Climate Science

Zero Carbon Analytics

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Net-zero progress overblown by inconsistencies in land carbon accounting

Key points:

- Nationally Determined Contributions (NDCs) - which outline national governments' commitments to emissions reduction - account for land-based carbon removal using different methods to the IPCC.
- When the methods are harmonised, NDCs reduce the budget for limiting warming within Paris Agreement goals by 15-18%, equivalent to bringing forward the deadline for net zero by five to seven years.
- This means governments need to set far more ambitious mitigation targets to achieve net zero as defined by the IPCC, than covered by their current methods.
- Differences in how emissions are reported from managed and unmanaged land in NDCs compared to the IPCC introduces opportunities for bias or misrepresentation, obscuring countries' true climate impacts.
- The amount of land designated for land-based removals in NDC pledges - about 1 billion hectares or the equivalent of around two-thirds of global arable land - is also impossible without complex trade-offs for food security, biodiversity and human livelihoods.
- IPCC models give unrealistically optimistic estimates of land-based removal potential because they don't consider land availability constraints, conflicts and human rights issues, or the erosion of land carbon sinks.
- By comparison, a recent analysis modelling the social and ecological risks of land-based carbon removal potentially reduces the amount of land available for carbon removal by up to 79% compared to IPCC estimates.
- This discrepancy suggests that status quo estimates of land-based carbon removal used to inform global and national climate ambition may be overblown and misleading.

Emissions reduction in NDCs

Under the Paris Agreement, adopted in 2015, countries around the world agreed to submit climate action plans called Nationally Determined Contributions (NDCs) every five years starting in 2020 to address greenhouse gas emissions.[1] NDCs translate global agreements into specific national targets and are the key mechanism for countries to show their commitment to reducing emissions - through, for example, phasing out fossil fuels, deploying renewable energy, decarbonising industries and electrifying transport.

Another approach to reducing emissions involves harnessing the ability of landscapes to capture and store carbon - a greenhouse gas inventory sector referred to as land use, land-use change, and forestry (LULUCF) by the Intergovernmental Panel on Climate

[1] Each new NDC submitted needs to be more ambitious than the last.

Change (IPCC).[2] Natural landscapes around the world store significant amounts of carbon in plants and soil – global forests absorb an average of 7.6 billion metric tonnes of carbon dioxide per year, equivalent to around one and a half times the annual emissions of the US.

In the LULUCF component of their NDCs, countries pledge to plant new forests (afforestation), restore degraded forests (reforestation), protect existing forests and implement sustainable forest management and soil conservation techniques. To a much lesser degree, they also project the use of bioenergy with carbon capture and storage (BECCS), whereby trees, crops or algae will, in theory, be grown to capture carbon dioxide from the atmosphere and then converted into energy, such as biofuels, with the emissions stored below ground.

These forms of carbon dioxide removal are appealing to governments and industries because they don't necessitate immediate, large-scale changes to a country's industrial and energy sectors. However, although most IPCC pathways that aim to limit warming to Paris Agreement targets of 1.5°C or 2°C include carbon sequestration in land sinks, enhancing these sinks alone is insufficient to achieve the necessary carbon reductions. Ambitious and timely NDC commitments this decade could close the emissions gap needed to keep temperatures within targets but require a rapid shift away from traditional fossil fuels in addition to land-based removal.

Due to several scientific and political reasons outlined below, the potential contribution of land carbon sequestration to emissions reductions is significantly overestimated in NDCs and scientific models. This overestimation renders the commitments outlined in NDCs unrealistic and endangers the goals of the Paris Agreement. While several publications have explored this issue, no comprehensive, easy-to-read resource has been created to synthesise the findings. The goal of this briefing is to provide a concise summary of the various reasons NDCs disproportionately rely on land for carbon removal and to outline the potential implications for the Paris Agreement.

