

<https://doi.org/10.1038/s43247-025-02494-9>

Land remains a blind spot in tracking progress under the Paris Agreement due to lack of data comparability

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Land carbon fluxes are key to the Paris Agreement. However, data comparability issues persist between countries' land greenhouse gas inventories and mitigation targets, and what land models (bookkeeping and integrated assessments) provide as Paris-aligned benchmarks for land. As a result, the Global Stocktake, aiming to track collective mitigation progress, did not explicitly consider country targets for land. This blind spot leaves countries uninformed of the 2030 gap between their ambitions for mitigation on land and models' benchmarks. Here we track the contribution and evolution of land-related targets under countries' 2020 Nationally Determined Contributions, splitting land pledges between reduced emissions and additional sinks. Land retains a quarter of the global mitigation pledges in 2030, mostly relying on external support (-1.5 ± 1.1 GtCO₂e/yr), of which -0.55 GtCO₂e/yr are additional sinks. It is crucial that future Global Stocktakes include appropriate comparisons between modelled and country-provided land use net emissions. We here offer some concrete suggestions.

The year 2023 concluded with the first Global Stocktake (GST) under the United Nations Framework Convention on Climate Change (UNFCCC). GSTs run in a five-year cycle and track our collective progress towards meeting the goals of the Paris Agreement in the light of the best available science. This is done by comparing aggregated economy-wide national actions and pledges from National Determined Contributions (NDCs) (Decision 19/CMA.1) against the Intergovernmental Panel on Climate Change (IPCC) modelled mitigation pathways aligned with 1.5 °C and 2 °C scenarios¹. The outputs of the first GST included a Synthesis Report (SYN 2023), which analysed the latest mitigation pledges submitted by countries under their second NDC submission (NDC-2020) with a cut-off date of September 2023. Among other outputs, the SYN report aims at identifying opportunities for and challenges in enhancing future mitigation ambition (e.g. NDC-2025). While NDCs have become more complete and

transparent¹, the conclusions from the NDC 2020 submission remain unchanged: governments remain off-track in their 2030 emission commitments to meet both the 1.5 °C and 2 °C goals^{1–4}.

To keep within the Paris Agreement's temperature goals, the Land Use, Land-Use Change and Forestry sector (LULUCF) has a key role to play⁵. Reducing land emissions, as well as conserving and enhancing land-based sinks, are a backbone of Paris-aligned emissions scenarios, which are the benchmarks against which the performance of countries' NDCs is analysed^{6–10}. The vast majority of these well-below 2 °C scenarios quickly eliminate deforestation emissions and rely on land to remove large amounts of CO₂ from the atmosphere (e.g. -4.0 GtCO₂/y from 2020 to 2050)^{5,11–14}. However, based on current performance, these high expectations on land are unlikely to be realised^{11,12,14}. Pledges to end net deforestation by 2030, such as the New York Declaration on Forests or the Glasgow Leaders'

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Declaration on Forests, are falling short^{15–17}, and the implementation of carbon removals on land is already resulting in a trackable gap^{11,12,14}. This gap, known as the Carbon Dioxide Removal (CDR) gap, is the difference between where we should be in terms of global anthropogenic removals under pathways that align with the Paris Agreement, and where we currently are^{11,12,14}. The land-use sector remains, however, highly popular, with ca. 80 percent of all countries including LULUCF measures in their NDCs^{1,18}, 55 percent pledging afforestation activities, and more than half aiming to transact land-based credits under Article 6¹. LULUCF mitigation has so far globally represented a quarter of the planned emission reductions in global pledges under the 2015 NDC submissions¹⁹, and multiple reports have highlighted the sector's potential with up to one-third of the total emission reductions required by 2030^{5,20–22}.

Land is crucial to countries' carbon neutrality strategies^{6,8–12} but its contribution is affected by large uncertainties^{23–25}. Methodological choices, data completeness and quality affect the uncertainty of LULUCF estimates (e.g. net emissions and trends)^{19,23–25}, together with aspects around permanence, additionality and leakage of the implemented activities^{5,13,26,27}. Besides these uncertainties, a well-known source of confusion in LULUCF estimates arises from the different understanding of what an 'anthropogenic' land CO₂ sink is between two major communities^{10,28–32}: 1. national GHG Inventory compilers that estimate historical net emissions (and NDC targets) for LULUCF, typically based on observational data, and 2. Land modellers providing land-use estimates and pathways that are used as emissions' benchmarks to define progress under the Paris Agreement^{10,28}. Due to differences in purposes and scope, these communities have different understandings of what 'anthropogenic' land sinks are, resulting in land estimates that remain incomparable^{10,28–32}. With all its limitations^{33,34}, modellers consider only the 'direct anthropogenic' effects, such as land-use change, harvest and regrowth, while national inventories cover both 'direct' and usually most 'indirect' anthropogenic influences (i.e. the natural response of land to increased atmospheric CO₂ concentration, nitrogen deposition, and climate driven effects such as extended growth-seasons)^{28,32}. As a result, while countries' GHG Inventories reported a global LULUCF net CO₂ sink for 2000–2020 (–2 to –3 GtCO₂/yr)³¹, global bookkeeping models reported it as a global net emission (+4 to +5 GtCO₂/yr)^{30,31,35}. The resulting discrepancy (ca. –7 GtCO₂/yr) is relevant, as it represents close to 20 percent of the global CO₂ net emissions in the same period³¹. Rosetta-stone' approaches that reconcile datasets have been described^{10,28,32}, but translation has relevant implications, i.e. the remaining global carbon budget is smaller and the timing to net zero anticipates^{28–30} and net-zero CO₂ is not enough to halt global warming³⁶.

Due to data incomparability, and to prevent LULUCF emissions uncertainties from propagating to other inventory sectors, the modelling community often omits country-provided LULUCF data from global analyses, both for historical assessments and projected 2030 pledges (NDC)⁴. This has also been largely the case for the first GST and the associated Synthesis Report (SYN 2023)¹, which offers aggregated global emission estimates focused on non-LULUCF sectors only. Hence, country inventory data and country pledged LULUCF emissions in 2030 have not been directly used in the global emission budget nor in the tracking of progress of the GST against the Paris Agreement's goals¹.

Excluding country-provided LULUCF estimates from the GST leaves us unaware of the role of land-use in the second round of NDCs (NDC 2020). As a result of this blind spot, countries lack crucial information about the 2030 gap between their land-based mitigation ambitions and the benchmarks set by IPCC models^{28–32}. This information gap comes at a critical time when accelerated warming^{35,37} and early signs of both vegetation saturation to elevated CO₂ fertilisation and negative impacts of climate extremes on terrestrial sinks^{38–40} are on the rise. However, these factors and not yet properly considered in many LULUCF scenarios that align with well-below 2 °C pathways^{9,12,29,31,40,41}, offering an overoptimistic approach of land's role in reaching Paris-aligned pathways. There is, therefore, an urgent need to track countries' dependence on land use sinks and the

implementation of land-related commitments, and to assess the risks posed to the permanence of these sinks^{9,12,29}.

In this study, we address this blind spot and offer suggestions to include country-provided LULUCF pledges in next GSTs. Estimates from this NDC 2020 analysis also act as a benchmark for future submissions under NDC 2025. We first assess the contribution (and evolution) of 2030 projected LULUCF net emissions under the second submission of NDCs (NDC 2020, cut-off date May 2024) and against NDC 2015's initial pledges (cut-off date April 2016). As a main contribution, we here attempt to disaggregate NDC 2020 LULUCF pledges into reduced emissions (e.g. reduced deforestation) and additional removals (e.g. enhanced forest sinks) by separating pledged activities per country (see Methods). Countries' pledges on additional land removals allow us to track progress of the CDR gap. We then assess 2030 land net emission discrepancies between NDC projected scenarios against model scenarios, to finally suggest next steps to include country-provided LULUCF data in future GSTs. To promote transparency and accountability, we disaggregate our analyses into regional level, also providing some country information.

We organise this manuscript around three blocks of questions (Q) that aim to cover the blind spot on land under the first GST and suggest ways forward for future GSTs:

- What global and regional 2030 mitigation commitments arise from the LULUCF sector in NDC 2020 (Q1), both through reduced emissions and additional sinks (Q2)?
- What is the role of LULUCF targets in relation to economy-wide pledges (Q3), and how have these evolved since the first NDC 2015 submission (Q4)?
- What net emission discrepancies exist in 2030 projected LULUCF scenarios between country-provided estimates (including additional land removals) and modelled estimates (including CDR pathways that align with the Paris Agreement goals)? (Q5)

To assess the role of the LULUCF sector, we focus on countries that account for up to 90 percent of global net emissions or 90 percent of global gross sinks (as defined later in the text), or largest forested countries (see methods and Supplementary Information, SI). A total of 111 countries responded to these requests (EU = 27 countries). 88 of them contained quantitative data for their 2030 LULUCF scenarios. These scenarios include Business as Usual (BAU, i.e. countries' expected net emissions in a given year without additional policy measures on land) and pledges for the LULUCF sector that are unconditional or conditional to external support (i.e. requiring financial, technical or capacity assistance) (see glossary in SI).

To retrieve quantitative data on LULUCF commitments in year 2030, we complemented NDCs with other UNFCCC reports: Long Term Strategies 2050, Biennial Update Reports, National Communications, REDD+ technical annex, other official reports (e.g. national legislation or emission pathways) (see SI Table S1). Mitigation commitments are estimated as the difference between countries' 2030 projected LULUCF scenarios (unconditional and conditional net emissions) and different temporal baselines. For many of our analyses, our baseline is the historical average of years 2011–2020. BAUs are not used here to estimate mitigation commitments, as historical trends provide better time coherence.

To ensure comparability with 2030 pledges, our historical LULUCF data incorporate non-CO₂ emissions whenever available. Since non-CO₂ emissions generally constitute a small fraction of the total net LULUCF emissions, their inclusion should not compromise the comparability with global models, which consider only CO₂³⁵, nor the temporal comparability of our datasets (e.g. historical net emissions vs projected 2030 scenarios)^{19,42}. Historical emissions from countries rely on national GHG inventory datasets (based on a May 2024 updated version of ref. 31), while modelled estimates rely on bookkeeping data from the Global Carbon Budget (2020–2023)³⁵. 2030 projections in this study rely on NDC submissions 2015 (cut-off date April 2016) and 2020 (cut-off date May 2024), while modelled estimates rely on Integrated Assessment Models (IAM) included

in Synthesis Reports (2023, 2016) (SYN 2023, 2016)^{1,2} and the Emission Gap Report (EGR 2023)⁴.

We follow the 2006 IPCC guidelines⁴³ to estimate two dimensions of LULUCF uncertainty—the uncertainty of net flux estimates for a given year (annual uncertainty), and the uncertainty of net flux changes over time (trend uncertainty). We compiled LULUCF net flux uncertainty data provided by 35 countries ($n = 23$ for non-Annex I (NAI), $n = 12$ for Annex I (AI) countries)²⁴. However, given the incomplete information on the uncertainty of national GHG Inventories (especially for NAI), the values used in this study should be considered as rough approximations. We conservatively assume that the uncertainty in the past (e.g. 2011–2020) will hold for the future (2030). We do not assess the uncertainty related to the implementation of policies, nor do we provide uncertainty estimates for emissions only and removals only. To assess if changes in net emissions are statistically discernible among periods, we apply two-sample t -tests ($p \leq 0.05$ and 95% Confidence Intervals) and compare emissions in five-year periods from 2000 to 2030. The analysis of the trend shows that for 2030, the BAU and the conditional scenario were both significantly different from the historical period (2011–2020). Please see further details in Methods and SI (S9–S11).

