine the C1 category (97 scenarios) to ensure that they not only achieve the 1.5°C target but do so in a manner that aligns with broader sustainable development goals (SDGs) (Roy et al., 2018). By integrating these considerations, we filtered out scenarios that overly depend on bioenergy from biomass, which could lead to land-use conflicts or threaten food security. Similarly, we excluded scenarios that rely heavily on BECCS deployments due to concerns about sustainability impacts, such as potential diversion of resources like land, water, and energy from essential needs like food production and ecosystem conservation, as well as huge uncertainties in terms of technological scale-up and long-term feasibility (IPCC, 2023). The scenario filtering process also involves constraining the reliance on afforestation and reforestation as primary carbon sinks to ensure their deployment remains within sustainable limits. This approach mitigates potential trade-offs, such as excessive competition for arable land, disruption of ecosystems leading to biodiversity loss, and risks to food security. By imposing these constraints, the filtering process prioritizes pathways that balance carbon sequestration objectives with the preservation of ecological integrity and the safeguarding of essential human needs. Additionally, we applied other criteria, such as excluding scenarios that presented CDR levels beyond current estimates, which could introduce high risks of failure

in projected deployment. Scenarios with net land use removals exceeding those set by the SBTi's FLAG sector were also filtered out to ensure that land-use practices remain consistent with established science and sustainable land management principles.
By applying these filtering criteria, the list of pathways is narrowed to those that maximize the synergies between climate mitigation and sustainable development (n=19). This ensures that the filtered scenario corridor not only limits global warming to 1.5°C with 50% probability by 2100, but also minimizes risks, thereby promoting a just and equitable transition that benefits both the environment and society.

7.2. Excluded scenarios from the C1 category based on the filtering criteria

Table S1 shows the scenarios from the C1 category that were excluded based on constraints on cumulative emissions from AFOLU between 2020 and 2050.

Supplementary Table S1: Overview of scenarios that were excluded from the analysis (n=2)

Model	Scenario
C-ROADS-5.005	Ratchet-1.5-limCDR-noOS
GCAM 4.2	SSP1-19

Table S2 shows the scenarios from the C1 category excluded based on constraints on maximum yearly biomass consumption above 100 EJ/yr., in any year between 2010 and 2050.

Supplementary Table S2: Overview of scenarios that were excluded from the analysis (n=67)

Model	Scenario
REMIND 2.1	R2p1_SSP5-PkBudg900
WITCH 5.0	EN_NPi2020_400f
REMIND 1.7	CEMICS-1.5-CDR12
POLES EMF33	EMF33_WB2C_full
WITCH-GLOBIOM 4.4	CD-LINKS_NPi2020_400
COFFEE 1.1	EN_NPi2020_400
REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050 - IPD-median
WITCH 5.0	EN_NPi2020_500
REMIND-MAgPIE 2.1-4.3	DeepElec_SSP2_def_Budg900
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600_COV
GCAM 5.3	R_MAC_50_n8

REMIND-MAgPIE 2.1-4.2	EN_NPi2020_200f
POLES EMF33	EMF33_WB2C_cost100
GEM-E3_V2021	EN_NPi2020_500
AIM/CGE 2.2	EN_NPi2020_600
REMIND 1.7	CEMICS-1.5-CDR8
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_400
REMIND 2.1	R2p1_SSP2-PkBudg900
REMIND 2.1	CEMICS_opt_1p5
WITCH 5.0	EN_NPi2020_450f
AIM/CGE 2.1	CD-LINKS_NPi2020_400
REMIND 1.7	ADVANCE_2020_1.5C-2100
GCAM 4.2	SSP1-19
IMAGE 3.2	SSP2_SPA1_19I_LIRE_LB
GCAM 5.3	R_MAC_40_n8
REMIND 1.7	CEMICS-1.5-CDR20
REMIND-MAgPIE 1.5	SSP2-19
IMAGE 3.2	SSP2_SPA2_19I_LI
REMIND-MAgPIE 2.1-4.2	SusDev_SSP1-PkBudg900
REMIND 2.1	CEMICS_HotellingConst_1p5
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_300f
REMIND-MAgPIE 1.7-3.0	PEP_2C_red_eff
WITCH 5.0	EN_NPi2020_450
REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050 - IPD-95th
AIM/CGE 2.2	EN_NPi2020_300f
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP2-1p5C-fullCDR