Land carbon fluxes are the most uncertain component of the global carbon budget

Countries annually report their progress on the emissions reductions pledged in their NDCs through National Greenhouse Gas Inventories (NGHGIs), following guidelines established by the United Nations Framework Convention on Climate Change (UNFCCC).

Collective progress towards the Paris Agreement goals is assessed every five years in the Global Stocktake, which provides benchmarks for countries for their NDC submissions. If NDCs are insufficient or lack ambition, there is a significant risk that the world will exceed the Global Carbon Budget - the total amount of carbon dioxide that can be emitted while keeping within global temperature targets, leading to temperature increases beyond the targets agreed upon in the Paris Agreement.

Because of the complex interactions of various human-driven effects on greenhouse gas fluxes from land - such as deforestation for agriculture - land carbon fluxes are the most uncertain component of the global carbon budget. At the national level, accurately tracking changes in forests and other land uses is also challenging due to variations in the quality and scope of land-use data, different reporting methods used, and difficulties in separating the influence of humans and climate on the environment as well as in reporting carbon movements in different ecosystems, with estimates relying significantly on simplified models. This means that estimates of emissions from LULUCF are less precise than those from fossil fuels, which are grounded in empirical data.

[2] LULUCF excludes non-carbon-dioxide agricultural emissions, such as methane from livestock.

As a result, the Paris Agreement allows flexibility for countries to determine how they account for emissions and removals from the LULUCF sector, such as the use of different accounting and monitoring methods or different definitions of land-use types in their climate targets. In addition, developing countries are encouraged to gradually adopt economy-wide emission reduction targets depending on their economic and developmental needs. In comparison, developed countries are required to specify a specific, measurable and economy-wide reduction in overall emissions – for example, a 40% emissions reduction compared to 1990 levels.

NDC net-zero may not mean net-zero global emissions

The use of different carbon accounting methods for land-based removal between NDCs and model-based methods, such as those used by the IPCC, makes it hard to measure the emissions and temperature outcomes of current national commitments under the Paris Agreement.

While both NGHGIs and the models used by the IPCC to assess the pathways necessary to achieve specific climate targets aim to identify greenhouse gas fluxes from land, they differ in how they account for the role of human activity in these fluxes. This affects the extent to which each approach attributes these fluxes to a country's mitigation efforts.[3]

This is especially problematic for countries that rely heavily on the land sector and forest management to achieve their NDCs, leading to over- or under-estimating true emissions and creating inconsistencies between national inventories and the global carbon budget.

A recent analysis illustrated how current NGHGIs for NDCs can make national emissions appear lower than the method applied by the IPCC in assessing alignment with the Paris Agreement. It concluded that once the methods are harmonised - such as by adjusting fluxes from land use - our overall carbon budget is reduced by 15-18%, which is equivalent to bringing forward the deadline for net zero up by five to seven years. What this means is that governments need to set far more ambitious mitigation targets to achieve net zero, as defined by the IPCC.

Unmanaged land is a blind spot in carbon accounting

Discrepancies in the LULUCF emissions estimates between IPCC models and NDCs arise partly because countries are not required to report emissions from unmanaged land – such as emissions from wildfires in remote forests where human intervention is minimal or absent – as these are considered natural rather than human-caused emissions. This has resulted in some highly forested countries designating large areas of forest as unmanaged. But as emissions are still released from these unmanaged areas, excluding them leads to an incomplete picture of the carbon cycle and a country's total emissions.

This has introduced opportunities for bias or misrepresentation. For example, Canada does not include emissions from forest wildfires in its inventory, as around 34% of its forests are classified as 'unmanaged'. This means that emissions from natural disturbances, such as wildfires, in these forests are not accounted for.[4] Additionally, fires within its managed forests are also classified as natural disturbances rather than human-caused disturbances, and so are also excluded from the inventory.

[3] One outcome is that estimates of land-use change due to afforestation or reforestation are in close agreement between NGHGIs and IPCC models, but differ for managed forests.
[4] The Canadian government does not have a database for the net carbon flux in unmanaged lands in the country, making it difficult to track carbon emissions and evaluate whether Canada's landmass is sequestering enough carbon to offset its emissions.