Results and discussion

Global and regional 2030 scenarios for land in NDC 2020, including disaggregated pledges (Q1, Q2)

The second round of NDCs (NDC 2020) sees the LULUCF sector as a global net sink in 2030 for all the emission scenarios (BAU, un/conditional) (Table 1 and Fig. 1a world). Conditional support is projected to enhance the global net carbon sink to -4.2 ± 1.4 GtCO₂e/y, representing an additional net sink of -1.5 ± 1.1 GtCO₂e/y relative to the -2.7 ± 0.7 GtCO₂e/y during the historical period 2011–2020. Most of these conditional commitments occur in developing countries (non-Annex I, NAI), where net LULUCF emissions would change from -0.8 ± 0.4 GtCO₂e/y in 2011–2020 to -2.1 ± 1.4 GtCO₂e/y in 2030 (Table 1 and Fig. 1a), with India, Indonesia, and Ethiopia hosting the highest pledges.

By disaggregating 2030 LULUCF pledges, we estimate that one-third (-0.55 GtCO₂e/y) of the conditional land pledge could come from additional land removals. Activities such as afforestation, forest/land restoration from developing countries lead to these additional removals, but are highly dependent on external support (Table 1 and Fig. 1b, World, NAI). The largest contribution of the LULUCF conditional pledge remains, however, linked to actions aimed at reducing emissions (e.g. avoided deforestation or degradation) (-0.91 GtCO₂e/y) (Table 1). Without external support, unconditional pledges report little additional domestic action in their NDC 2020 (-0.2 ± 0.3 GtCO₂e/y), slightly enhancing the historical sink from -2.7 ± 0.7 to -2.9 ± 0.7 GtCO₂e/y (Table 1 and Fig. 1a, World). Even if domestic action remains low, their outcomes are better than scenarios presented by countries' BAUs, that foresee a major decrease in the global sink, compared to the historical average (from -2.7 ± 0.7 to -1.2 ± 0.5 GtCO₂e/y) (2011–2020) (Table 1 and difference between the red bar and the blue bar in Fig. 1a). While countries' BAUs tend to underestimate currently implemented land policies¹⁹, some decreases in the global net sink could be expected due to worsening climatic envelopes^{12,38–41,44}, age-class structures (e.g. decreasing growth rates in older stands)³¹, growing demand within the global bio-commodity trade (crops, meat, milk and wood)^{16,17}, urban expansion²⁶, mining and oil development^{45,46}, and energy policies^{20,26}, which are all expected to lead to a global squeeze in the finite land resources¹⁶.

Regionally, the largest land pledges under NDC 2020 for year 2030 come from Asia and Latin America (Fig. 1a, black and grey bars), while Africa would require major funding to reverse their intended increase in land emissions in 2030, visible in their BAU and unconditional emissions (Fig. 1a). Asia leads the global LULUCF mitigation pledge with all its scenarios being net sinks (Fig. 1a) (all bars are negative emissions), and committing to additional net sinks under conditional support (e.g. grey bar, Asia). Latin America has been a net source of emissions historically

Table 1 | Historical LULUCF net emissions and 2030 mitigation summary

2019	LULUCF GHG Inventory (GtCO ₂ e/y)				NDCs (GtCO ₂ e/y)			
	2011–2020		2030 net emissions		2030 net emissions		Mitigation against BAU	
	Net emissions	Gross emissions ^a	Gross removals ^a	BAU	BAU	Gross removals ^a	Unconditional	Conditional
World	-2.8 ± 0.8	$5.4 (3.9)$	$-8.2 (-6.9)$	-1.2 ± 0.5	-1.2 ± 0.5	-2.9 ± 0.7	-1.7 ± 0.5	-3.0 ± 1.1
AI	-1.7 ± 0.4	$0.8 (0.2)$	$-2.7 (-2.3)$	-1.8 ± 0.4	-1.8 ± 0.4	-2.1 ± 0.4	-0.3 ± 0.3	-0.3 ± 0.3
NAI	-1.0 ± 0.6	$4.6 (3.6)$	$-5.5 (-4.6)$	0.6 ± 0.4	0.6 ± 0.4	-0.8 ± 0.6	-1.4 ± 0.4	-2.7 ± 1.1
Mitigation disaggregation (GtCO₂e/y)								
BAU mitigation Unconditional			BAU mitigation Conditional			Historical mitigation Unconditional		
Emission reduction			Emission reductions			Emission reductions		
World	-0.73	-1.00	-1.54	-0.31	-0.31	0.10^*	-0.55^*	-0.55^*
AI	-0.07	-0.21	-0.18	-0.11	-0.11	-0.10	-0.10	-0.10
NAI	-0.66	-0.77	-1.37	-0.20	-0.20	0.20	-0.45	-0.45
Additional sinks			Additional sinks			Additional sinks		
World	-0.73	-1.00	-1.54	-0.31	-0.31	0.10^*	-0.55^*	-0.55^*
AI	-0.07	-0.21	-0.18	-0.11	-0.11	-0.10	-0.10	-0.10
NAI	-0.66	-0.77	-1.37	-0.20	-0.20	0.20	-0.45	-0.45

Net LULUCF emissions (GtCO₂e/y) for the World, Annex I (developed) and non-Annex I (developing) countries, for the year 2019 and for the historical period (2011–2020), with disaggregated gross emissions and gross removals. 2030 scenarios cover Business as Usual (BAU), unconditional and conditional net emissions as net presented in countries' NDCs and other UNFCCC reports, with a cut-off date of May 2024. LULUCF mitigation is the difference between the pledged net emission scenarios in 2030 (un/conditional) and a baseline: either BAU (Business as Usual projections for 2030) or countries' own historical average (2011–2020), for the LULUCF sector. Mitigation against a country's own historical baseline offers more coherent data on LULUCF net emission trends. Mitigation estimates are disaggregated between intended emission reductions (e.g. fire management, avoided deforestation, avoided degradation), and intended additional sinks (e.g. afforestation, reforestation, restoration), as presented in countries' reports, or derived from their historical disaggregated trends. See methods for further information. Historical net emissions, including year 2019, rely on an update of ref.

^aGross emissions include LULUCF emissions deriving from deforestation and organic soils. 'Gross' sinks are the addition of net forest sinks (forest growth and harvest, including carbon stock changes in harvested wood products) and net sinks from croplands, grasslands, and wetlands, mostly due to soil carbon capture.

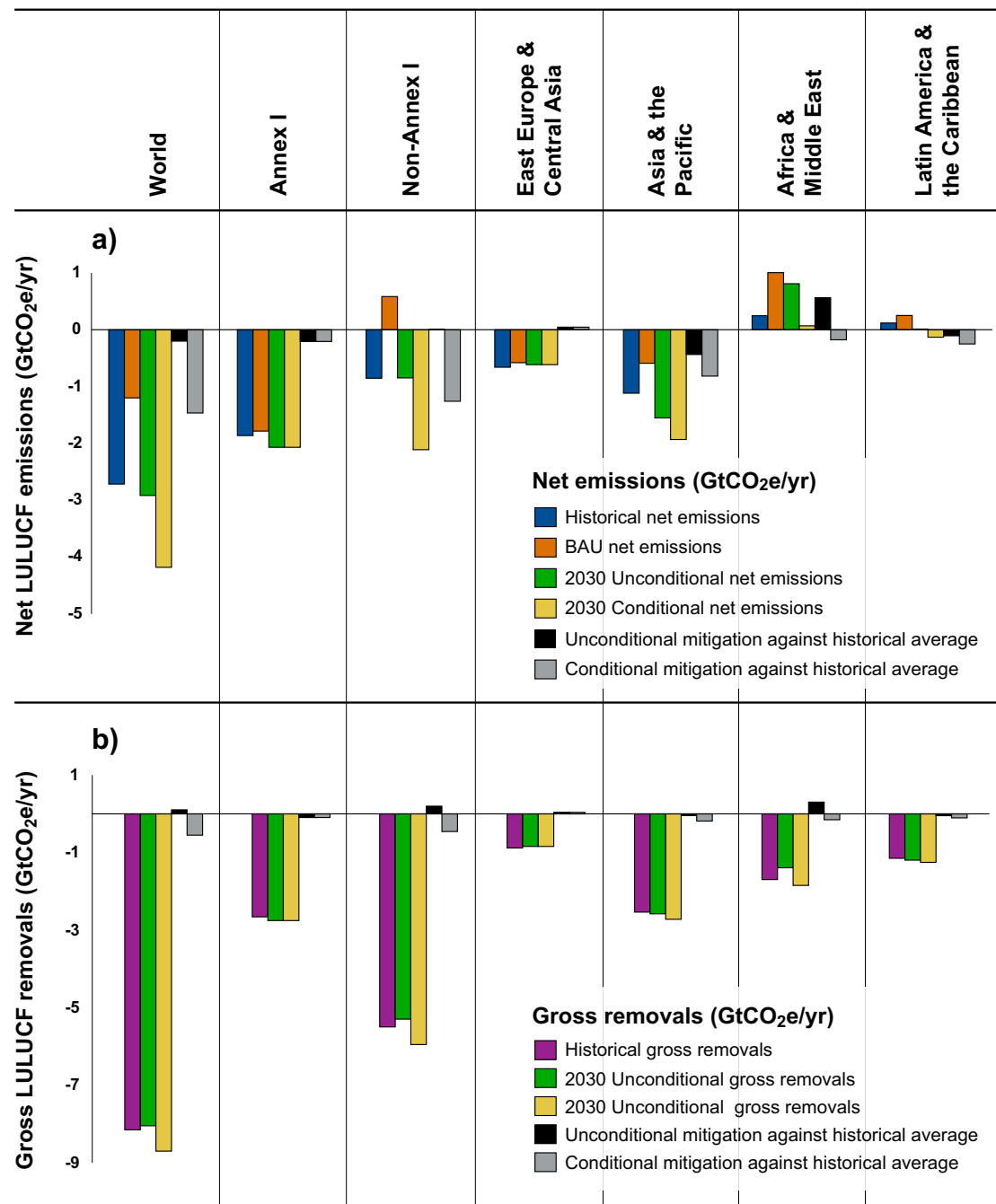


Fig. 1 | Regional net emissions, gross removals, and mitigation commitments under NDC 2020. a Global and regional net LULUCF emissions and **(b)** ‘gross’ removals (sinks), for the historical period (2011–2020), for 2030 scenarios (Business as Usual (BAU), unconditional, conditional); and for mitigation commitments in GtCO₂e/y. Mitigation is here estimated as the difference between projected 2030 net emission scenarios (conditional and unconditional) and countries’ historical net emissions (2011–2020). Estimates are disaggregated for the World, Annex I (developed), and Non-Annex I (developing) countries, and four regions: Eastern Europe & West-central Asia, Asia and developing Pacific, Africa and Middle East,

and Latin America and the Caribbean (see SI, Tables S13, S12–S1). ‘Gross’ removals are the additional net sinks from forests (net result of forest growth and harvest, including carbon stock changes in harvested wood products) and from croplands, grasslands, wetlands (mostly due to soil carbon capture). Please note that World, AI, and NAI data are also presented in Table 1 and are retained here to allow comparability with other regions. No BAU is presented here for gross LULUCF removals as no data exist on how countries disaggregate their 2030 BAU scenarios into gross emissions and removals.