REMIND-MAgPIE 2.1-4.2	CEMICS_SSP2-1p5C-minCDR
REMIND 2.1	CEMICS_GDPgrowth_1p5
REMIND-MAgPIE 1.7-3.0	PEP_1p5C_full_eff
GCAM 5.3	R_MAC_30_n0
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-minCDR
IMAGE 3.2	SSP2_SPA1_19I_D_LB
AIM/Hub-Global 2.0	1.5C
GEM-E3_V2021	EN_NPi2020_600_COV
POLES EMF33	EMF33_WB2C_nofuel
MESSAGEix-GLOBIOM 1.0	CD-LINKS_NPi2020_400
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-fullCDR
REMIND-MAgPIE 1.7-3.0	PEP_1p5C_red_eff
MESSAGE-GLOBIOM 1.0	EMF33_1.5C_cost100
MESSAGE-GLOBIOM 1.0	SSP2-19
REMIND 2.1	R2p1_SSP1-PkBudg900
REMIND-MAgPIE 1.7-3.0	EMF33_1.5C_nofuel
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_500
IMAGE 3.2	SSP1_SPA1_19I_LIRE_LB
GCAM 5.3	R_MAC_35_n8
MESSAGEix-GLOBIOM_1.1	NGFS2_Divergent Net Zero Policies
REMIND-MAgPIE 2.1-4.2	SusDev_SSP2-PkBudg900
IMAGE 3.2	SSP2_SPA1_19I_RE_LB
REMIND 2.1	CEMICS_Linear_1p5
GCAM 5.3	R_MAC_45_n8
REMIND-MAgPIE 1.7-3.0	CD-LINKS_NPi2020_400
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_450

MESSAGE-GLOBIOM 1.0	ADVANCE_2020_1.5C-2100
POLES ADVANCE	ADVANCE_2020_1.5C-2100
MESSAGE-GLOBIOM 1.0	EMF33_1.5C_full
REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050

Table S3 shows the scenarios from the C1 category that were excluded based on constraints on the CDR level (above 2.3 $MtCO_2$ per year) in 2020

Supplementary Table S3: Overview of scenarios that were excluded from the analysis (n=5)

Model	**Scenario**
WITCH-GLOBIOM 3.1	SSP1-19
REMIND-MAgPIE 2.1-4.3	DeepElec_SSP2_ HighRE_Budg900
GCAM 4.2	SSP1-19
REMIND-MAgPIE 2.1-4.3	DeepElec_SSP2_def_Budg900
WITCH-GLOBIOM 3.1	SSP4-19

Table S4 shows the scenarios from the C1 category that were excluded based on constraints on maximum yearly sequestration via af-/reforestation (above 3.6 $GtCO_2$ per year) in any year between 2010 and 2050.

Supplementary Table S4: Overview of scenarios that were excluded from the analysis (n=18)

Model	**Scenario**
REMIND-MAgPIE 1.7-3.0	CD-LINKS_NPi2020_400
REMIND-MAgPIE 1.7-3.0	PEP_2C_red_eff
REMIND 1.7	CEMICS-1.5-CDR8
IMAGE 3.2	SSP2_SPA1_19I_LIRE_LB
REMIND-MAgPIE 1.7-3.0	SMP_2C_lifesty
IMAGE 3.2	SSP1_SPA1_19I_RE_LB
IMAGE 3.2	SSP1_SPA1_19I_LIRE_LB
REMIND-MAgPIE 1.7-3.0	PEP_1p5C_red_eff
C-ROADS-5.005	Ratchet-1.5-limCDR-noOS
REMIND-MAgPIE 1.7-3.0	PEP_1p5C_full_eff
IMAGE 3.2	SSP1_SPA1_19I_D_LB

IMAGE 3.2	SSP2_SPA1_19I_D_LB
REMIND 1.7	CEMICS-1.5-CDR12
REMIND 1.7	CEMICS-2.0-CDR8
IMAGE 3.2	SSP2_SPA2_19I_LI
IMAGE 3.2	SSP2_SPA1_19I_RE_LB
REMIND 1.7	CEMICS-1.5-CDR20

Table S5 shows the scenarios from the C1 category that were excluded based on constraints on maximum cumulative CCS between 2010 and 2050 (Gt).