This oversight leaves significant emissions unaccounted for, obscuring Canada's true climate impact. Around 114 million metric tonnes of emissions was excluded per year from its inventory between 2005 and 2021 - equivalent to around half the total carbon dioxide emissions from gas in Canada in 2023.[5] In 2023, a year of record-breaking wildfires, natural disturbances released an estimated 640 million metric tonnes of carbon from Canada's forests, which is more than Canada's carbon dioxide emissions from fossil fuels in 2022.

Managed land can lead to overestimates of climate progress

Flexible guidelines also mean that there is variation in what constitutes managed and unmanaged land. Under the Kyoto Protocol adopted in 1997, countries agreed to count greenhouse gas emissions and removals from land activities towards their climate targets only if they result from direct human actions. However, the IPCC later noted that as human activities and environmental changes are closely linked, they are not practical to separate in greenhouse gas inventories - for example, forest loss from both logging and climate-induced drought. Therefore, 'managed land' was introduced as a proxy for human effects in NDC guidelines, with all greenhouse gas fluxes occurring on managed land being counted regardless of whether they are driven by humans or the environment. This is not a feature of the IPCC's models that are used for estimating carbon fluxes, which clearly distinguish between emissions from managed and unmanaged forests.

This means that countries can classify natural forests as managed land in their NGHGIs, enabling them to report natural carbon removal as emissions reductions. Including natural land as managed land can also give a misleading picture of a country's actual climate efforts by overestimating carbon removals and making progress seem greater than it is. This is further aggravated by the fact that some countries - particularly those that are afforded flexibility in emissions accounting - also report implausibly high forest sinks, have incomplete assessments or have inconsistent estimates across reports. Some forest-dense countries are claiming credit for the carbon that their unmanaged forests are sequestering, using this as a means to justify fossil fuel extraction while also making net-zero claims.

Land-based removal plans are unrealistic

The lack of stringent accounting guidelines has led to a significant over-allocation of land for carbon removal in NDC pledges, beyond what is technically feasible or safe. The Land Gap Report calculated that there is about 1 billion hectares of land for land-based carbon removal included in NDC pledges to 2060 - equivalent to around two-thirds of the world's arable land and a land area bigger than China. Such large-scale commitments would be impossible without catastrophic impacts, including the displacement of food production and threats to biodiversity.

