REPORT

10 YEARS AFTER THE PARIS AGREEMENT - KEEPING 1.5°C IN REACH

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Introduction

The Paris Agreement temperature goal and the Long Term Global Goal (LTGG) of the UNFCCC, adopted in 2015, is to limit global warming to well below 2°C and make efforts to limit warming to 1.5°C, recognising that this would reduce climate impacts and risks. The Paris Agreement entered into force on November 4, 2016, following ratification by member governments.

The Equinox Workshop, held in Brussels on 10–11 February 2026. It took place 10 years after the period between the adoption and entry into force of the Paris Agreement. It was convened by JPI Climate, with the support of the Magica project, and brought together experts working in the science-policy interface to reflect on progress since the adoption of the Paris Agreement in 2015 and to examine pathways for keeping global warming within 1.5°C. The workshop took place at a key moment for international climate policy, marked by ongoing discussions on strengthening European climate targets, continued implementation of the Paris Agreement following the first Global Stocktake, and increasing recognition that current efforts to reduce greenhouse gas emissions and enhance removals are insufficient to limit global warming to 1.5°C – a level that has become totemic for climate policy since the UNFCCC COP26 held in Glasgow in 2021, and at subsequent COP and Paris Agreement meetings.

At COP30/CMA8 in Belém in 2025, the Parties reaffirmed the centrality of multilateral cooperation, equity, best available science, and continued implementation of the Paris Agreement. The Mutirão Decision reiterated their "resolve to pursue efforts to limit the temperature increase to 1.5°C. However, it also marked the first formal acknowledgement of the possibility of 1.5°C temperature being temporarily exceeded and emphasised that any "temperature overshoot" should be temporary, i.e., limited in both magnitude and duration.

The workshop explored these topics in the science policy setting. It was noted that many terms which have accepted definitions within the research community and the IPCC may not be understood in a similar manner outside these communities, including the term "overshoot". A list of such terms is included in a glossary. However, the report is written in a manner that seeks to provide clarity on such terms without reference to the glossary.

1.1. Pathways to Limit Warming to 1.5°C

Limiting global warming to 1.5°C above pre-industrial levels is termed the 'north star' to guide climate policy for countries, sectors, and actors globally. Following a request from the UNFCCC COP in 2015, the IPCC published a Special Report on global warming of 1.5 °C in 2018. That report explored a series of possible development pathways that are consistent with this level of global warming. A range of emissions scenarios was explored using Integrated Assessment Models (IAMs), which combine assumptions on technologies and their deployment, current and future energy systems, land use, and socioeconomic trends. These were further updated and developed ahead of the completion of the IPCC 6th Assessment Report (AR6) in 2022. These reflect the ongoing process to develop and reflect socio-economic and technological developments.

Subsequent scenario analyses suggest that the landscape of mitigation pathways has shifted significantly since the publication of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6). Changes in technological deployment, particularly the rapid expansion of renewable energy, have raised questions on the plausibility of previously assessed pathways and the emergence of others. These provide new insights on the feasibility of limiting warming to 1.5°C, the role of carbon dioxide removal (CDR).

1.1.1. **Ongoing greenhouse gas (GHG) emissions and technological development mean that the global emissions scenarios have shifted since the publication of the IPCC AR6**. Global GHG emissions have continued to increase since 2020. However, the rapid deployment of renewable energy, particularly solar and wind energy, has reduced the plausibility of the occurrence of the highest warming scenarios included in AR6. At the same time, the most ambitious mitigation pathways assessed in AR6, which represent pathways that limit warming to 1.5°C with no or minimal temporary overshoot[1], are no longer considered attainable.

1.1.2. **The updated scenarios indicate that the lowest peak warming level is around 1.7°C (50% likelihood).** As a result, no currently assessed pathway stabilises global warming at 1.5°C without a temporary exceedance of this temperature. Scenarios that return warming to 1.5°C by 2100 rely on the deployment of substantial carbon dioxide removal (CDR) to provide net-negative CO_2 emissions during the second half of the century.

1.1.3. **These developments highlight the importance of limiting both the magnitude and duration of any temperature overshoot and place increasing emphasis on the feasibility, scalability, and sustainability of large-scale CDR deployment**. Temperature overshoot refers to pathways in which global mean temperatures temporarily exceed 1.5°C before later declining, typically with sustained large-scale negative emissions (Reisinger et al., 2025).

1.1.4. **The deployment of CDR is subject to multiple constraints, including land availability, energy system requirements, geological storage capacity, deployment rates, and broader sustainability considerations**. Significant uncertainty remains regarding the feasible scale and rate of deployment of CDR technologies.

1.1.5. **The Shared Socioeconomic Pathways (SSPs), which describe alternative global development trajectories and associated emissions patterns, are highly sensitive to underlying assumptions**, including on technological availability, socioeconomic development trajectories, governance effectiveness, and international cooperation, which influence real-world decision-making.

1.1.6. **Historically, the assumptions and analysis approaches used in IAMs have been subject to questions on their transparency. IAMs have become increasingly transparent in recent years, with models and scenario databases now available as open-source resources.** The outputs are explorations of possible global futures based on a series of assumptions and choices, expressed as scenarios. These are designed to assist in decision-making, not predict outcomes.

1.1.7. **Further integration of IAMs and Earth system models is needed to inform policy-making.** There is an increasing requirement for analysis that links mitigation costs, the role and cost of CDR, climate impacts, adaptation requirements, and their costs. Estimating costs of climate impacts remains a challenge due to complex biophysical and socioeconomic interactions. Socio-political uncertainty further complicates such analysis.