Supplementary Table S5: Overview of scenarios that were excluded from the analysis (n=14)

Model	**Scenario**
GCAM 5.3	R_MAC_35_n8
AIM/CGE 2.2	EN_NPi2020_600
GCAM 5.3	R_MAC_45_n8
IMAGE 3.2	SSP2_SPA1_19I_D_LB
IMAGE 3.2	SSP2_SPA2_19I_LI
IMAGE 3.2	SSP2_SPA1_19I_LIRE_LB
AIM/CGE 2.2	EN_NPi2020_300f
MESSAGE-GLOBIOM 1.0	ADVANCE_2020_1.5C-2100
GCAM 5.3	R_MAC_40_n8
IMAGE 3.2	SSP1_SPA1_19I_RE_LB
IMAGE 3.2	SSP1_SPA1_19I_LIRE_LB
GCAM 5.3	R_MAC_50_n8
GCAM 5.3	R_MAC_30_n0

IMAGE 3.2	SSP2_SPA1_19I_RE_LB

Table S6 shows the scenarios from the C1 category that were excluded based on constraints on maximum cumulative CCS of above 214 $GtCO_2$ per year between 2010 and 2050.

Supplementary Table S6: Overview of scenarios that were excluded from the analysis (n=14)

Model	Scenario
GCAM 5.3	R_MAC_35_n8
AIM/CGE 2.2	EN_NPi2020_600
GCAM 5.3	R_MAC_45_n8
IMAGE 3.2	SSP2_SPA1_19I_D_LB
IMAGE 3.2	SSP2_SPA2_19I_LI
IMAGE 3.2	SSP2_SPA1_19I_LIRE_LB
AIM/CGE 2.2	EN_NPi2020_300f
MESSAGE-GLOBIOM 1.0	ADVANCE_2020_1.5C-2100
GCAM 5.3	R_MAC_40_n8
IMAGE 3.2	SSP1_SPA1_19I_RE_LB
IMAGE 3.2	SSP1_SPA1_19I_LIRE_LB
GCAM 5.3	R_MAC_50_n8
GCAM 5.3	R_MAC_30_n0
IMAGE 3.2	SSP2_SPA1_19I_RE_LB

Table S7 shows the scenarios from the C1 category that were excluded based on constraints on maximum BECCS of above 3 $GtCO_2$ per year between 2010 and 2050.

Supplementary Table S7: Overview of scenarios that were excluded from the analysis (n=62)

Model	Scenario
REMIND 2.1	R2p1_SSP5-PkBudg900
REMIND 1.7	CEMICS-1.5-CDR12
POLES EMF33	EMF33_WB2C_full
WITCH-GLOBIOM 4.4	CD-LINKS_NPi2020_400
COFFEE 1.1	EN_NPi2020_400

REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050 - IPD-median
REMIND-MAgPIE 2.1-4.3	DeepElec_SSP2_def_Budg900
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600_COV
GCAM 5.3	R_MAC_50_n8
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_200f
POLES EMF33	EMF33_WB2C_cost100
AIM/CGE 2.2	EN_NPi2020_600
REMIND 1.7	CEMICS-1.5-CDR8
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_400
REMIND	R2p1_SSP2-PkBudg900
REMIND 2.1	CEMICS_opt_1p5
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_400f
AIM/CGE 2.1	CD-LINKS_NPi2020_400
REMIND 1.7	ADVANCE_2020_1.5C-2100
IMAGE 3.2	SSP2_SPA1_19I_LIRE_LB
GCAM 5.3	R_MAC_40_n8
REMIND 1.7	CEMICS-1.5-CDR20
REMIND-MAgPIE 1.5	SSP2-19
IMAGE 3.2	SSP2_SPA2_19I_LI
REMIND-MAgPIE 2.1-4.2	SusDev_SSP1-PkBudg900
REMIND 2.1	CEMICS_HotellingConst_1p5
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_300f
REMIND-MAgPIE 1.7-3.0	PEP_2C_red_eff
WITCH 5.0	EN_NPi2020_450
REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050 - IPD-95th