(2011–2020), and country projections foresee an increase in LULUCF net emissions under its BAU 2030 (blue and red bars in Fig. 1a, Latin America). However, Latin America pledges mitigation action both unconditionally and under conditional support, leading to net sinks (e.g. grey and black bars). As mentioned above, Africa is a regional net source and foresees the LULUCF sector to remain as a net source in 2030 (Fig. 1a, Africa) (all bars are positive emissions), except under the conditional support scenario.

In terms of gross removals (sinks), Asia, Africa and Latin America lead the contribution under conditional support (Fig. 1b, grey bars for the cited regions). In our study, gross removals are the additional net sinks from forest (net result of forest growth and harvest, including carbon stock changes in harvested wood products) and net sinks from croplands, grasslands and wetlands, mostly due to soil carbon capture. ‘Gross’ additional removals are relevant as they are the basis to

compare country pledges against projected CDR needs and the CDR-Gap^{11,12,14}.

Country-wise, Russia and China have long contributed to regional net sinks but foresee reductions in their sinks in 2030 due to both natural and human drivers: age-class structures, reduced afforestation rates, higher natural disasters, increased harvesting, market pressure, etc (see SI Table S12 and S13 for country data). Contrarily, India, Thailand, Vietnam, which have long been sinks, aim at raising their land sinks in 2030. Some countries like Brazil, Indonesia, Ethiopia and Côte d'Ivoire that have recently suffered from high deforestation emissions are planning on ambitious unconditional emission reductions. Countries like Mali or Papua New Guinea foresee heavy increases in emissions, with active expansion of their deforestation and agro-commodity sector⁴⁷. India, Indonesia, Thailand, Lao, Brazil and Cuba are the countries committing the most to enhancing their additional removals on land.

The 2030 Carbon Dioxide Removal (CDR) gap (Q5). Pledged removals under NDCs represent additional sinks from countries' historical averages. Estimates in NDC 2020 foresee an additional net sink of -0.55 GtCO₂e/y in 2030, largely dependent on conditional support. This would be a moderate increase compared to the global gross sink of -8.2 GtCO₂e/y from GHG Inventories for 2011–2020 (Table 1 and Fig. 1b world), which is driven by standing forests (-6.9 GtCO₂e/y from forest growth and harvested wood products minus harvest), mostly in developing countries (-5.4 GtCO₂e/y). These values are broadly aligned with satellite-derived fluxes from managed forest land (2001–2022)⁴⁸, and regional contributions of global sinks⁴⁹.

If fully realised, 2030 additional land removals would fall short of the CDR needed to align with well-below 2 °C pathways (minimum of -0.7 GtCO₂e/y for 2030)¹¹, distancing us from CDR needs of -4 GtCO₂e/y for 2050^{11,12,14}. Studies on land's mitigation potential have long shown land's major role on decarbonisation pathways (e.g. -1 to -15 GtCO₂/y at ≤ 100 USD/tonne), but implementation remains low^{5,20–22}. Land ambition is fundamental for reaching the net-zero CO₂ targets expected around 2050 and 2070 under the 1.5 °C and 2 °C scenarios, respectively^{5,11,12,36,37}. Without progressive additional human action to expand and restore the integrity of the existing biosphere sinks, overshooting scenarios seem inevitable^{11,50}.

The tracking of the CDR gap suffers from similar problems than the comparison of LULUCF *net emissions* between IPCC communities. To connect GHG Inventory projections of additional land removals with CDR pathways, data translation is needed^{11,14}. Inventory land removals are typically estimated from ground data collection, such as National Forest Inventories and their numbers integrate both human and environmental drivers influencing forest growth, under managed land. Contrarily, CDRs derive from models that focus only on 'direct anthropogenic' sinks and exclude 'indirect anthropogenic' effects, although this partitioning is highly uncertain^{33,34}. Differences are mostly driven by standing forests, with managed land covering much larger areas in GHG Inventories than in models²⁸.

While some translation effort has already been done for the historical period¹¹, for 2030 projections it is assumed that the disaggregated additional land removals in NDCs are all 'direct anthropogenic' (e.g. afforestation, soil carbon farming, improved forest management, etc.). It can also be assumed that the short-term effects (e.g. 2020–2030) of atmospheric fertilisation and environmental drivers can be neglected, since the additional sink areas are globally small^{11,14}. Until a better approach is available, disaggregated country pledging can offer insights on projected additional removals that are comparable with CDR trajectories.

Evolution of LULUCF pledges under NDCs submissions and economy-wide contribution (Q3, Q4)

Between NDC 2020 and NDC 2015, twenty new countries have added LULUCF commitments. In spite of this increase, only conditional pledges

see a significant increase in LULUCF ambition, with an additional increase of ca. -0.5 (-0.7 to -0.2) GtCO₂e/y (Table 2). The unconditional pledge does not add significant extra mitigation (-0.04 (-0.2 to 0.3) GtCO₂e/y), suggesting a sustained reliance on external support (e.g. funding, capacity, technological assistance). When comparing ambition trends *only* for countries included in NDC 2015 ($n=68$), we see no significant mean increase neither in the conditional (ca. -0.09 (-0.31 to 0.14)) GtCO₂e/y nor in the unconditional pledging (ca. 0.16 (-0.06 to 0.39)) GtCO₂e/y (SI, Table S14). New countries' submissions seem, therefore, to be raising global ambition in NDC 2020. These results remain, however, highly dependent on the selected baseline periods (see results for different periods in Table 2, and SI Table S14). Choosing baselines that include multiple time periods, rather than individual years, helps to capture inter-annual emission variability and offers more robust assessments of land commitments' trends.

Although there is little evidence of individual countries increasing their ambition on land, the LULUCF sector remains highly significant within economy-wide pledges in NDC 2020. Land continues to account for a quarter of the global mitigation commitment (Table 3), similar to its role in NDC 2015¹⁹, but still highly reliant on conditional support.

Changes in 2030 scenarios (emissions in particular) can reflect increases in aggregated NDC ambition but also updates to emission projections and historical emission estimates. Our study captured a striking update of historical LULUCF net emissions that added -3.1 ± 0.9 GtCO₂/y between NDC resubmissions, mostly led by developing countries (Fig. 2). Figure S3 in SI shows slight decreases in NDC 2020 pledges, when considering *only* NDC 2015 countries ($n=68$). The observed downward shift in LULUCF net emissions affects the magnitude of the sink rather than the trend (Fig. 2) (see SI Tables S15–S16 for further details). This large increase in the sink reflects a more complete reporting, including the addition of ca. extra 300 million hectares of forests under managed land. Larger areas of managed land respond to enhanced capacities and improved data access, but also to methodological updates. As examples: countries shifting from activity-based IPCC guidance (IPCC 1996)⁵¹ to land-use reporting (IPCC 2006)⁴³, or countries updating their historical LULUCF estimates by including *both* emissions and removals.

Together with the observed increase in the net sink, both NDC submissions (2015 and 2020) show decreasing trends in their historic LULUCF net emissions (Fig. 2). This trend is mostly driven by increasing LULUCF gross removals (Fig. 3a), rather than by reduced emissions (See SI Fig. S4), with NAI countries, and particularly the Asian region, leading the sink (Fig. 3b). China's and India's large reforestation and plantation activities drive the regional sink, together with Thailand's increasing sink trends. GHG inventory data for 2000–2020 shows that gross removals have increased globally by -1.2 GtCO₂e in the last 20 years (Fig. 3a), led by forest growth (-0.62 GtCO₂e), soil sinks from non-forest land (croplands in Asia and grasslands in the US and Russia) (-0.46 GtCO₂e), and a reduction in global deforestation (-0.65 GtCO₂e) (see SI Table S17).

Changes in historical baselines and associated NDCs shifts are here the result of time series recalculations, which veil for temporal data consistency and data quality in GHG inventories. They are welcome as they reflect higher capacities, better data availability, and updated methodological choices. However, shifting LULUCF baselines can affect the assessment of the land use sector's contribution to global net emission budgets and enlarge the discrepancies with modelled land estimates, affecting net-zero trajectories^{28–32}. Time series recalculations are neither exclusive of the land use sector, nor of countries' GHG Inventories. Similar shifts have also affected the modelling community with increased LULUCF sinks of -2 GtCO₂ for bookkeeping models. As an example, LULUCF estimates pre/post year 2020 under the Global Carbon Budget reduced from $+6.6$ to $+4.6$ GtCO₂/y⁴¹. This shift consequently reduced global net emissions under the IPCC AR6 (e.g. from 59 ± 6.6 GtCO₂e to 56 CO₂e for year 2019)^{17,41}, and partly affected UNEP's Emission Gap

Table 2 | Evolution of LULUCF commitments under NDC 2015 and NDC 2020 submissions

MtCO ₂ e/y	NDC 2015				NDC 2020				NDC 2020–NDC 2015			
	2030 LULUCF Net emissions		2030 LULUCF mitigation commitments		2030 LULUCF Net emissions		2030 LULUCF mitigation commitments		Difference in 2030 LULUCF commitments			
	Unconditional	Conditional	Baseline	Unconditional	Conditional	Baseline	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional
	2005				2005				2005			
World ^a	–0.41	–1.14	0.84	–1.25	–1.98	–4.18	–2.92	–4.18	–1.46	–2.72	–0.21	–0.74
AI	–1.71	–1.71	–1.77	0.06	0.06	–2.07	–2.07	–2.07	–1.91	–0.16	–0.22	–0.22
NAI	1.30	0.56	2.61	–1.31	–2.05	–2.11	–0.85	–2.11	0.45	–2.56	0.01	–0.51
	2001–2010				2001–2010				2001–2010			
World ^a	–0.41	–1.14	0.79	–1.2	–1.93	–4.18	–2.92	–4.18	–1.97	–2.21	0.25	–0.28
AI	–1.71	–1.71	–1.69	–0.02	–0.02	–2.07	–2.07	–2.07	–1.97	–0.10	–0.08	–0.08
NAI	1.30	0.56	2.49	–1.19	–1.93	–2.11	–0.85	–2.11	0.03	–2.14	0.31	–0.21
	2003–2007				2003–2007				2003–2007			
World ^a	–0.41	–1.14	1.00	–1.41	–2.14	–4.18	–2.92	–4.18	–1.32	–2.86	–0.19	–0.72
AI	–1.71	–1.71	–1.68	–0.03	–0.03	–2.07	–2.07	–2.07	–1.92	–0.15	–0.12	–0.12
NAI	1.30	0.56	2.68	–1.38	–2.12	–2.11	–0.85	–2.11	0.61	–2.72	–0.08	–0.60
	2000–2005				2000–2005				2000–2005			
World ^a	–0.41	–1.14	1.23	–1.64	–2.37	–4.18	–2.92	–4.18	–1.61	–2.57	0.33	–0.20
AI	–1.71	–1.71	–1.58	–0.13	–0.13	–2.07	–2.07	–2.07	–1.95	–0.12	0.01	0.01
NAI	1.30	0.56	2.81	–1.51	–2.25	–2.11	–0.85	–2.11	0.34	–2.45	0.32	–0.20
					Average				Average			
									–0.04 ± 0.3 ns (–0.2 to 0.3)			
									–0.5 ± 0.3 ^{***} c. (–0.7 to –0.2)			

Evolution of 2030 LULUCF conditional and unconditional emission scenarios and mitigation commitments (MtCO₂e/y) between NDC 2020 and NDC 2015 (cut-off dates May 2024 and April 2016, respectively), for all countries ($n = 111$). Estimates are for the world, Annex I (AI) countries (developed) and non-Annex I (NAI) countries (developing). Mitigation commitments are the difference between 2030 LULUCF net emission scenarios (unconditional and conditional) and selected baselines (years 2005, 2001–2010, 2003–2007, 2000–2005). To compare LULUCF commitments between NDCs, we anchor the analysis around year 2005, as selected by Grassi et al's (ref. 19) in their NDC 2015 research. Baselines include year 2005 to help account for interannual emission variability. 2030 data derives from NDCs and other country reports under the UNFCCC (e.g. Long Term Strategies 2050). Analyses only for countries included in NDC 2015 ($n = 68$) are in SI Table S14.