1.1.8. **Current research increasingly stress-tests emissions pathways against system disruptions and Earth system feedbacks**. Climate feedbacks are an increasing concern, including loss of ice cover, ice-albedo change, permafrost thaw and methane release, and natural carbon sink saturation. Future modelling frameworks will need to better capture these uncertainties and real-world complexities. These dynamics are particularly consequential when determining the scale of CDR required to hedge against uncertain feedbacks, with direct implications for the feasibility of temporary 1.5°C exceedance and subsequent return below the threshold (Schleussner et al., 2024). See 1.3.3.

[1] Minimal overshoot is defined as keeping warming to around +0.1°C above the 1.5°C.

1.1.9. **National development perspectives, particularly from emerging and low-income economies, are increasingly recognised as important to improving the credibility and fairness of global scenario frameworks**. Whereas the IAM community remains concentrated in Europe and North America, modelling capacity is expanding to other regions, bringing issues of equity and representation to the forefront in IAMs and scenario modelling. Initiatives to support and capture these are emerging.[2]

1.1.10. **While the lowest-warming (C1) scenarios with minimal overshoot[3] are no longer considered attainable, updated benchmarks for pathways that limit warming to below 1.5°C indicate that global GHG emissions reductions of approximately 60% by 2035 and 80-90% by 2050 relative to 2019 would be required**. Such pathways also require a two-to-threefold increase in non-biomass renewables by 2035, alongside substantial reductions in fossil fuel use including declines in coal use of 75-100%, oil use of 50-70%, and gas use of 40-90% by 2050. Global net zero CO_2 emissions is reached between 2050 and 2060. While Biomass Energy with Carbon Capture and Storage (BECCS) and Direct Air Capture with Carbon Storage (DACCS) are increasingly integrated into mitigation scenarios, other CDR methods remain underrepresented, and concerns persist regarding the durability of land-based sinks.

Key insights

Limiting global warming to 1.5°C without overshoot is no longer attainable. The lowest projected peak warming is approximately 1.7°C, and returning to 1.5°C by 2100 required large-scale CDR deployment to achieve net-negative emissions – a goal subject to significant feasibility constraints and uncertain Earth System feedbacks.

Strengthening scenario frameworks required greater integration of Earth System models, more transparent modelling assumptions, and broader regional representation. Improved communication of scenarios and their underlying assumptions is essential to support policymakers in determining what constitutes an acceptable level of temperature exceedance. This requires scientific and technical assessments and ethical considerations.

1.2. A balance of GHG emissions and removal

Parties to the Paris Agreement aim to achieve a global "balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century". In physical terms, this balance is considered to correspond to the condition required to stabilise the global temperature. Scientific analysis shows that global warming stabilises when additional net anthropogenic CO_2 emissions reach zero. This is frequency termed net zero CO_2 as cited in COP/CMA Decisions (Solomon et al., 2009; Meinshausen et al., 2009; Allen et al., 2009; Matthews et al., 2009; Gregory et al., 2009; Zickfeld et al., 2009). Achieving this requires balancing ongoing emissions from fossil fuels and land-use change with anthropogenic carbon dioxide removals (CDR) stored on comparable timescales (Allen et al., 2022; Allen et al., 2024). Natural uptake by ocean and land currently removes a substantial share of anthropogenic CO_2 emissions (Friedlingstein et al., 2026a). Emerging evidence suggests that these passive sinks are dynamic and are weakening in response to climate change (Friedlingstein et al., 2026b). Understanding the physical meaning of "balance" therefore requires distinguishing between geological-origin (i.e. fossil) CO_2 emissions versus land-origin CO_2 emissions and removals, and also distinguishing anthropogenic versus natural sinks.

[2] The Scenario Compass Initiative (SCI) aims to collect, vet, and curate global emissions scenarios independently of the IPCC assessment cycles. Vetting based on recent technological trends, feasibility threshold, and sustainability criteria yields a subset of roughly 200 from an initial 1,600 scenarios

[3] Minimal overshoot is defined as keeping warming to around +0.1°C above the 1.5°C.

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1.2.1. **Achieving and sustaining net-zero global anthropogenic CO_2 emissions, alongside declining non-CO_2 radiative forcing, would halt anthropogenic warming on multi-decadal timescales (*high confidence*).** Peak temperature is then primarily determined by cumulative net global anthropogenic CO_2 emissions up to the time of net zero (*high confidence*) and the level of non-CO_2 radiative forcing (*medium confidence*). Over longer time scales, sustained net-negative global anthropogenic CO_2 emissions and further reductions in non-CO_2 radiative forcing would be required to return to lower warming levels, counteracting Earth system feedbacks, reversing ocean acidification (*medium confidence*), and to minimise further sea level rise (*high confidence*).

1.2.2. **The physical basis for stabilising global warming can be expressed through a climate-neutrality equation linking temperature change to cumulative CO_2 emissions and radiative forcing:** $\Delta T_s = k_E[\Delta G + (p_F - p_E)G\Delta t] + \kappa_F(\Delta F + \rho_F F \Delta t)$. The change in global mean temperature ΔT_s is determined by two components: (i) warming driven by cumulative CO_2 emissions and (ii) warming driven by other anthropogenic radiative forcing, such as methane and nitrous oxide.