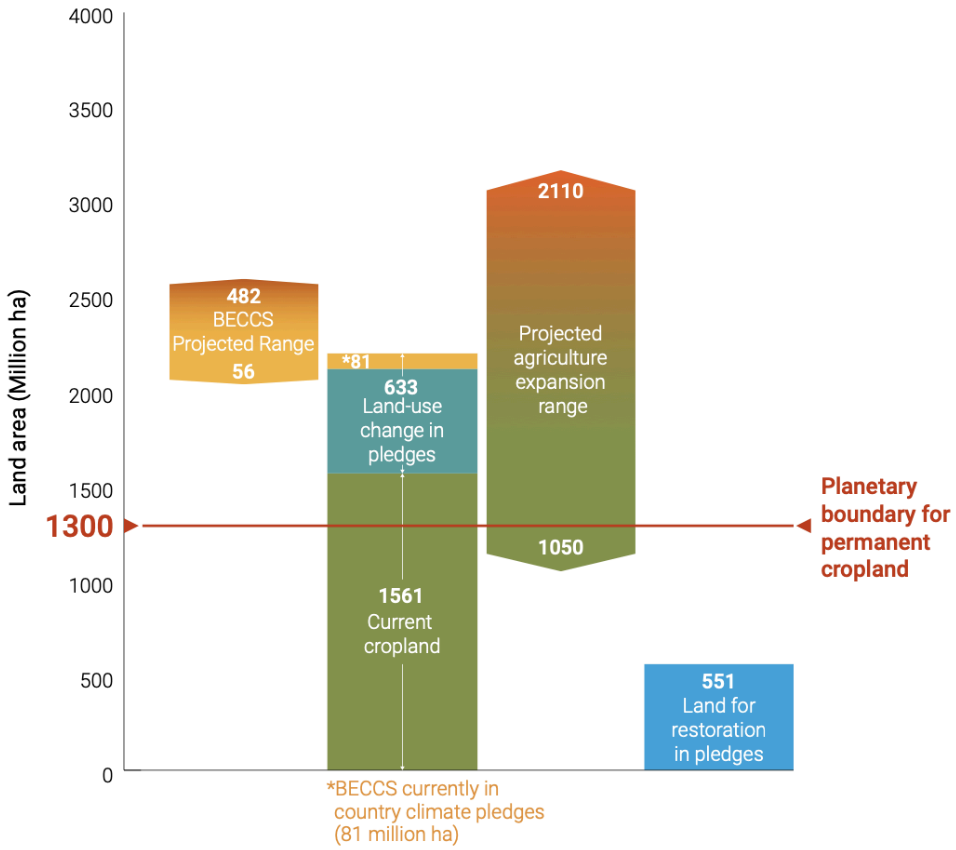
Pledges for land-based removal in NDCs rely heavily on planting new forests or plantations, with about half of the land proposed for carbon removal in NDCs requiring changes in present land use. Land-use change is already the biggest driver of biodiversity loss, which is essential for ecosystem resilience and the provision of ecosystem services such as food and water security and carbon sequestration.[6]

In addition to the risks around increased competition for land use, estimates suggest that the 'safe limit' for expanding agriculture has already been passed, resulting in ecosystem degradation. Figure 1 shows that global cropland already exceeds the planetary boundary

[5] This is compounded by the fact that Canada classifies removals from mature forests as human-caused.
[6] Agricultural land is already under significant pressure from rising global food demand, expanding populations and the need to balance land use with biodiversity conservation and climate mitigation efforts. A 2022 analysis estimated that afforestation and bioenergy production could place an additional 41.9 million people at risk of hunger by 2050 due to higher food prices and displacement of agricultural land.

for sustainable land use, with land-use changes in pledges and current and projected BECCS projects adding nearly an extra two-thirds to the current land-use change area. There is very little land left that can be used for carbon dioxide removal without complex trade-offs. To be genuinely effective, carbon removals plans need to factor in ecological limits and support biodiversity.

Figure 1. Land for mitigation crosses planetary boundary thresholds



Source: The Land Gap Report, 2022.

Even if the estimates of removal potential from land in NDCs were technically feasible, a 2023 analysis calculated that current NDCs are insufficient for meeting Paris Agreement targets - actions outlined in NDCs are due to result in warming of 2.5-2.9°C by 2100.

Limitations in IPCC models of future land carbon removal

While NDCs focus on near-term actions to reduce greenhouse gas emissions, Integrated Assessment Models (IAMs) used by the IPCC project long-term scenarios for achieving climate goals. IAMs assess the interactions between climate, energy, land use and economic systems to understand the long-term implications of different policy choices and emissions trajectories, offering different pathways that illustrate how various strategies can achieve climate targets. IPCC pathways offer a framework for countries to set their emissions reduction targets and to align their NDCs to demonstrate their commitment to international climate agreements.

However, recent research argues that the methodologies in IPCC models are over-relying on land-based removal by building in assumptions about land use that are unrealistic. The models do not reflect real-world conditions such as land availability, lack nuance by failing to capture the complexities of human systems and ecosystems, and expose vulnerable communities to avoidable risks. As IPCC reports are the primary mechanism informing the

UNFCCC, inappropriate models have the potential to lead to misguided policies and ineffective climate action, ultimately hindering efforts to reduce greenhouse gas emissions and meet international climate goals.

Hidden assumptions mean models over-rely on land

A key challenge with the representation of land-based carbon removal in IAMs is the assumption that significant emissions generated in the near term will be offset in the distant future through decades of land-based removal.