^{***}Significantly different using a two-sample t -test ($p \leq 0.05$, 95% confidence).

ns: non significantly different.

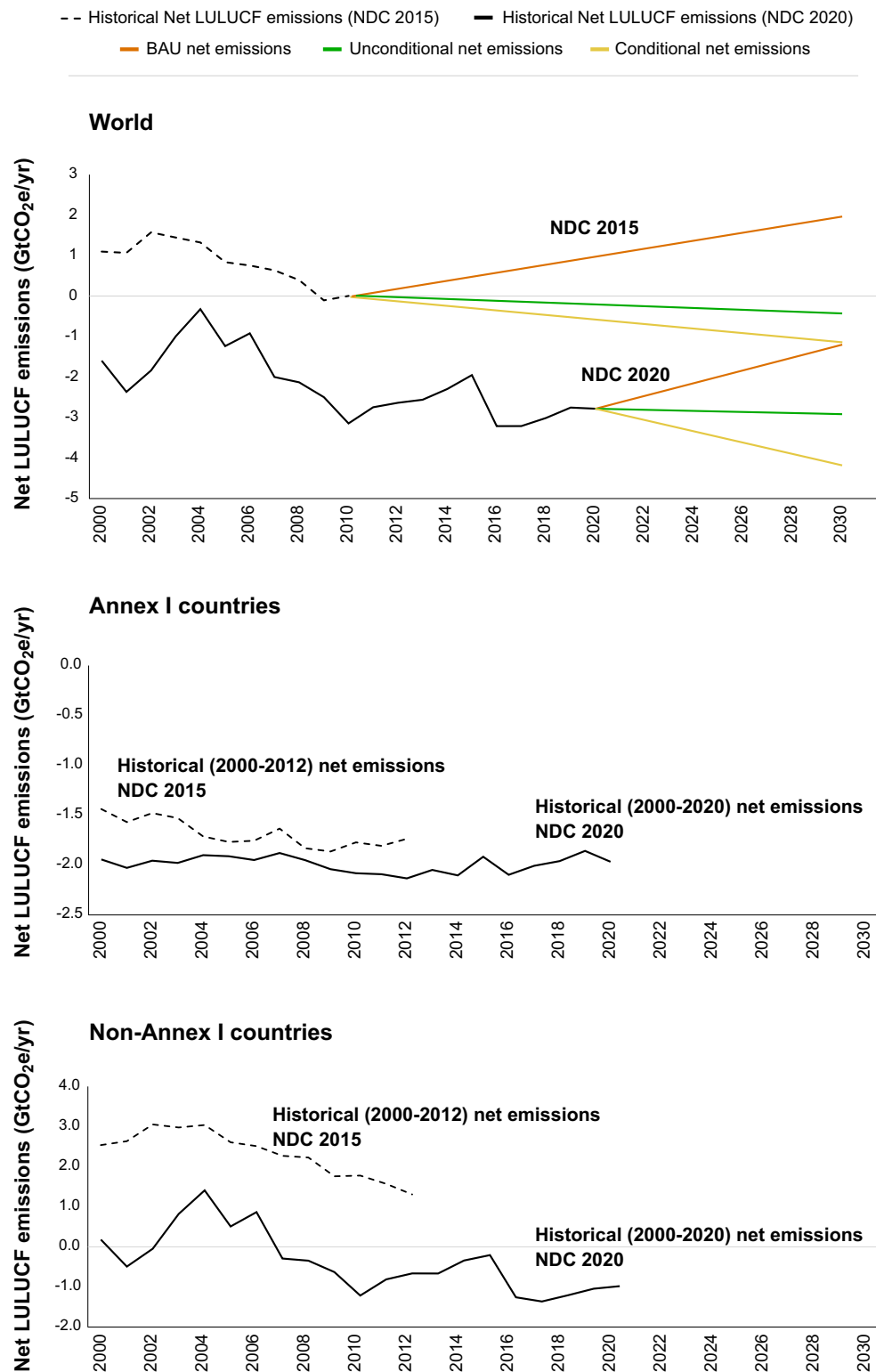


Fig. 2 | LULUCF evolution between NDC 2015 and NDC 2020's submissions. Historical net LULUCF emissions (2000–2012 and 2000–2020) and 2030 projections, for NDC submissions 2015 and 2020 respectively, for the World, Annex I (developed) countries, and Non-Annex I (developing) countries. 2030 projections

under NDCs rely on countries' submitted documents with cut-off dates April 2016 and May 2024, respectively. Historical net LULUCF emissions for NDC 2015 and NDC 2020 are an April 2016 update of ref. 19 and a May 2024 update of ref. 31 of countries' LULUCF GHG Inventories, respectively.

Report EGR (2023)⁴, which highlighted a decrease of -1.5 GtCO₂e between reports 2022 and 2023. As new datasets emerge and methodological updates continue, changing baselines both in country-data and models can be expected to continue in the future, altering the discrepancy between datasets.

2030 LULUCF discrepancies between countries' NDCs and land modelled estimates (Q5)

Discrepancies in projected 2030 net emissions between NDC estimates and modelled estimates from the SYN (2023) are large, and vary between -6.3 and -5.1 GtCO₂e/y in 2030 for conditional and unconditional scenarios,

Table 3 | LULUCF historical and 2030 mitigation commitments under NDC 2015 and NDC 2020 as provided by countries GHG Inventories and modelled estimates

NDC 2020	2030 Modelled emissions (GtCO ₂ e/y)				2030 NDC-country emissions (GtCO ₂ e/y)			
	SYN (2023) ^a		EGR (2023)		This study		Forsell et al.	
	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional
Global emissions in 2030 with LULUCF	55.4 (54–56.9) ^b	51.9 (50.4–53.4)	55.1 (53.8–57.1)	51.7 (50–55.3)				
2030 global BAU scenario	56.3		56 (52–60)					
2030 economy-wide mitigation	–4.4	–4.4	–3.1	–5.9				
LULUCF emissions in 2030	2.1	2.1	2.0	1.7	–2.9	–4.2	–4.7	–5.9
LULUCF emissions in 2019	3.7		3.2		–2.8		–4.0	
LULUCF mitigation in 2030 (against 2019)	–1.6	–1.6	–1.2	–1.5	–0.1	–1.4	–0.7	–1.1
LULUCF contribution to global 2030 pledges	36%		25%		25–32% ^c		32–43%	
LULUCF emission discrepancy against 2019					–6.5–6.0 ^d		–7.7–7.2	
LULUCF emission discrepancy against 2030					–5.1–4.9 ^d	–6.3–5.9	–6.8–6.7	–8–7.6
NDC 2015								
2030 Modelled emissions (GtCO ₂ e/y)								
	SYN (2016) ^a		EGR (2016)		Grassi et al.		Forsell et al.	
	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional	Unconditional	Conditional
Global emissions in 2030 with LULUCF	57.9 (54.4–59.3) ^b	56.2 (52–59.3)	56 (54–59)	54 (52–57)				
2030 global BAU scenario	61.4		60					
2030 economy-wide mitigation	–3.5	–5.2	–4	–6				
LULUCF emissions in 2030	2.7	2.7 ^f			–0.4	–1.1		2.1
LULUCF emissions in 2005	3.7				0.8		3	
LULUCF mitigation in 2030 (against 2005)		–1 ^f			–1.2	–1.9		–0.9
LULUCF contribution to global 2030 pledges		19%				25% ^g		15%
LULUCF emission discrepancy against 2005					–2.9		0.3	
LULUCF emission discrepancy against 2030					–3.1	–3.8		0.7

Comparison of LULUCF net emission estimates (GtCO₂e/y) between global reports (Synthesis Report, and UNEP's Emission Gap Report) (SYN, EGR) that rely on modelled estimates of LULUCF for 2030 (ref. 1,2,4,62–65), and studies (including *This Study*) that derive their 2030 estimates from countries' NDCs reports complemented with other official UNFCCC documents (e.g. Long-term strategies 2050) (Forsell et al. (ref. 55,56), Lamb et al. see Methods). To allow comparison among studies, we anchor mitigation commitments against year 2019 and 2005. Mitigation estimates thus differ from other values in the text that use other reference years (e.g. historical period 2011–2020). Emissions for year 2019 use a May 2024 update of Grassi et al.'s LULUCF GHG Inventories (ref. 31), and bookkeeping modelled estimates, extracted from the global reports. See SI Table S18 for further details on this table.

^aBased on 168 country submissions (up to 25 Sep 2023), representing 195 Parties and 94.6% of global emissions (ref. 1)

^bEstimates represent median (minimum–maximum range)

^cAgainst the economy-wide conditional mitigation commitment estimated by the EGR for this study (e.g. –5.9 GtCO₂e/y) and SYN (2023) (–4.4 GtCO₂e/y).

^dRanges capture SYN (2023) and EGR (2023) variability.

^eBased on 161 country submissions (up to 4 April 2016), covering 189 Parties to the Convention, representing c. 99 per cent of the emissions of all Parties to the Convention. (ref. 2)

^fFigure 1 and paragraph 19 of the Technical Annex of the Synthesis Report (2016) (ref. 66).

^gNote 4.5, SYN (2016) (ref. 2).

^hData from Grassi et al. (ref. 19).