1.2.3. **The relationship between additional CO_2 emissions and the global temperature is characterised by the Climate Response factor to the CO_2 emission (k_E),** i.e., the change in global average temperature per mass of additional CO_2 emitted. This is largely independent of when the additional CO_2 was emitted, i.e., during this or the previous century (Matthews & Solomon, 2012; Collins et al., 2013; Herrington & Zickfeld, 2014; MacDougall & Friedlingstein, 2015; Canadell et al., 2021). The scale of CO_2 warming is determined by the cumulative anthropogenic CO_2 emissions (not accounting for the natural land and ocean carbon sink) since pre-industrial times. The increase in this warming will stop when additional anthropogenic CO_2 emissions end (Sheshadri, 2021). This point is termed net-zero CO_2.

1.2.4. **Stabilising CO_2 concentrations is not in itself sufficient to stabilise global temperatures, which would continue to rise gradually, unless emissions cease and atmospheric CO_2 concentrations start to decline.** The rate of global temperature increase for a stable CO_2 concentration is approximately 0.3% per year. This is broadly matched by the slow response of the active carbon cycle, which naturally draws down atmospheric CO_2 – and its associated warming effect – at a similar rate of approximately 0.3% per year. These two processes correspond to what are termed the thermal adjustment rate (p_F) – the gradual warming commitment already locked in by accumulated CO_2 concentration – and the slow carbon-cycle adjustment rate (p_E) – the rate at which natural carbon sinks progressively reduce atmospheric CO_2 concentrations and hence warming. Because both thermal and carbon adjustment rates are approximately equal, they largely cancel each other out (MacDougall, Frölicher & Jones, 2020; Jenkins et al., 2022; Allen et al, 2022). As a result, when anthropogenic CO_2 emissions fall to zero, warming by CO_2 stabilises.

1.2.5. **Net-zero CO_2 emissions is achieved when additional CO_2 emissions ΔG, consisting of those from geological-origin CO_2, i.e. from fossil fuel uses and industrial processes, and net biogenic CO_2 emissions, from anthropogenic land-use change, are balanced by "like-for-like" storage**. As such, a key component is described as Geological Net Zero (GNZ), meaning one tonne of CO_2 permanently restored in geological-timescale storage for every tonne still generated from fossil sources (Allen et al., 2025).

1.2.6. **A clear distinction must be made between anthropogenic removals and the "passive" uptake of CO_2 by natural ocean and land systems, such as enhanced vegetation growth owing to CO_2 fertilisation**. Ocean and land (terrestrial ecosystems) "passively" remove a substantial share, around 50%, of anthropogenic CO_2 emissions between 2015 and 2024 (Friedlingstein et al., 2026a). If this "passive" uptake were counted as active anthropogenic removal when determining net-zero CO_2, atmospheric CO_2 concentrations might stabilise, yet temperature would continue to rise (see 1.2.4): by counting passive natural uptake as anthropogenic removal, the slow-carbon cycle adjustment rate – which would otherwise counterbalance the thermal adjustment rate and halt further warming – would be zero as the passive uptakes are already accounted for to balance the anthropogenic CO_2 emissions, leaving the thermal adjustment uncompensated (Allen et al., 2024).

1.2.7. **One indicator emerging from this analysis is the net geological carbon intensity (NetGCI): the fraction of CO_2 produced from fossil sources that remains in the atmosphere rather than being captured and returned to geological-timescale storage.** Under credible GNZ pathways, NetGCI must decline steadily toward zero, with illustrative benchmarks suggesting capture and storage levels of ~10% by the mid-2030s, ~50% by the mid-2040s and near 100% by the 2050s. In practice, implementing NetGCI would initially involve countries tracking and reporting the indicator through their Nationally Determined Contributions (NDCs), providing a transparent measure of progress toward temperature stabilisation. Over time, this could inform the development of regulatory frameworks that align fossil fuel and industrial sectors with GNZ-consistent pathways, embedding NetGCI as a structuring principle in climate governance.

1.2.8. **Stabilising warming from non-CO_2 GHG requires that their net radiative forcing declines gradually over time,** unless their residual warming effect is offset by carbon dioxide removal. In either case, the net warming influence of non-CO2 gases must decrease by approximately 0.3% per year.

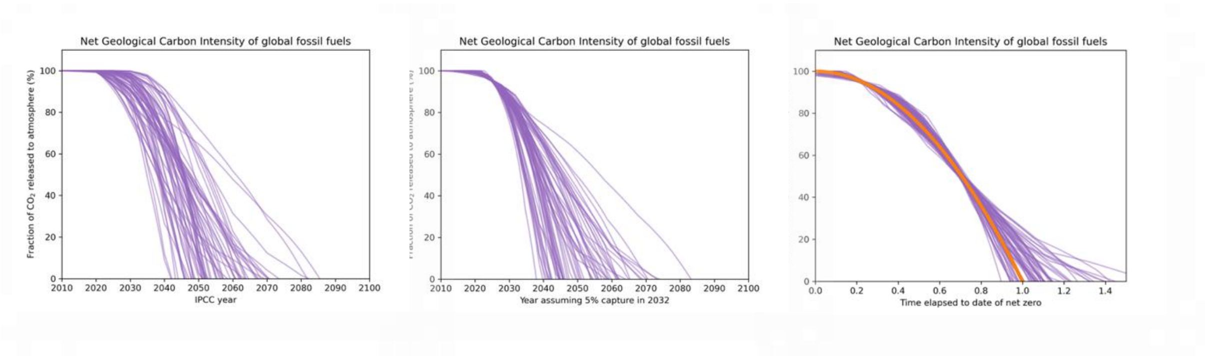

Figure 1. Net Geological Carbon Intensity (netGCI) Pathways. Panel (a) shows the fraction of all CO_2 produced that is emitted to the atmosphere rather than captured or recaptured and stored on geological timescales. The netGCI declines to zero at the date of geological net zero. Panel (b) presents the same scenarios assuming that all pathways reduce netGCI at the same time. Panel (c) additionally aligns the date of geological net zero across scenarios, illustrating the resulting approximate netGCI trajectory. **Source**: Allen 2026

Ocean Sinks

1.2.9. **The global oceans represent the largest sink for carbon dioxide (CO_2) to the atmosphere caused by human activities**. Over the past decade, the ocean sink took up approximately 29% of additional CO_2 emissions, equivalent to about 3.2 GtC[4] per year (Friedlingstein et al., 2026a).