Because of their emphasis on cost-effectiveness, least-cost pathways and supply-side technologies, IAMs often assume that large-scale BECCS and afforestation projects can be implemented easily, without considering competing demands for land. This leads to overestimations of the amount of land available for future carbon removal in the LULUCF sector. To demonstrate this, a 2018 study assessed the rate at which land uses change in IAMs and found that in scenarios limiting warming to 2°C by 2100, cropland for BECCS is projected to expand by 8.8 million hectares per year. This expansion rate is more than three times as fast as the historical expansion of soybean, which is currently the fastest-growing commodity crop and a significant driver of deforestation in the Amazon.

IAMs also have idealised assumptions that do not fully consider the technical, social and economic barriers to scaling up such efforts, such as land tenure issues, governance challenges, the potential for conflict over land use and human rights issues, including rights to food, water and a healthy environment.

IAMs are built on assumptions of 'empty land' that do not consider nomadic or Indigenous lifestyles or non-forest ecosystems, such as savannas, and also broadly assume that forests can be converted to cropland for bioenergy. BECCS only features in the NDCs of seven countries, totalling 80 million hectares of land, but it is much more prominent in modelled IPCC pathways, with a median land demand of 199 million hectares (ranging from 56 million to 482 million hectares) in 1.5°C-consistent pathways. However, given such a significant land demand for BECCS from a small number of countries in current NDCs, a land demand of 199 million hectares in future pathways is likely to be an underestimate if BECCS becomes as widespread as in modelled pathways.

The models have also been criticised by researchers for being opaque, with specific value judgments about the future buried in the mathematics of the model. By assuming that the financial costs of mitigation technologies will fall in the future – through applying a high discount rate in the model – solutions like BECCS, which has not yet been proven to work at scale, can appear more cost-effective than proven, readily implementable actions. As BECCS is considered 'carbon neutral' in the models, many IAMs also favour large-scale BECCS over renewable technologies to meet the requirements of one of the more ambitious climate pathways that assumes significant reductions in greenhouse gas emissions.[7]

A 2024 analysis found that a high discount rate in IAM models favours high overshoot scenarios - where global average temperatures temporarily exceed a warming target before dropping back down to, or below, the target in the future - rather than scenarios that would mitigate long-term warming effects. This is because of the short timescale over which economic adaptation is assessed in the models. These high overshoot scenarios result in a heavy reliance on land-based carbon dioxide removal in the future as emissions are not reduced fast enough to limit warming. Overshoot is estimated to be cheaper than longer-term solutions and is therefore favoured by the models. However, overshoot comes

[7] The RCP 2.6 emissions pathway in the IPCC's Sixth Assessment Report.

with various risks and uncertainties, such as species extinction and ecosystem collapse, and has potentially irreversible consequences. Overshoot also raises moral concerns, as climate-related impacts disproportionately affect vulnerable populations, especially in low-income countries.

Reliance on land carbon removal raises sustainability risks

A recent analysis proposed thresholds for land-based sequestration that account for social and ecological risks, thereby developing realistic and sustainable estimates for land-based CDR while accounting for environmental and resource limits (Table 1). The analysis estimates that the sustainable potential of LULUCF measures for carbon removal, including limited reforestation, forest restoration, reduced forest harvest, agroforestry and silvopasture, and BECCS is 3.3 billion-3.8 billion tonnes per year.[8]

The study finds that at high sustainability risk – the point at which multiple ecological and social sustainability limits are likely to be overstepped with potentially irreversible consequences - the value is 6.4 billion tonnes per year. These estimates of sustainable - and hence feasible - removal potential are more conservative than the average estimates in the IPCC's Sixth Assessment Report – 15.6 billion metric tonnes of carbon dioxide per year between 2020 and 2050 for BECCS, forest and ecosystem protection, restoration and management, and agroforestry, as well as the Emissions Gap Report which included estimates of 5.9 billion tonnes per year by 2030 and 8.4 billion tonnes by 2035 for forestry-related land management,[9] and the State of CDR Report at 7 billion-9 billion metric tonnes by 2050 from forestry-related removal, BECCS, ecosystem restoration and novel technologies such as direct air capture. Compared to IPCC estimates, a low sustainability risk scenario potentially reduces land available for carbon removal by around 79%.[10]