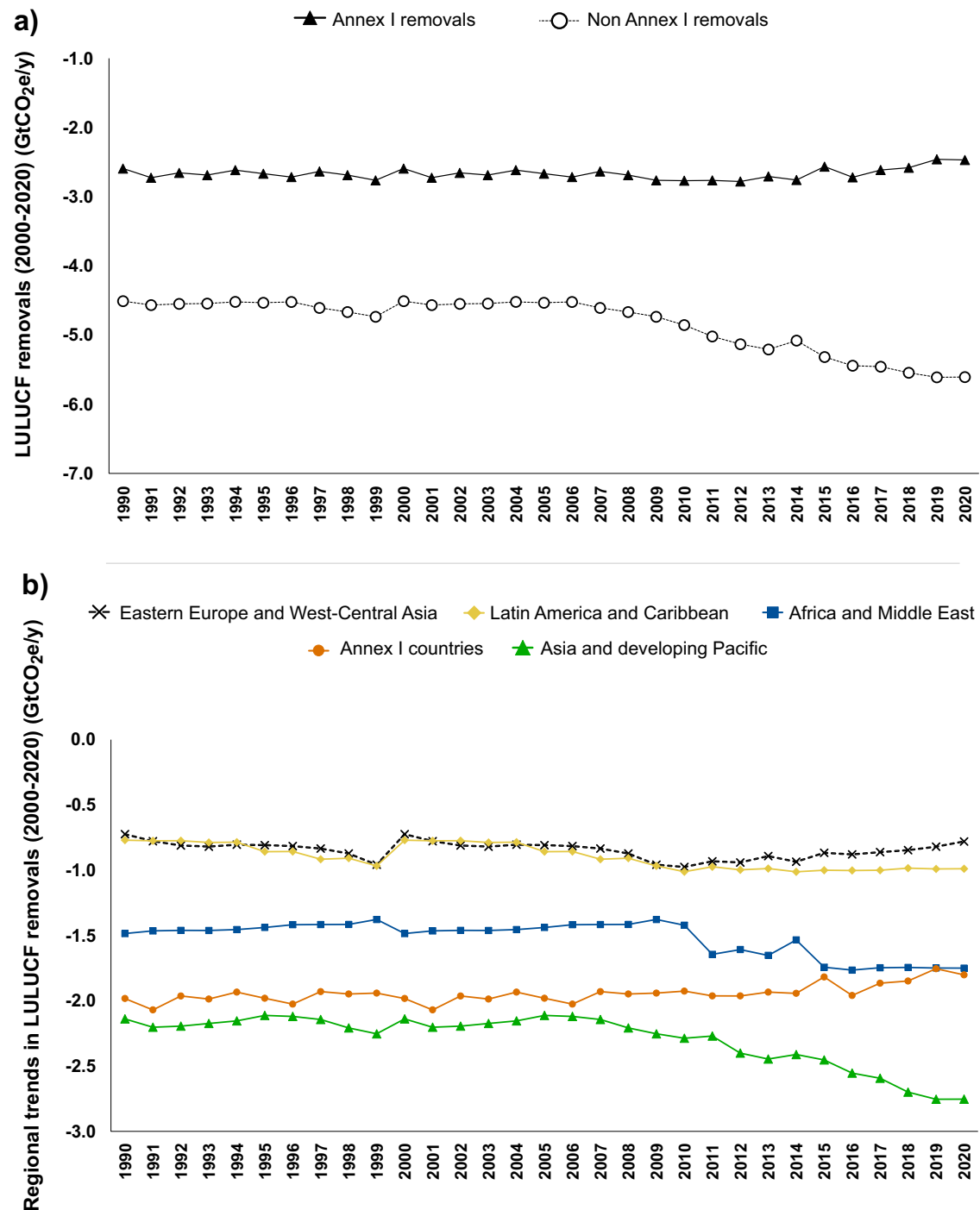


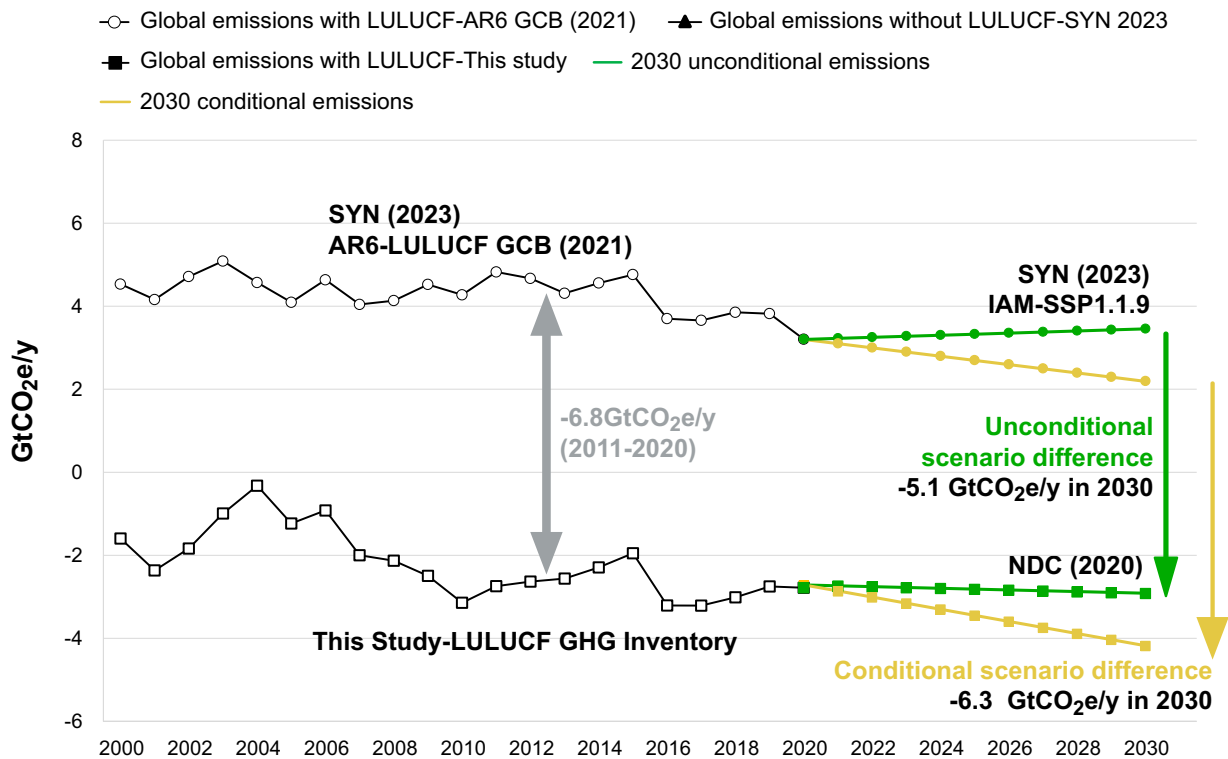
Fig. 3 | Historical removal trends at regional scales. a 2000–2020 gross removal trends for Annex I (developed) countries and Non-Annex I (developing) countries. The downward shift in historical emissions is mostly driven by removals in Non-Annex I countries, as seen between 2000 and 2020. Emissions remain almost

constant for the same period (see SI, Fig. S4). **b** Regional contribution to the global increase in removals, for the 2000–2020 period, including Eastern Europe and West-Central Asia, Asia and the developing Pacific, Africa and Middle East, Latin America and the Caribbean, and developed (Annex I) countries.

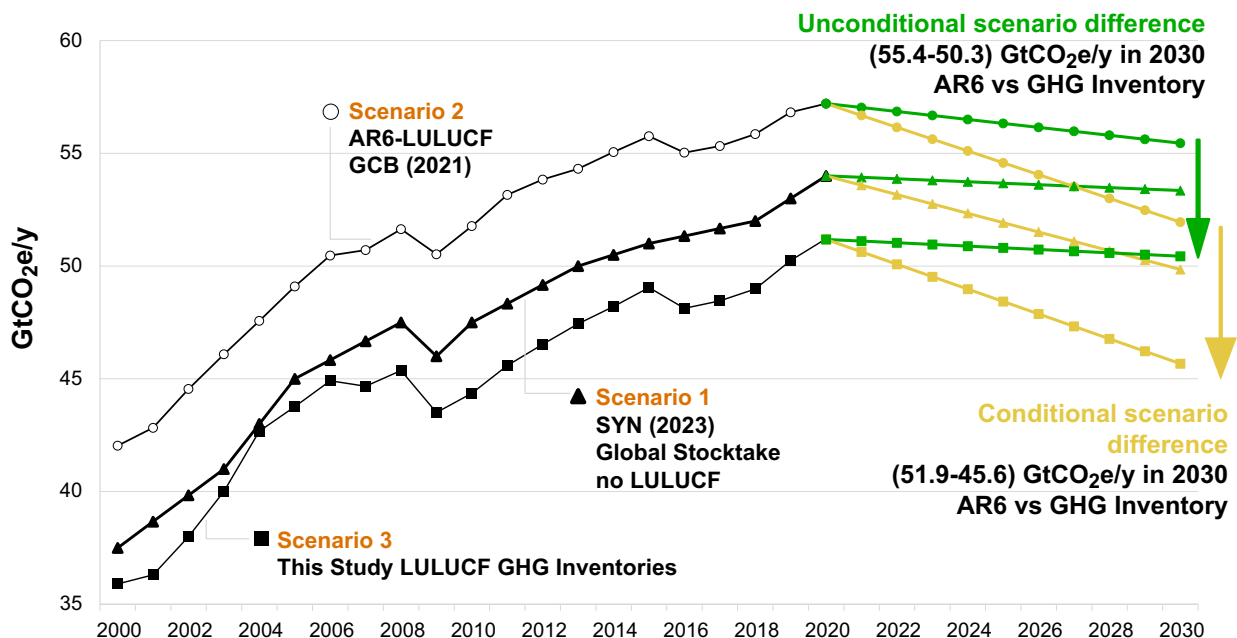
respectively (Fig. 4a, Table 3). Similar discrepancies are found against the EGR (2023) (−4.9 and −5.9 GtCO₂e/yr for unconditional and conditional scenarios, respectively) (Fig. 4a and Table 3). These values divert from historical discrepancies (e.g. −6.8 GtCO₂e/y in 1919) and make the tracking of land more challenging (Fig. 4a). Projecting LULUCF data for 2030 introduces additional sources of variability, such as the impacts of methodological choices, assumptions about countries' commitments (e.g. conditional actions, implementation success), or the effects of worsening climatic conditions, among others.

The primary cause for 2030 discrepancies remains the aforementioned conceptual difference on what an 'anthropogenic' sink is^{10,28–32,36,52}. As a result, in this study, countries continue seeing land as a net sink in 2030 (−2.9 and −4.1 GtCO₂e/y for unconditional and conditional scenarios, respectively), while models see it as a net source (+2.1 GtCO₂e/y for both scenarios in SYN (2023) or +2.0 and +1.7 GtCO₂e/y in EGR (2023) (Table 3). Net emission discrepancies confuse policymakers and land practitioners alike, as these differences affect the speed and ambition of national mitigation pledges to remain aligned with the temperature goals of

a) LULUCF scenarios



b) Economy-wide emissions including LULUCF scenarios



the Paris Agreement. As currently presented, modelled pathways and their associated milestones (remaining global carbon budget, net-zero timing) appear easier to achieve than they would be under translated country data^{28–32,36,52}. While this translation has become operational for the historical period^{31,32,35}, and platforms exist for dataset comparison (e.g. the Global land use carbon fluxes data hub,<https://forest-observatory.ec.europa.eu/carbon/>

fluxes), it is more challenging for data projections^{28,29}. Model translation towards Inventory frameworks rely on Dynamic Global Vegetation Models (DGVMs). Modelled land fluxes in DGVMs provide for the ‘indirect anthropogenic’ sinks^{10,28,29,31,32,35} that are added to model estimates (Book-keeping and IAMs). For projections, this requires combining climate and management scenarios, at global, regional and possibly country scale.