1.2.10. **Ocean CO_2 uptake is driven primarily by two mechanisms: (i) the solubility pump**, which is based on the ocean temperature and chemistry in which CO_2 is taken up in cold, sinking water[5], and **(ii) the biological pump**, through which carbon is taken up by biological processes such as photosynthesis in organisms and eventually transported into deeper ocean layers through sinking of organic material. Ocean carbon uptake is temporally and spatially heterogeneous (Takahashi et al., 2009), varying significantly across regions and time (Landschützer et al., 2016).

[4] For $GtCO_2$, multiply by 3.664.
[5] Air-ocean CO_2 exchanges depend on differences in CO2 partial pressure between the atmosphere and the ocean surface and wind-driven kinetic transfers (waves).

1.2.11. **Continued CO_2 uptake by the ocean is driving ocean acidification and gradually weakening the ocean's buffering capacity** (Müller and Gruber, 2024; Ma, Gregor & Gruber, 2023). Climate-driven processes are also influencing ocean carbon dynamics, including warming surface waters, increased stratification that limits vertical mixing, and changes in wind patterns that affect the transport and mixing of carbon-rich deep waters (Bunsen, F., Nissen, C., & Hauck, 2024).

1.2.12. **Recent analyses indicate that climate-driven processes have already reduced the ocean carbon uptake** by approximately 7% over the past decade (Friedlingstein et al., 2026a,b).

1.2.13. **Short-term climate variability and extremes can affect ocean carbon uptake**. Extreme events such as marine heatwaves, such as the El Niño in 2023-2024 (Müller et al., 2025), produced measurable short-term reductions in ocean CO_2 uptake. This contributed to an unexpected decline in the ocean carbon sink between 2023 and 2024. This highlights the sensitivity of the ocean carbon sink to climate variability and extremes and underscores the risks of assuming a stable passive ocean carbon sink.

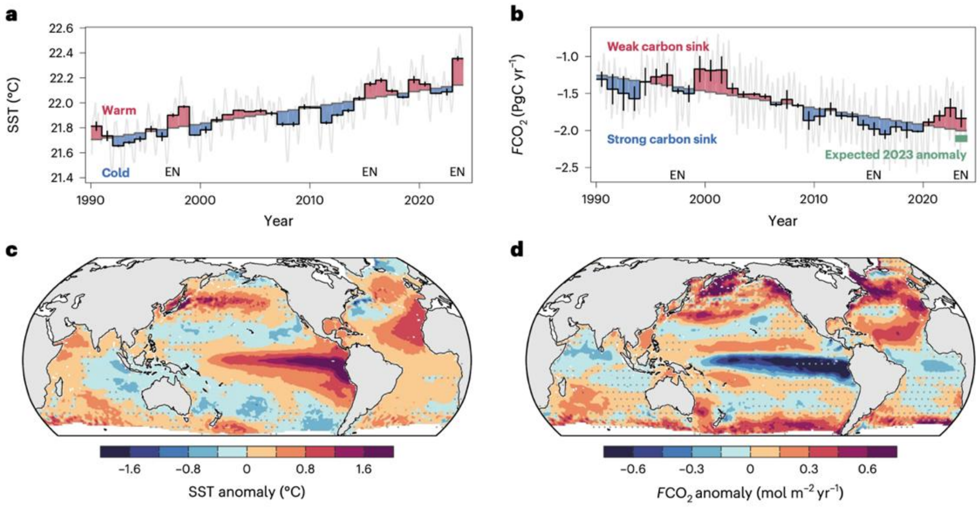

Figure 2. Impact of record-high sea surface temperatures on air-sea CO_2 fluxes. The figure shows time series of mean sea surface temperatures and air-sea CO_2 fluxes. Panels (a) and (b) display the annual (black) and monthly (grey) fluctuations, while annual mean anomalies relative to linear long-term trends are represented in red and blue. Panels (c) and (d) present maps of the global oceans showing observation-based anomalies. **Source**: Müller et al., 2025.

1.2.14. **Projections suggest that ocean carbon uptake declines in low emission scenarios due to saturation effects; however, even in high emission scenarios with continued emissions, the carbon uptake capacity declines towards the end of the century** due to ocean warming and declining ocean buffer capacity linked to ocean acidification (IPCC, 2022).

Terrestrial Sinks

1.2.15. **Terrestrial ecosystems also play a major role in the global carbon cycle**. Land systems absorbed approximately 2.4 GtC per year over the decade 2014-2023, equivalent to around 21% of anthropogenic emissions (Friedlingstein et al., 2026a).

1.2.16. **The dominant driver of terrestrial carbon uptake is the CO_2 fertilisation effect**. Higher atmospheric CO_2 levels stimulate plant growth and increase carbon sinks in vegetation and soils.