AIM/CGE 2.2	EN_NPi2020_300f
IMAGE 3.2	SSP1_SPA1_19I_RE_LB
WITCH-GLOBIOM 3.1	SSP1-19
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP2-1p5C-fullCDR
REMIND 2.1	CEMICS_GDPgrowth_1p5
REMIND-MAgPIE 1.7-3.0	PEP_1p5C_full_eff
GCAM 5.3	R_MAC_30_n0
IMAGE 3.2	SSP2_SPA1_19I_D_LB
AIM/Hub-Global 2.0	1.5C
POLES EMF33	EMF33_WB2C_nofuel
MESSAGEix-GLOBIOM 1.0	CD-LINKS_NPi2020_400
REMIND-MAgPIE 2.1-4.2	CEMICS_SSP1-1p5C-fullCDR
REMIND-MAgPIE 1.7-3.0	PEP_1p5C_red_eff
IMAGE 3.2	SSP1_SPA1_19I_D_LB
WITCH-GLOBIOM 3.1	SSP4-19
MESSAGE-GLOBIOM 1.0	EMF33_1.5C_cost100
REMIND 2.1	R2p1_SSP1-PkBudg900
REMIND-MAgPIE 1.7-3.0	EMF33_1.5C_nofuel
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_500
IMAGE 3.2	SSP1_SPA1_19I_LIRE_LB
GCAM 5.3	R_MAC_35_n8
REMIND-MAgPIE 2.1-4.2	NGFS2_Divergent Net Zero Policies
REMIND-MAgPIE 2.1-4.2	SusDev_SSP2-PkBudg900
IMAGE 3.2	SSP2_SPA1_19I_RE_LB
REMIND 2.1	CEMICS_Linear_1p5
GCAM 5.3	R_MAC_45_n8

REMIND-MAgPIE 1.7-3.0	CD-LINKS_NPi2020_400
POLES ADVANCE	ADVANCE_2020_1.5C-2100
MESSAGE-GLOBIOM 1.0	EMF33_1.5C_full
REMIND-MAgPIE 2.1-4.2	NGFS2_Net-Zero 2050
WITCH-GLOBIOM 4.4	CD-LINKS_NPi2020_1000

7.3 Scenarios from the C1 category selected based on the filtering criteria

Supplementary Table S8. Scenarios and models retained from the C1 category of the AR6 database after applying filtering criteria (based on the principles described in Table 1)

Model	**Scenario**	**Literature Reference**
MESSAGEix-GLOBIOM 1.0	LowEnergyDemand_1.3_IPCC	Grubler, A., Wilson, C., Bento, N., Boza-Kiss, B., Krey, V., McCollum, D. L., ... & Valin, H. (2018). A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. Nature energy, 3(6), 515-527. https://doi.org/10.1038/s41560-018-0172-6
C-ROADS-5.005	Ratchet-1.5-noCDR	Holz, C., Siegel, L. S., Johnston, E., Jones, A. P., & Sterman, J. (2018). Ratcheting ambition to limit warming to 1.5°C–trade-offs between emission reductions and carbon dioxide removal. Environmental research letters, 13(6), 064028. https://doi.org/10.1088/1748-9326/aac0c1
C-ROADS-5.005	Ratchet-1.5-noCDR-noOS	(as above)
MESSAGEix-GLOBIOM_1.2	COV_GreenPush_550	Kikstra, J. S., Vinca, A., Lovat, F., Boza-Kiss, B., van Ruijven, B., Wilson, C., ... & Riahi, K. (2021). Climate mitigation scenarios with persistent COVID-19-related energy demand changes. Nature Energy, 6(12), 1114-1123.

		https://doi.org/10.1038/s41560-021-00904-8
MESSAGEix-GLOBIOM_1.2	COV_NoPolicyNoCOVID_550	(as above)
MESSAGEix-GLOBIOM_1.2	COV_Restore_550	(as above)
MESSAGEix-GLOBIOM_1.2	COV_SelfReliance_550	(as above)
MESSAGEix-GLOBIOM_1.2	COV_SmartUse_550	(as above)
MESSAGEix-GLOBIOM_1.1	NGFS2_Net-Zero 2050	NGFS Climate Scenarios for central banks and supervisors, NGFS June 2021. https://www.ngfs.net/sites/default/files/media/2021/08/27/ngfs_climate_scenarios_phase2_june2021.pdf
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_COV	Riahi, K., Bertram, C., Huppmann, D., Rogelj, J., Bosetti, V., Cabardos, A. M., ... & Zakeri, B. (2021). Cost and attainability of meeting stringent climate targets without overshoot. Nature Climate Change, 11(12), 1063-1069. https://doi.org/10.1038/s41558-021-01215-2; Bertram, C., Riahi, K., Hilaire, J., Bosetti, V., Drouet, L., Fricko, O., ... & Luderer, G. (2021). Energy system developments and investments in the decisive decade for the Paris Agreement goals. Environmental Research Letters, 16(7), 074020. https://doi.org/10.1088/1748-9326/ac09ae; Hasegawa, T., Fujimori, S., Frank, S., Humpenöder, F., Bertram, C., Després, J., ... & Riahi, K. (2021). Land-based implications of early climate actions without global net-negative emissions. Nature Sustainability, 4(12), 1052-1059. https://doi.org/10.1038/s41893-021-00772-w

MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR4p	(as above)
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR3p	(as above)
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR2p	(as above)
MESSAGEix-GLOBIOM_1.1	EN_NPi2020_600_DR1p	(as above)
REMIND-MAgPIE 2.1-4.2	EN_NPi2020_600f_COV	(as above)
REMIND-MAgPIE 2.1-4.2	SusDev_SDP-PkBudg1000	Soergel, B., Kriegler, E., Weindl, I., Rauner, S., Dirnaichner, A., Ruhe, C., ... & Popp, A. (2021). A sustainable development pathway for climate action within the UN 2030 Agenda. Nature Climate Change, 11(8), 656-664. https://doi.org/10.1038/s41558-021-01098-3
REMIND 2.1	LeastTotalCost_LTC_brkLR15_SSP1_P50	Schultes, A., Piontek, F., Soergel, B., Rogelj, J., Baumstark, L., Kriegler, E., ... & Luderer, G. (2021). Economic damages from on-going climate change imply deeper near-term emission cuts. *Environmental Research Letters*, *16*(10), 104053. DOI 10.1088/1748-9326/ac27ce
WITCH 5.0	EN_NPi2020_500f	Bertram, C., Riahi, K., Hilaire, J., Bosetti, V., Drouet, L., Fricko, O., ... & Luderer, G. (2021). Energy system developments and investments in the decisive decade for the Paris Agreement goals. *Environmental Research Letters*, *16*(7), 074020. DOI 10.1088/1748-9326/ac09ae
MESSAGEix_GLOBIOM_1.1	EN_NPi2020_500	Hasegawa, T., Fujimori, S., Frank, S., Humpenöder, F., Bertram, C., Després, J., ... & Riahi, K. (2021). Land-based implications of early

climate actions without global net-negative emissions. *Nature Sustainability*, *4*(12). DOI 1052-1059.10.1038/s41893-021-00772-w

7.4 Description of variables

Supplementary Table S8: Description of the variables analyzed and respective formulations

net emissions from energy and industrial processes	=	'Emissions|CO2|Energy and Industrial Processes', and 'Emissions|CO2|Energy' + 'Emissions|CO2|Industrial Processes'
technological carbon dioxide removal (CDR)	=	'Carbon Sequestration|CCS|Biomass', + 'Carbon Sequestration|Direct Air Capture', + 'Carbon Sequestration|Enhanced Weathering'
gross emissions from energy and industrial processes	=	'Emissions|CO2|Energy and Industrial Processes' + 'technological carbon dioxide removal'
n2o emissions from energy and industrial processes	=	'Emissions|N2O|Energy' + 'Emissions|N2O|Industrial Processes' + 'Emissions|N2O|Other' + 'Emissions|N2O|Waste'
ch4 emissions from energy and industrial processes	=	'Emissions|CH4|Energy' + 'Emissions|CH4|Industrial Processes' + 'Emissions|CH4|Other' + 'Emissions|N2O|Waste'
emissions from the land sector	=	'Emissions|CO2|AFOLU' + 'Emissions|CH4|AFOLU' + 'Emissions|N2O|AFOLU'

carbon capture and storage (CCS)	=	'Carbon Sequestration|CCS'
total carbon dioxide removal	=	'Carbon Sequestration|CCS|Biomass', + 'Carbon Sequestration|Direct Air Capture', + 'Carbon Sequestration|Enhanced Weathering' + 'Carbon Sequestration|Land Use'
industrial process CCS	=	'Carbon Sequestration|CCS|Industrial Processes'

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