Fig. 4 | LULUCF scenarios and suggested additions for future Global Stocktake assessments. **a** LULUCF net emission discrepancy between modelled and NDC country-provided estimates. Modelled estimates rely on AR6 LULUCF net emissions from bookkeeping data (+4.1 GtCO₂e/y for 2011–2020) (Global Carbon Budget 2021) and from Integrated Assessment Models (IAM) under SSP1-1.9 (+2.1 GtCO₂e/y for 2030, for both conditional and unconditional net emissions). Country-based LULUCF estimates rely on GHG Inventories (May 2024 update of Grassi et al.³¹) (−2.7 GtCO₂e/y, for 2011–2020), and country-derived NDC 2020 data for 2030 (−2.9 and −4.2

GtCO₂e/y for un/conditional, respectively in this study (May 2024 cut-off date).

b Economy-wide net historical emissions (2000–2020) and 2030 projections for **Scenario 1** excluding LULUCF country data, as presented in Figure 7 in the First Global Stocktake (SYN 2023) (ref. 1), and two extra Scenarios that include LULUCF net emissions. **LULUCF Scenario 2**, modelled LULUCF emissions from bookkeeping data and Integrated Assessment Models, and **LULUCF Scenario 3**: Country-based LULUCF data from GHG Inventories and country-derived NDC 2020 data for 2030.

Other factors amplify or increase the uncertainty of the 2030 discrepancy, including changing historical baselines, variability in model-based projections, and/or variability in country-derived 2030 estimates, as discussed below.

Changing historical baselines: since LULUCF discrepancies are estimated as the difference between net land emissions in certain moments in time (e.g. 2030 projections, or historical periods), changing historical baselines can be a most relevant driver of divergence. As an example, our observed increase in sink between NDC submissions (−3.1 GtCO₂e/y) is largely behind the increase in the 2030 discrepancy under NDC 2015 (−3.1 to −3.8 GtCO₂e/y, for the unconditional and conditional scenarios, respectively) to the currently observed −5.1 and −6.3 under NDC 2020 (Table 3). Contrastingly, modelled estimates between NDCs submissions have changed little: +2.7 GtCO₂e/y in NDC 2015 and +2.1 GtCO₂e/y in NDC 2020 (based on Synthesis Reports from 2016 and 2023, respectively)^{1,2} (Table 3). Synthesis reports rely on Shared Socio-economic Pathway SSP 1-1.9 to extract their Paris Agreement-aligned land pathways for well below 2 °C targets, and therefore do not vary freely. When country-provided data is compared with SSP scenarios in models, changing baselines in LULUCF GHG Inventories will largely impact 2030 discrepancies.

Variability in model-based 2030 projections: methodological differences among bookkeeping models (for the historical period) and/or among IAMs (for projected periods) can lead to largely different modelled estimates for land³⁵. As an example, methodological differences between global reports such as the SYN (2023) and EGR (2023) have led to past disagreements of up to +2 to +3 GtCO₂e (e.g. year 2021). These differences have now been resolved after harmonisation of the historical emissions in EGR (2023)⁵³. Since year 2023, the two reports offer fully consistent messages despite differences in approaches and modelling choices. Detailed methodological differences between these two global reports are annually published under the UNEP repository, including year 2023⁵⁴.

Variability in 2030 country-based projections: methodological choices among studies that assess country-based 2030 scenarios and commitments also lead to different results. As an example, Table 3 shows how our 2030 LULUCF net emission estimates for the unconditional and conditional scenarios (−2.9 and −4.2 GtCO₂e/y) range between Forsell et al. (−4.7 and −5.9 GtCO₂e/y) and Lamb et al. (−3.9 and −4.4 GtCO₂e/y). Several factors lead to these differences: (i) the number of countries with country-specific LULUCF data included (e.g. 88 in this study, 80 in Forsell et al.⁵⁵ and 58 in Lamb et al. (EU = 27)), (ii) different methods (e.g. direct quantification using numbers presented in country reports (*this study*) vs 2030 emission/removal projections (Forsell et al.) vs 2030 percent targets including/excluding LULUCF in relation to reference years (Lamb et al.)). (iii) Timing of the cut-off dates for each report: May 2024 for *This study* and for Forsell et al.⁵⁵, but January 2024 for Lamb et al., (iv) assumptions on NDC data adjustments (when NDCs are significantly off from their historical averages), or for the periods against which adjustments are made: in *This study* we apply adjustments to the historical period (2011–2020) but Forsell et al.⁵⁵ and Lamb et al. adjust against countries' reported reference year/period. Data adjustment can also apply to net emissions (*This study*, Lamb et al.) or can apply to gross emissions or gross removals (Forsell et al.)^{55,56}.

Inclusion of LULUCF country data in future Global Stocktakes

Including country-provided LULUCF data into Global Stocktake and associated SYN reports will help countries understand where their land

commitments stand and stimulate action on data translation. As a first step, we suggest adding two new LULUCF scenarios into the data presented in future Synthesis Reports (2023). As currently reported, Figure 7 in SYN (2023) shows economy-wide net emissions only from non-LULUCF sectors. Our Fig. 4b presents this SYN (2023) scenario, excluding LULUCF (**Scenario 1**), and now includes the historical trends and 2030 projected estimates of two new LULUCF scenarios (Scenario 2 for modelled LULUCF estimates and Scenario 3 for country-provided LULUCF data). While these last two scenarios are not directly comparable, they illustrate the range of net LULUCF emission discrepancies over time, including future pledges. **Scenario 2** relies on AR6 bookkeeping models (e.g. as done in the Global Carbon Budget)⁵⁷ for the historical LULUCF period (+4.1 GtCO₂e/yr, 2011–2020), and 2030 LULUCF estimates from IAM SSP1-1.9 emission pathway for well below 2 °C (+2.1 GtCO₂e/y) (Table 3). **Scenario 3** covers country-provided LULUCF estimates based on countries' GHG inventory data for the historical period (−2.7 GtCO₂e/y, 2011–2020) (*This study*), and 2030 un/conditional scenarios extracted from countries' reports (NDCs) (−2.9 and −4.2 GtCO₂e/y) (*This study*).

Besides adding these two scenarios, including LULUCF, we suggest that future GSTs also include 2030 LULUCF-specific mitigation commitments and land contribution to economy-wide pledges. Unlike net emissions, mitigation commitments (estimated as the difference between 2030 net emissions and a baseline) offer well-aligned values among different studies, but only for the conditional scenario (e.g. −1.4, −1.9, −1.6 GtCO₂e/y for NDC-derived estimates, and −1.6 and −1.5 GtCO₂e/y for modelled estimates, all against year 2019) (Table 3). Alignment remains poor, however, for unconditional commitments where models generally foresee higher domestic mitigation action (−1.6 and −1.2 GtCO₂e/y) than country-based estimates (−0.1, −0.7–1.1 GtCO₂e/y) (Table 3). Further insights on how models and countries foresee future unconditional action would be needed to understand these differences (e.g. inclusion-exclusion of 'current' and 'planned' policies).

Models and country estimates fully agree that, at least, land retains a quarter of global mitigation pledges under conditional scenarios requiring external support (Table 3). While this contribution reinforces the importance of land, it also raises awareness of overreliance on land under uncertain climate and socio-economic envelopes^{12,31,40,50}.

To promote data comparability, future GSTs should explicitly translate LULUCF datasets, so that policymakers can better track global progress and more effectively act on their own national mitigation ambition towards net-zero. As already seen, translation can be run in different ways^{10,14,28–32}. However, since ground data collection does not allow separating 'direct' and 'indirect' anthropogenic influences, and countries implement their policies based on such empirical evidence, the IPCC Expert Meeting on "Reconciling land use emissions"⁵² recommends model estimates to be translated into the GHG Inventory framework. This recommendation is now included into the chapter outlines of WG1 and WG3 of the IPCC AR7⁵⁸. Future Assessment Reports are thus expected to provide both the original LULUCF estimates from global models and their translated versions into the inventory framework for the historical and projected periods (e.g. 2030, 2050). Translation will allow countries' actions and pledges to be linked to Paris-aligned pathways, while highlighting the implications of differing definitions of 'anthropogenic sinks' on net-zero trajectories³⁰. In practice, two sets of model results will be needed. First, the original model's results translated to

align with the national inventory definition of anthropogenic CO₂ sink, i.e. total forest carbon sinks that result from different processes ('direct' and 'indirect' effects) on all managed land areas. This translation is needed to link countries' actions and pledges to the Paris-aligned pathways. At the same time, the original model results (estimating 'direct' effects only) are useful to highlight the implications of differing definitions of 'anthropogenic sinks' on net zero trajectories³⁰. While the partitioning between 'direct' and 'indirect' CO₂ fluxes in models remains highly uncertain^{33,34}, it helps estimate the size of the 'natural sink' in GHG Inventories that is not included in IPCC scenarios nor in the net-zero concept, which still underpins most climate policies. Globally, we would eventually need to become net-negative by approximately the amount of 'natural sink' included in the national GHG Inventories, and not included in the model estimates³⁶.

Translation does not undermine the value of countries' mitigation efforts but highlights the need for enhanced communication among policymakers, modellers, and country inventories on the consequences of data translation⁵².

Conclusions and recommendations

Under the second submission of NDCs (2020) (cut-off-date May 2024), government pledges remain off-track from pathways that would reach the long-term goals of the Paris Agreement. Planetary emissions are still growing^{1,4,37}, mean global temperatures have already crossed the 1.5 °C increment for an entire year in 2024⁵⁹, and global sinks are showing signs of declining strength^{38–40}. There is a looming inevitability of overshooting the 1.5 °C target^{12,50}.

Under this context of much-needed mitigation ambition, LULUCF pledges could raise the global ambition by additional -1.5 ± 1.1 GtCO₂e/y in 2030, under conditional support. This is a significant commitment, representing a quarter of the economy-wide pledges by 2030. Only a third of these mitigation efforts reflect additional land sinks (-0.55 GtCO₂e/y), which still remain insufficient to cover the CDR-gap by 2030, furthering away from 2050 needs under well below 2 °C scenarios^{11,12,14}. External support (financial, technical, capacity building) remains a barrier to realise the LULUCF pledges, with very little additional domestic action seen in our study. External dependence for mitigation action remains problematic as current financial flows are insufficient to support global mitigation efforts⁶⁰, and UNFCCC activities like the national REDD+ mechanism have been financially under-resourced for decades^{60,61}. Even with appropriate funding, land-related pledges by 2030 will have to compete with alternative land development programmes, such as agro-commodity expansion, petrol operations, and mining^{16,26,45,46}. Moreover, worsening climate envelopes raise additional caution against the over-reliance of land for future mitigation^{12,31,40,50}. The further we are from the goal, the higher the climate-related impacts we can expect^{12,40,44}.