1.2.17. **The effect of climate change is to reduce the land carbon sink.** Over the last decade, climate change led to a land carbon sink reduction of 25% (Friedlingstein et al., 2026a,b).

1.2.18. **Land carbon fluxes also represent a significant CO_2 source, with significant uncertainty in the global carbon budget.** Emissions of CO_2 from land-use, land-use change and forestry (LULUCF) were estimated at 1.4 ± 0.7 GtC yr−1, over 2015-2024 (Friedlingstein et al., 2026a). The wide uncertainty ranges reflect the difficulty of monitoring LULUCF activities on an annual basis, and the complexity of associated processes leading to CO_2 emissions or removals.

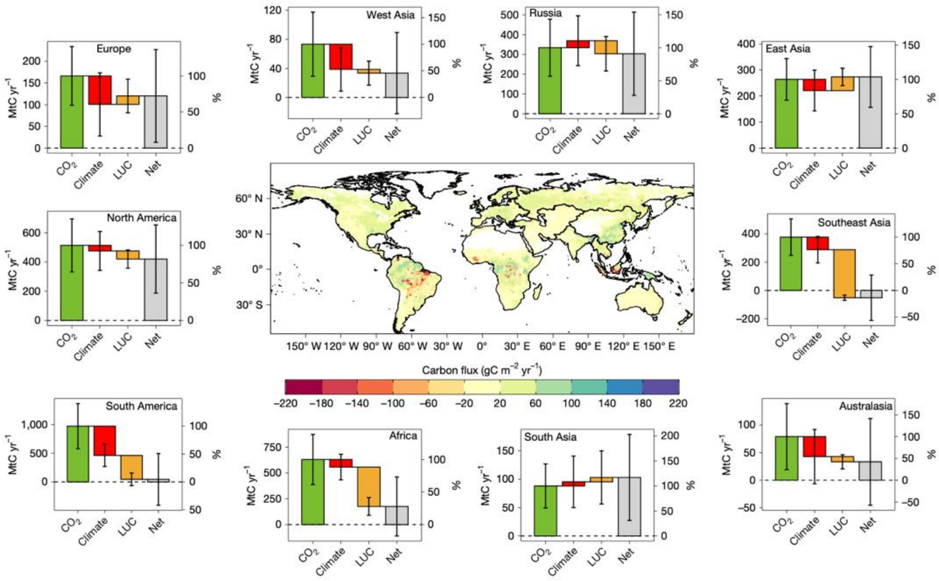

Figure 3. Net land CO_2 fluxes and attribution effects. The figure presents the mean of the net land CO_2 flux for the period 2014-2023. Bars represent CO_2 fertilisation effect (green), climate impacts (red), and land-use change (orange). **Source**: Friedlingstein et al., 2026b

1.2.19. **Extreme climate events can significantly reduce ecosystem carbon uptake**. The 2023-2024 El Niño led to substantial reductions in carbon uptake by ecosystems, particularly in tropical regions, where the land sink declined by approximately 66% relative to pre-El Niño levels in 2022 (Ke et al., 2024).

1.2.20. **Rising temperatures, drought stress, and ecosystem disturbances, such as invasive species and infestations, can reduce the capacity of vegetation to sequester carbon, i.e., weaken the carbon sink**. Observational evidence has indicated emerging regional "hotspots" where the carbon sinks are weakening, for example, in parts of the Amazon (Hubau et al., 2019) and in Europe (Migliavacca et al., 2025), where droughts and increased tree mortality have contributed to a downward trend in scale carbon uptake. At the same time, climate change may increase carbon uptake in some high-latitude regions, where longer growing seasons and warming conditions enhance vegetation growth (Lombardozzi et al., 2025). Yet, these gains are unlikely to compensate for a declining sink in tropical to temperate ecosystems.

1.2.21. **Globally current Earth system models do not identify clear tipping points for ocean or land sinks during the twenty-first century,** with most scenarios projecting that terrestrial and ocean ecosystems will remain a carbon sink rather than source, although the magnitude and stability of the future sink remains uncertain.

Key insights

Stabilising global temperature requires immediate and sustained reductions in GHG emissions, with CO_2 anthropogenic emissions reaching net-zero and non-CO_2 emissions reduced or balanced by CDR at a rate sufficient to reduce their contribution to the global energy imbalance. Reaching net-zero CO_2 emissions is essential, and CDR must be provided on a like-for-like basis – with managed land and geological removals addressing emissions from their respective sources. For fossil fuel and industrial emissions, this required geological-timescale storage, consistent with a Geological Net Zero (GNZ) pathway. The net geological carbon intensity (NetGCI) provides a transparent indicator of progress toward GNZ.

Natural sinks are vulnerable to climate impacts and extremes and show signs of weakening. Their long-term removal capacity is poorly known. Hence, careful monitoring – and where feasible, active management to enhance resilience – is essential.

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A clear distinction must be maintained between: (i) natural passive uptake by ocean and terrestrial systems; (ii) human-induced nature-based sinks, such as afforestation and restoration of degraded lands; and (iii) geological removals through with storage on geological timescales. Conflating these categories risks overstating progress toward genuine and durable temperature stabilisation.

1.3. Removals required to keep 1.5℃ in reach

Since its adoption, Parties to the Paris Agreement have cited their ambition to keep 1.5°C within reach as a central component of their climate commitments. This increasingly requires the deployment of large-scale carbon dioxide removals. Consequently, (i) removals have become a core component of net zero strategies which limit warming to 1.5°C, (ii) the scale of required removals and risks of reliance on removals in the overshoot context, and (iii) the technical and political challenges of measuring, reporting, and governing removals.