Overall, the greatest risks are linked to scenarios with slower emission reductions and higher reliance on future carbon removal technologies. This highlights the need to reduce emissions quickly and significantly and not rely on future carbon removals – including from land – in order to avoid the worst outcomes.

[8] Values obtained from Supplementary Table S1 in the report.
[9] Values obtained from Table 6.2: Sectoral mitigation potentials in 2030 and 2035.
[10] This is a rough calculation assuming a direct comparison between land-use footprint in the IPCC technical mitigation potential and the analysis in Deprez et al. (2024) and was calculated as the difference between the IPCC estimates of 15.6 billion metric tonnes and the lower sustainability risk estimate of 3.3 billion tonnes.

Table 1. Sustainability risks for land-based carbon dioxide removal for the five IPCC Illustrative Mitigation Pathways compatible with the Paris Agreement.

	2°C		1.5°C high overshoot		1.5°C limited or no overshoot					
	IMP-GS General strengthening of policies		IMP-Neg Negative emissions		IMP-LD Low demand		IMP-SP Shifting pathways		IMP-Ren Renewables	
	2050	2100	2050	2100	2050	2100	2050	2100	2050	2100
CO2 emissions % change to 2020 levels	-72	-115	-73	-135	-95	-110	-85	-109	-95	-104
Sequestration (billions of tonnes of carbon dioxide per year)										
Total CDR	2.7	10.4	5.1	15.1	3.2	6	1.7	4.2	2.6	3.0
BECCS	0.7	2.3	4.2	8.3	0	0	0.9	2.4	2.4	2.5
A/R	2	4.1	0.7	0.1	3.2	6	0.8	1.7	0.2	0.4
Land footprint (million km2)										
BECCS & A/R larger footprint	2.7	7	7.2	13.3	2.5	4.8	2.1	5.3	4	4.4
BECCS & A/R medium footprint	2	4.7	3	5.1	2.5	4.8	1.2	2.8	1.6	1.9

Sustainability risk level				
	Very high	High	Medium	Low

Data source: Sustainability limits needed for CO2 removal, 2024.
A/R refers to afforestation/reforestation. BECCS & A/R larger footprint assumes a low capture rate and conversion efficiency, while BECCS & A/R medium footprint assumes a medium capture rate and conversion efficiency.

Models do not account for land's declining ability to store carbon

As IAMs are global in scale, their assumptions are simplified and generalised, and therefore they can miss key local dynamics, leading to ill-suited projections at the regional level.[11] IAMs often oversimplify ecosystems, which do not always behave linearly in response to human activities or climate change. For instance, land-use changes can trigger feedback loops that are difficult to capture accurately in simplified models. A 2024 analysis found that IAMs tend to underestimate the risks associated with the interaction between wildfire disturbances and climate change, particularly regarding their impact on the ability of forests to sequester carbon, risking an overly-optimistic estimate of how much carbon forests can remove and store, and inaccurate predictions of future emissions.

[11] The IPCC recommends that these models are interpreted in the context of their assumptions.

This is significant because land and ocean sinks are increasingly absorbing less carbon with rising temperatures. In higher emissions scenarios, the interaction between climate change and the carbon cycle becomes more uncertain due to the risk of positive feedback loops – such as forest fires and permafrost thaw – amplifying climate change impacts. These types of ecosystem responses are not fully integrated into models simply because of their sheer complexity. While models have tended to predict a slow erosion of natural carbon sinks over the next 100 years or so, other estimates suggest that the impact from feedback loops is happening much sooner than anticipated.