In spite of the current political momentum, with the US abandoning the Paris Agreement, the accurate tracking of global progress towards a carbon-neutral future remains a fundamental step, with land use expecting to play a crucial role towards net-zero. However, the first Global Stocktake and the associated Synthesis Report¹ essentially excluded the assessment countries LULUCF data, leaving a blind spot on the role of land-use in the second round of NDCs. Comparability with modelled estimates, used as benchmarks under the Paris Agreement, is a key factor that prevented this inclusion. Specifically, the 'direct-only' anthropogenic net emissions produced by land models do not match the 'direct and indirect' anthropogenic net emissions from countries' Inventories.

Here we provide concrete suggestions to help ensure that the LULUCF sector does not remain a blind spot in future Global Stocktake assessments:

1. Include countries' LULUCF data using graphical representations, such as in our Fig. 4a, to offer a visual assessment of land-related pledges, as well as to highlight the discrepancies in LULUCF estimates between inventories and models.

2. Incorporate LULUCF in economy-wide assessments of mitigation efforts, including both the countries' data and the models' estimates for the historical period and for scenarios, such as in Fig. 4b. Following IPCC

recommendations, including the expert meeting on land⁵² and the approved outlines of the 7th Assessment Report⁵⁸, model LULUCF estimates will also need to be translated to ensure comparability with inventories. The implications for the net-zero trajectories and remaining carbon budget should also be assessed³⁰.

3. Disaggregate the assessment of LULUCF pledges regionally, such as in our Fig. 1a. Regional aggregates (and country analyses) help identify commitments and implementation progress, enabling the prioritisation and channelling of external support, including finance.

4. Disaggregate the commitments between additional sinks (e.g. afforestation, improved forest management, soil carbon capture) and reduced emissions (e.g. reduced deforestation and forest degradation). The methodological approach used in this study (see Fig. 1b) is an attempt to provide this disaggregation, which can also help for CDR-related assessments.

To support transparency of inventory data, we also suggest that countries offer more detailed data and maps on managed land areas, forest types, methods, and factors used to estimate land net emissions and projections for 2030⁵². Clearer information on unconditional NDC scenarios is key, and disaggregation of pledged commitments into reduced emissions and additional sinks would also be important.

Methods

LULUCF emissions and pledged mitigation in 2030

This study quantifies the role of the Land Use, Land Use Change, and Forestry (LULUCF) sector under NDC 2020 (cut-off date May 2024). Agricultural emissions are not part of LULUCF budgets and are therefore excluded. We searched for LULUCF data provided by countries' reports under the UNFCCC, for three scenarios in year 2030: Business as Usual (BAU), unconditional and conditional scenarios. We mostly relied on NDCs to obtain country data ($n = 44$ countries), but when numerical information was not provided, we included Long Term Strategies 2050 ($n = 5$ countries), Biannual Updated Reports or National Communications ($n = 13$ countries), and official projections or legislative documents ($n = 4 + 27$ EU countries). Table S1 in SI summarises the sources of data used for each country under NDC 2020.

We rely on several data sources to respond to our questions. For Q1–Q2 (the contribution of the LULUCF sector in NDC 2020, and the disaggregation of the pledges between reduced emissions and enhanced land removals), we produce our own LULUCF estimates (*This study*) (Table 3). Our estimates include country-derived data for the historical period (e.g. May 2024 update of Grassi et al.'s ref. 31. GHG Inventory data), and projected 2030 scenarios obtained from NDCs and other UNFCCC reports. For Q3 (LULUCF contribution to economy-wide pledges), we contrast our 2030 LULUCF estimates (*This study*) against economy-wide pledges provided by the EGR 2023⁴ and SYN 2023¹. Q4 (evolution of LULUCF ambition between NDCs) relies on the NDC 2015 analysis done by Grassi et al.¹⁹ (cut-off date April 2016) and our estimates in *this study* for NDC 2020 (cut-off date May 2024). Historical LULUCF data for the NDC 2015 period uses GHG Inventories from ref. 19, which was an April 2016 update of NDC submissions. Q5 focuses on emission discrepancies between LULUCF country-provided data and modelled data. It covers two topics: topic 1) the tracking of committed additional land removals *versus* the needs for Carbon Dioxide Removal (CDR) pathways, to align with Paris Agreement's 1.5 °C and 2 °C targets. And topic 2) the discrepancy between net emissions from NDC (country-provided) data and modelled land estimates. Topic 1 relies on our own estimates of gross land removals for the historical period (GHG Inventory data) and our disaggregation of 2030 countries' pledges into additional land removals. Historical gross land removals are the addition of net forest sinks (forest growth and harvest, including carbon stock changes in harvested wood products) and net sinks from croplands, grasslands, and wetlands, mostly due to soil carbon capture. 2030 scenarios for gross land removals (unconditional and conditional) are the addition of the historical gross values and the 2030 additional land removals obtained from our disaggregation of country pledges. Topic 2 relies on our country-derived net

emissions (*This study*) against data provided by Integrated Assessment models (IAM) that include NDC 2020 commitments. These estimates are provided by the EGR (2023) (cut-off date Sep 2023)^{4,62–65}, and by the Global Stocktake's Synthesis Report (SYN 2023)¹ (cut-off date Sep 2023). To assess the range of variability between 2030's net emissions and associated pledges for land under NDC 2020, we contrast our own estimates (*This study*) against estimates provided by Forsell et al. ref. 55 and Lamb et al. See methods below for Lamb details. To assess the variability of country-provided LULUCF estimates under NDC 2015, we relied on model data from Synthesis Report (2016)^{2,66}, as well as country data from^{19,56}.

Datasets

Country-derived LULUCF scenarios in 2030

Due to the large amount of country reports to read, we prioritised country search according to their contribution to: 1. global LULUCF removals in the historical period 2000–2020 (90 percent contribution), or 2. economy-wide net emissions in the period 2000–2020 (90 percent contribution), or 3. largest forested countries. To select countries responding to these three requirements, we relied on PRIMAP-hist's database for economy-wide emissions⁶⁷ and Grassi et al. for LULUCF GHG Inventory data (May 2024 update).

NDC 2020. (i) *This study*: From a total of 195 countries reporting under the UNFCCC, 111 countries responded to our LULUCF requirements. 88 out of 111 included quantitative LULUCF data for their 2030 scenarios. AFOLU (Agriculture, Forestry and Other Land Uses), instead of LULUCF, was presented as a target in several Western and Central African (e.g. Mali, Nigeria, Niger, Central African Republic). We extracted their LULUCF targets relying on their LULUCF/AFOLU historical ratios, obtained from their latest GHG Inventories under different UNFCCC reports (e.g. BUR, NC, NDCs). Historical LULUCF net emissions (e.g. 2011–2020) (ref. 31 update) consist on annual LULUCF data provided by AI countries under their GHG Inventories, and on multiple UNFCCC reports for NAI (see SI Table S1, S12). LULUCF includes emissions from deforestation, forests (sink of standing forest with or without management and regrowth), organic soils, and 'other' emissions (mostly soil sinks in croplands and grasslands). Harvested wood products are included under forest management for AI countries, with unclear inclusion for NAI. For countries out of our priority list or without a LULUCF target ($n=92$, 10% of the global net historical emissions), we retained their averaged historical net emissions (2011–2020) as their 2030 scenarios (BAU and un/conditional scenarios). This assumption leads to conservative 2030 BAUs for developing countries (e.g. same deforestation values are kept constant until 2030), and null LULUCF mitigation action against BAU. 11 countries (representing 13% of the global gross emissions) did not report LULUCF historical emissions in their GHG Inventories (Egypt, Iraq, Libya, Kiribati, Maldives, Marshall Islands, Nauru, Oman, Qatar, Sierra Leone, Tuvalu). 2030 data adjustments are applied to seven countries whose NDCs values included historical data that significantly differed from their GHG Inventories ($\geq \text{abs}20 \text{ MtCO}_2/\text{y}$) (e.g. Democratic Republic of Congo, Namibia, Central African Republic, Côte d'Ivoire, Tanzania) or 20% of the national absolute LULUCF emissions (e.g. Belarus, El Salvador, Sri Lanka) (see SI data adjustments).

(ii) Forsell et al.⁵⁵: Estimates include the most recent 2030 scenarios from NDC 2020, from 167 countries and the European Union EU = 27) (cut-off date May 2024). 80 of these countries included LULUCF data. Methodology follows Forsell et al.⁵⁶, which consists on projecting LULUCF emissions or removals based on their national BAU scenario and their national NDC mitigation scenario, in line with a full implementation of the conditional pledge. The LULUCF projections are based on estimates provided in the national NDCs (where available) and/or projections and estimates presented in the National Communications or in supporting documents as officially provided. Only quantitative LULUCF information was gathered from NDCs. Where insufficient information was available to

estimate 2030 LULUCF scenarios and targets, it was conservatively assumed that the sectorial emissions and removals would stay constant over time, and LULUCF data for year 2020 was used in substitution.

(iii) Lamb et al.: estimates include the most recent NDC submissions (cut-off date: January 2024) from 136 countries (European Union = 27). Country search was prioritised by their contribution to global land use fluxes, based on Grassi et al.'s³¹ data. Quantitative information was gathered from each NDC, and to the extent possible, was used to calculate economy-wide targets with and without the LULUCF sector (with the difference equating to the LULUCF contribution to 2030 pledges). Calculations depended on the type of target: (1) for absolute emissions targets (e.g. Gabon, Argentina, Peru), we subtract the absolute level in 2030 with the LULUCF sector minus the level in 2030 without the LULUCF sector; (2) for base year targets (e.g. Brazil, USA, Russia), we multiply base year emissions by the described reduction rates to 2030, and again subtract the result with LULUCF from that without; (3) for business as usual targets (e.g. Indonesia, Ethiopia, Türkiye) we take the reduction rate against the BAU scenario and recalculate the implied reduction rate against baseline emission levels described in the NDC, again calculating this with and without the LULUCF sector to take the difference; (4) for emissions intensity targets (e.g. China, India, Malaysia), we use estimates from Climate Resource. In cases #2 and #3, we adjust base year emissions in the final calculation to PRIMAP Hist-CR v.2.5.1 data⁶⁷ for non-LULUCF sectors and Grassi et al. data³¹ for LULUCF, taking account of the fact that for some NDCs, national inventories have since been updated and baseline emissions accordingly changed. Finally, in cases where countries do not provide either the specific contribution of LULUCF to their pledges in the NDC documents, or do not provide both pledges with and without LULUCF (allowing it to be inferred), we assume no change in 2030 for the LULUCF sector compared to historic levels (2011–2020 average) for that country.

NDC 2015. (i) Grassi et al.¹⁹: 68 (EU = 27) out 195 countries with provided LULUCF data (April 2026 cut-off date), covering 83% of global forest area based of FAO-FRA⁶⁸. Historical data rely on GHG Inventories (1990 to 2013) for all Annex I countries, in most cases including Harvested Wood Products. For developing countries, data are from BURs when available or from latest National Communications, typically not including Harvested Wood Products. Unlike 2030 LULUCF estimates from NDC 2020, which are values extracted from countries' reports, estimates from NDC 2015 added some expert-judgment interpretation on 2030 projections for NAI countries, when needed. Thus, if 2030 scenarios were available in NAI's reports, averaged historical net emissions (2000–2009) or projections from FAOstat and FRA⁶⁸ were used.