1.3.1. **Article 4.1 of the Paris Agreement establishes that Parties aim to peak GHG as soon as possible** and undertake rapid reductions thereafter, and in accordance with best available science, "*achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century*".

1.3.2. **As global GHG emissions have continued to increase, the role of carbon dioxide removal (CDR) is becoming a central element of Paris-aligned climate policy.** Most plausible emissions pathways involve residual emissions that must be counterbalanced by CDR. An exceedance of 1.5°C can only be reversed through large-scale CDR. CDR therefore serves multiple roles: enabling the achievement of net-zero CO_2 emissions, enabling net-negative CO_2 required to reverse the temperature increase following exceedance (IPCC 2018, 2022). CDR deployment may also carry implications for the allocation of historical responsibility, with some jurisdictions potentially obligated to contribute disproportionately greater volumes of CDR to reflect their larger historical emissions (Ganti et al., 2026).

1.3.3. **Successful CDR deployment may reduce some long-term overshoot risks, such as Earth system feedbacks and irreversible thresholds,** by enabling temperature decline after peak warming. However, overconfidence in a large-scale "warming reversal" in itself represents a significant risk (Schleussner et al., 2024). Some analyses suggest the need for precautionary CDR capacity beyond median pathway requirements to hedge against Earth system uncertainty (Schleussner et al., 2024), though it is worth noting that the same logic applies equally to accelerating near-term emissions reductions, raising questions about whether CDR is fit to bear a disproportionate share of precautionary risk management.

1.3.4. **Current global CDR is dominated by land-based removals and falls significantly short of the removals requirement in scenarios that limit warming to 1.5°C following an overshoot.** The scale of required CDR is determined by the rate of emissions reductions to net-zero CO_2, which may create an unachievable burden for actors at this point. Novel non-land-based CDR represents only a small share of the total deployed removals, despite their prominent role in many mitigation scenarios and the current size of fossil CO_2 emissions (Smith et al., 2024).

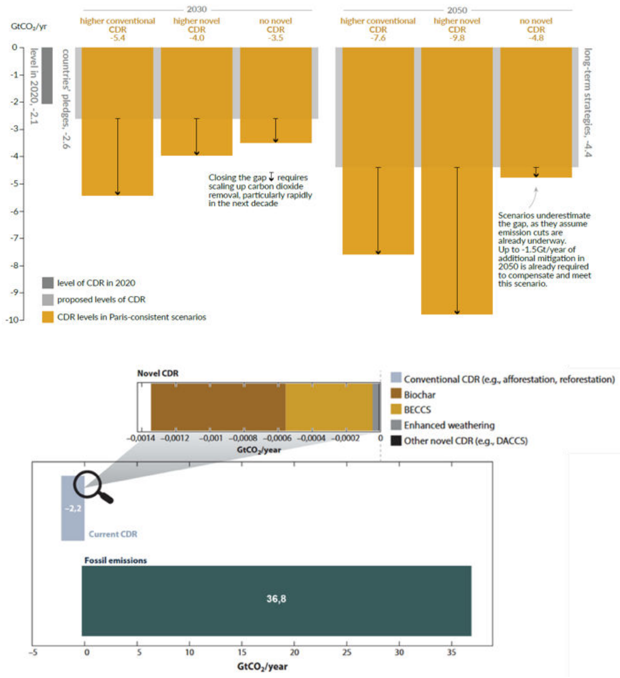

Figure 4. The global state of CDR compared to fossil CO_2 emissions. The figure illustrates the gap between current and proposed levels of CDR and fossil CO_2 emissions in 2023. compared to fossil CO_2 emissions in 2023. Panel (a) compares the proposed levels of CDR (grey bars) with the levels required to meet the Paris Agreement temperature goal (orange bars). Panel (b) compares the current global CDR capacity of approximately 2.2GtCO₂ per year, of which 0.002 GtCO₂ represents novel CDR methods, with global fossil CO_2 emissions of 36.8 GtCO₂ per year in 2023. **Source**: Edenhofer et al., 2025.

1.3.5. **Land-use emissions and removals play an increasingly significant role in mitigation pathways and national climate strategies**. The land use, land-use change and forestry (LULUCF) sector is estimated to contribute to approximately 20-30% of net emissions reductions required in 1.5°C - 2°C pathways, reflecting both reduction of land-use emissions and the enhancement of terrestrial carbon removals (IPCC, 2022).

1.3.6. **Observations indicate that forest carbon sinks are dynamic rather than static.** In Europe, the forest sink has weakened in the past decade, moving the EU further from its LULUCF objectives for 2030 (Korosuo et al., 2023; Migliavacca et al., 2025). Several drivers have contributed to this decline, including increased harvesting, more frequent and severe disturbances such as fires, storms, and pests, slowing forest expansion, ageing forests, and climate-related impacts on productivity. These pressures can reduce carbon sequestration capacity for extended periods and weaken forest ecosystem resilience.

1.3.7. **Different accounting approaches between national GHG inventories and global carbon budget models create significant inconsistencies in estimates of anthropogenic land CO_2 fluxes**. National GHG inventories use a "managed land" proxy to identify anthropogenic emissions and removals. Global carbon budget models instead separate direct human drivers from indirect effects such as CO_2 fertilisation, nitrogen deposition, and climate change (i.e., "passive sink"). A substantial gap has emerged between inventory-based estimates and model-based estimates of anthropogenic land CO_2 fluxes (Grassi et al., 2023), totalling approximately 9 GtCO₂ per year for the period 2015-2024 (Friedlingstein et al., 2026a; Melo et al., 2026), with national inventories reporting larger net sinks than global models.