2030 mitigation estimates along NDC submissions. To compare LULUCF pledges along NDC submissions (2015 and 2020), we anchored the mitigation analysis on the same reference year/period for the different studies. For NDC 2020, we chose year 2019, as presented in the SYN (2023). For NDC 2015 we chose year 2005, as presented in Grassi et al.¹⁹. Since the year 2005 was anomalously dry, we estimate the mitigation targets against several baseline periods that contain year 2005 (e.g. 2000–2005, 2005–2010, 2003–2007 to better capture inter-annual variability (Table 2). We applied two-sample *t*-test ($p \leq 0.05$, 95% confidence) to track significant differences between mitigation commitments in NDC 2020 and 2015.

Model-derived LULUCF scenarios in 2030

Estimates for NDC 2020 period. Modelled LULUCF estimates rely on two influential global reports tracking progress of global net emissions and commitments against Paris Agreement-aligned pathways. The UNFCCC Synthesis Report (SYN (2023))¹, and UNEP's Emissions Gap Report (EGR (2023))⁴. Synthesis Reports have been annually produced since 2016. SYN (2023) helped conclude the First Global Stocktake (2023). Modelled LULUCF data in SYN (2023) tracked progress against

median SSP1.1.9 LULUCF scenarios (AR6). The same value was offered for conditional and unconditional scenarios (see Table 3). The EGR is an annual assessment that considers the latest scientific studies and modelling results with updates from key countries. EGR (2023) relies on countries' reported 2030 LULUCF pledges in their NDCs (e.g. countries percentage reductions including/excluding LULUCF) as well as policy information to build the 2030 'currently implemented policies' baseline. 2030 net emissions under the EGR (2023) are the median of four models (PBL-IIASA, JRC-GECO, Climate Resource, Climate Action Tracker)^{4,62–65}. The four models include LULUCF emissions as the difference between NDC targets with/without LULUCF, with cut-off dates Nov 2022. But only the first two offer publicly available 2030 LULUCF scenarios. As a main difference with SYN, EGR offers separated conditional and unconditional LULUCF estimates. The SYN report modelling framework includes countries' full GHG inventories to estimate emission levels for total GHG emissions, excluding LULUCF. Modelled estimates that include 'direct anthropogenic emissions only' are later added to allow comparison with IPCC AR6 scenarios. Mitigation estimates were recalculated against the year 2019 for these two global assessments.

Estimates for NDC 2015 period. We extracted modelled LULUCF estimates presented in the Technical Annex of SYN (2016)⁶⁶. We could not re-run EGR (2016)⁶⁹ models to extract LULUCF data for NDC 2015 because not all countries presented their LULUCF sectoral targets in the first submission.

Mitigation disaggregation: reduced emissions vs additional sinks

To offer information on projected sinks and to connect them with the CDR-gap, LULUCF mitigation pledges were disaggregated into commitments to reduce emissions (activities targeting deforestation, degradation, fire management, fuelwood reduction, etc) and commitments to enhance land removals (plantations, a/reforestation, restauration, etc). While absolute LULUCF targets were available in many countries, the description of the proposed LULUCF activities and associated pledges was not always clear. We then relied on several assumptions:

1. Countries with restoration/reforestation/forest cover expansion, Art 6-international crediting goals clearly stated in their documents, were mostly disaggregated into additional land removals (e.g. China, Cuba, India, Korea, Japan, Thailand, etc).
2. Countries with emission reductions and/or REDD+ avoided emissions goals clearly stated in their documents, where disaggregated into reduced emissions (e.g. Congo, Gabon, Paraguay, etc).
3. Countries with multiple commitments but with enough quantitative information provided to disaggregate between reduced emissions and additional land removals, were so disaggregated (e.g. Argentina, Cameroon, DRC, Indonesia, Mexico, Peru, etc).
4. Countries with multiple commitments but without enough quantitative information provided to estimate their disaggregation, we either assumed equal contribution (e.g. USA, Belarus, Niger) or proposed a plausible disaggregation based on their described activities (Ethiopia, Niger, Papua New Guinea).
5. For countries with no data on disaggregated commitments, we applied their historical ratio of emissions vs removals (2011–2020), from the updated (cut-off date May 2024) Grassi et al.³¹ database. This database annually disaggregates the net LULUCF emissions into four categories:
 - a. (1) *forests remaining forests (including Harvested Wood Products)* + (2) *other land*, which includes non-forest land within LULUCF (grasslands, croplands, wetlands, settlements and other land). These categories are frequently removals.
 - b. (3) *deforestation/degradation* + (4) *organic soils*: these categories are frequently emissions.

Based on these four categories, we estimate annual gross emissions vs annual gross removals for the historical period (2011–2020), and their ratio.

We apply this ratio to the pledged LULUCF mitigation when country documentation prevents disaggregation.

Country grouping into different uncertainty levels

To account for the above-mentioned assumptions and for the uncertainty of the disaggregation, we grouped countries into several categories (A, B1, B2) depending on the level of information and transparency of the documents (See SI Tables S7, S8).

- **Group A:** countries with no information regarding their mitigation target and the contribution of LULUCF. For these countries, we assume that removals in 2030 retain their historical average (2011–2020). ($n = 24$, c. 1 percent of the net sink in 2011–2020),
- **Group B1:** countries with a specified LULUCF target in 2030, but unclear information regarding the disaggregation of the LULUCF commitments ($n = 51$, EU = 27). For these countries we either applied the historic ratio of emissions and removals (2011–2020) or create our best estimates based on available information. These countries represent almost half of the global net sink in 2011–2020.
- **Group B2:** countries with a specified LULUCF target in 2030, and with information on the specific contribution of removals. We directly report these removals in our analysis. ($n = 37$). These countries represent the other half of the net emissions in 2011–2020.

Uncertainties

LULUCF net emission uncertainties depend on many factors, including the level of aggregation and the different coverage of land uses, carbon pools, and gases. Moreover, countries reporting on their National GHG Inventories still offer incomplete data on uncertainties and methodologies, making it challenging to assess LULUCF net emission aggregated uncertainties²⁴. Given the incomplete information on the uncertainty of National GHG Inventories (especially for NAI countries), the values used in this study should be considered as rough approximations.

We are interested in two dimensions of LULUCF uncertainty – the uncertainty of flux estimates for a given year (annual uncertainty) and the uncertainty of flux changes from one year to another (also called trend uncertainty in IPCC guidance) (see SI Fig. S1). Trend uncertainty estimates utilise annual uncertainty estimates as well as assumptions about the correlation between flux estimates over time. While most Annex I (AI) countries provide quantitative LULUCF uncertainty estimates, few NAI countries do ($n = 23$ for NAI, $n = 12$ for AI countries) (see SI, Tables S9–S11). For those NAI countries that do, most uncertainty estimates are based on IPCC default assumptions for aboveground forest biomass stock change. To identify each country's LULUCF uncertainty estimate, we review their most recent UNFCCC communications where a GHG inventory could be included (NC, BUR, REDD+, NDC) and record all instances where a country reports both a central estimate and an uncertainty estimate for the LULUCF sector. We convert all uncertainty values to the 95% confidence interval in a single direction as a percentage of the central value. We then find total AI and NAI LULUCF uncertainty by aggregating all reported values using error propagation. This results in 20% annual uncertainty for AI and 65% for NAI. To estimate trend uncertainty, we disaggregate the total LULUCF uncertainty estimates into uncertainty attributable to activity data (AD – for example, total deforested area) vs. emissions factors (EF – for example, grams of CO₂ emitted per deforested hectare). Using expert judgement, we assume the AD and EF contribution to annual LULUCF uncertainty is consistent with Grassi et al. (ref. 19). This results in 12% uncertainty for AD and 16% for EF in AI countries, and of 32% for AD and 57% for EF in NAI (again, percentages here reflect the one direction 95% confidence interval as a percentage of the central value). The uncertainty of the trend is dependent on whether or not the errors of AD and EF are correlated over time, for which we applied the basic assumption under the IPCC guidelines: LULUCF errors of AD are not correlated, and errors of EF are fully temporally correlated. To assess if changes in net emissions are statistically discernible among periods, we apply two-sample t-tests ($p \leq 0.05$ and 95% Confidence Intervals) and compared emissions in

five-year periods from 2000 to 2030. The analysis of the trend shows that the LULUCF responses are only statistically significantly different from zero at for the 2006–2010 period (compared to 2001–2005). For 2030, the BAU and the conditional scenario were both significantly different from the historical period (2011–2020) (See SI Fig S2). We do not provide uncertainty estimates for emissions only and removals only. This is because countries do not provide uncertainty estimates at this level of detail, in general, and deriving such estimates would require assumptions about how much of total LULUCF uncertainty can be attributed to emissions vs. removals activities and emissions factors.

Disaggregation of greenhouse gases

Since NDC targets are mostly expressed in CO₂ equivalents, we chose CO₂e estimates of LULUCF data for the historical period for Annex I countries. For non-Annex I countries, whose historical LULUCF emissions are frequently expressed in CO₂ only, we added CO₂e estimates in countries with relevant non-CO₂ emissions like peatlands in Indonesia, Malaysia, and fire in India. For the remaining non-Annex I countries, including those with relevant fire activity like Brazil or Southern Africa, that did not provide disaggregated data on their non-CO₂ emissions, we reported CO₂-only in their historical net emissions. CH₄ and N₂O gases represent, however, about 2–3% of total CO₂e forest fluxes, and should not represent a major reason for discrepancy with historical trends⁴², while promoting comparability with bookkeeping models, which are CO₂-only³⁵. Future land reporting, with better disaggregation of GHG gases, should help minimise comparability between historical trends and NDC projections.

Data availability

Original data presented in this study are at country level and fully available at UNFCCC websites: [UNFCCC NDC registry](#), [Long-Term country strategies for 2050](#), [Biannual Updated Reports](#), [National Communications](#), [REDD+ submissions](#). Figures in the main text and data-rich tables from the supplement are available at: <https://doi.org/10.6084/m9.figshare.29149394.v1>. Please cite source when using data.

Received: 4 November 2024; Accepted: 30 May 2025;

Published online: 28 July 2025

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Author contributions

R.M.R.C. and G.G. organised the structure and goals of the paper. RMRC, GG led the writing with Md.E., W.L., Z.A., N.F., E.M., M.M., S.F., K.K., M.G., J.M. and S.R.A.K. all inputting. R.M.R.C., G.G., Md.E., W.L., N.F., Z.A., K.K. and M.G. all provided data and processed new data for the manuscript. J.M., S.R., A.K. and K.K. helped refine historical data, Md.E., W.L., Z.A., N.F. and M.G. helped discuss 2030 projections and methodologies. M.G. performed this research prior to joining P.N.N.L. and U.M.D. R.M.R.C. and G.G. produced the figures.

Competing interests

The authors declare no competing interests.

Additional information

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s43247-025-02494-9>.

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Peer review information *Communications Earth and Environment* thanks Viola Heinrich and the other, anonymous, reviewer(s) for their contribution to the peer review of this work. Primary Handling Editor: Alice Drinkwater. [A peer review file is available].

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