1.3.8. **Rather than selecting a single "correct" accounting approach, one proposed solution is to develop transparent translation methods that allow for direct comparison of results from different frameworks**. Providing both original model outputs and translated values aligned with national inventory definitions could improve comparability between reported emissions and scenario pathways. Such translated results would significantly influence estimates of the remaining carbon budget (Grassi et al., 2021; Gidden et al., 2023) and interpretations of what achieving "net zero" implies for temperature outcomes (Allen et al., 2024). Specifically, in the absence of this translation, countries' climate progress would appear better than it actually is.

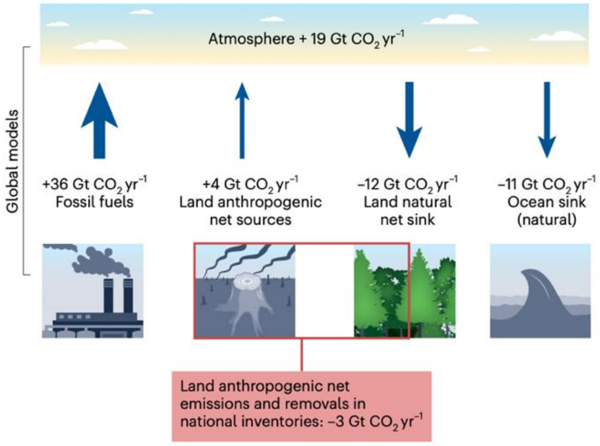

Figure 5. Mismatch in anthropogenic land CO_2 emissions and removals. National GHG inventories (red box) use a broader definition of CO_2 emissions and removals compared to the global models. Numbers from the Global Carbon Project 2025. **Source**: Grassi et al., 2025.

1.3.9. **Uncertainties surrounding land sinks and increasing disturbance risks mean that countries may need to plan for emissions reductions and removals beyond net zero targets.** This reinforces the importance of transparency and interoperability in reporting systems, complementary data from GHG observations, and clear communication on the physical conditions of what is required to durably stabilise global warming.

1.3.10. **Large-scale CDR raises sustainability challenges**. Decisions about CDR deployment require comparison between the risks of climate impacts at given warming levels and the ecological and social risks associated with large-scale removal strategies (Prütz et al., 2026). For example, scaling land-based removals involves complex governance challenges related to land tenure, institutional capacity, financing, and local participation (Sanz Sánchez & Blazquez, 2025). These challenges are significant as land systems differ fundamentally from energy systems, with highly fragmented ownership structures and strong local socio-cultural influences

1.3.11. **Under conditions of deep uncertainty, portfolio approaches that explore a range of uncertainties may support more robust decision-making than single-method optimisation (Rodriguez et al., 2025).** Such approaches can yield important insights for policy and finance, for example, blended finance mechanisms that combine public, philanthropic, or concessional capital with private investment to fund high-integrity, high-impact CDR projects.

1.3.12. **Strengthening accountability and demand within the climate governance frameworks is key, particularly in relation to historical emissions and responsibility for 'overshoot' outcomes** (Ganti et al., 2026). Voluntary carbon markets may contribute to demand for novel CDR but are unlikely to close the deployment gap on their own (Fuss et al. in Smith et al., 2024). Demand for CDR may therefore be supported through procurement mechanisms and compliance frameworks. Managing first-of-a-kind investment risks will also require targeted policy instruments, including carbon contracts for difference (CCfDs) and other public finance mechanisms. Emerging proposals for more rules-based funding and carbon-debt frameworks may strengthen transparency and accountability in financing CDR deployment (Bednar et al., 2021; Edenhofer et al., 2024).

1.3.13. **Forest management strategies may need to prioritise ecosystem resilience**, **with mitigation treated as a co-benefit rather than the dominant objective** (Dooley et al., 2024). Biodiversity and carbon sink integrity are closely linked: greater species diversity enhances ecosystem resilience to climate change, while projected losses of plant species could themselves result in significant additional carbon emissions (Weiskopf et al., 2024). Over-reliance on "carbon farming" narratives may risk reinforcing unsustainable agricultural practices without delivering timely emissions reductions. Overshoot scenarios may further increase pressure for land-based CDR deployment, raising governance challenges and trade-offs between climate mitigation, biodiversity protection, and food systems (Perkins et al., 2023).

1.3.14. **Effective governance requires context-specific approaches rather than uniform policy templates**. Standards and methodologies are insufficient without early stakeholder dialogue, distributive financial incentives, actor-specific and context-specific planning, and governance systems capable of learning and adapting over time (Honegger et al.,2022; Batement et al., 2024; Dörpmund, 2025; Holland-Cunz and Baatz, 2025).

1.3.15. **Critically, the current CDR deployment is far from sufficient to compensate for ongoing GHG emissions or to meet the scale required in overshoot scenarios.** Emissions reductions and CDR deployment must therefore be pursued in parallel and at scale – as complementary but distinct imperatives – ensuring that reliance on future removals does not substitute for, or undermine, the urgent and deep emissions reductions required to keep 1.5°C within reach.

Key insights

Carbon dioxide removal (CDR) has become a central element of Paris-aligned climate policy. Most plausible pathways to 1.5°C involve residual emissions that must be counterbalanced by CDR, and any temperature exceedance can only be reversed through large-scale net-negative CO_2 emissions. However, current CDR deployment, dominated by land-based removals, falls significantly short of what these pathways require.

Land carbon sinks are dynamic and vulnerable Forest sinks are weakening in key regions due to harvesting pressures, climate disturbances, and ageing forests. Significant inconsistencies between national GHG inventories and global carbon budget models, estimated at approximately 9 $GtCO_2$ per year, risk distorting interpretations of net zero targets and progress.

Scaling CDR raises substantial sustainability, governance, and equity challenges. Land-based approaches involve complex trade-offs between climate mitigation, biodiversity, and resilient systems. CDR deployment may also carry implications for the distribution of historical responsibility across jurisdictions. Portfolio approaches, blended finance mechanisms, and compliance frameworks will be needed to close the deployment gap, alongside context-specific governance that priorities stakeholder engagement, transparency, and adaptive management.

1.4. Beyond the “balance”

As mitigation pathways increasingly imply an overshoot of 1.5 °C. Climate policy must address not only how to reduce emissions to net zero, but also how to govern a world in which temperatures temporarily exceed 1.5°C before declining. This might raise a set of scientific, political, and institutional questions around the achievement of the “balance” in Article 4.1 of the Paris Agreement. The Belém text on overshoot introduces additional complexity. The risks include the possibility of greater climate impacts, increased reliance on CDR, and intensified distribution conflicts over responsibility, finance, and burden-sharing.

1.4.1. **Temperature overshoot refers to pathways in which global mean temperatures temporarily exceed 1.5°C before later declining, typically through sustained emissions reductions combined with large-scale CDR** (Reisinger et al., 2025). A single year above 1.5°C does not necessarily mean that the Paris Agreement temperature level has been formally “exceeded” because the Agreement refers to long-term global temperature averages. Overshoot pathways are increasingly considered plausible as most pathways now involve either residual emissions or delayed reductions that require subsequent temperature decline.

1.4.2. **The concept of a temperature overshoot is considered in illustrative pathways presented in the IPCC Special Report on Global Warming of 1.5°C**. Those scenarios included both pathways with no or limited overshoot and pathways with higher levels of overshoot with extensive deployment of CDR.

1.4.3. **Overshoot should not be interpreted as a desirable or manageable alternative to deep and rapid reductions in GHG emissions**. Overshoot represents a “second-best world” characterised by heightened climate risks, increased costs, intensified trade-offs, reduced resilience, and greater uncertainty in both Earth system responses and policy outcomes (Schleussner et al., 2024).

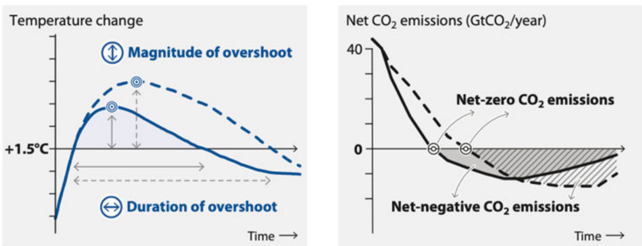

Figure 6. Conceptual dimensions of overshoot. Source: Reisinger et al., (2025)

1.4.4. **International climate negotiations have recently started to recognise the likelihood and risk of temperature exceedance,** with the COP30 Mutirão marking the first international commitment to limit the magnitude and duration of overshoot.

1.4.5. **Contributing to achieving a return to 1.5°C is not an established political objective at the national level.** Few countries – if any – have articulated quantified commitments consistent with sustained global net-negative emissions. Where long-term strategies reference national net-negative aspirations, corresponding legislative and regulatory frameworks remain nascent and/or non-existent.

1.4.6. **Research on overshoot increasingly integrates Earth system feedbacks, adaptation limits, loss and damage, and questions of justice and legal responsibility**. These emerging research areas highlight the need to move beyond modelling exercises and incorporate societal and ecological responses to overshoot conditions. Overshoot also raises governance questions around how responsibility for temperature exceedance should be allocated and how obligations associated with net-negative emissions might be distributed across countries and sectors (Geden and Reisinger, 2025). Quantified net-negative commitments by developed countries could trigger escalating expectations related to historical responsibility and carbon debt (Geden and Reisinger, 2025; Mohan et al., 2021). Many developing countries remain cautious about new long-term commitments when financial support and technology transfer remain uncertain. Overshoot, therefore, risks intensifying long-standing equity debates.

1.4.7. **Sectoral governance presents challenges**. While some scenarios assume net-negative contributions from specific sectors, few sectors have articulated commitments to deliver net-negative emissions. Conventional "polluter pays" policy mechanisms are designed to incentivise emissions reductions but are less suited to compelling actors to deliver removals for temperature reversal. This may shift responsibility towards governments as "removers of last resort", raising questions of fiscal capacity and intergenerational equity and pointing to the need for new governance mechanisms – such as a Carbon Central Bank – to oversee CDR procurement at scale (Lessman et al., 2026).

Key insights

Overshoot introduces significant governance, communication, and equity challenges for climate policy. While temperature exceedance and decline may be embedded in modelled mitigation pathways, it should not be interpreted as a substitute for rapid emissions reductions.

A credible policy narrative must link immediate mitigation, management of residual emissions, and the eventual deployment of CDR for temperature reversal. Overshoot also raises new questions about intertemporal responsibility, burden-sharing across countries and sectors, and the need for robust governance of net-negative emissions. Given the uncertainty surrounding large-scale CDR deployment and the absence of clear policy frameworks for temperature decline, strategies should prioritise minimising peak warming and reducing climate risks, rather than relying on the reversibility of warming through future removals.

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