IPCC Expert Meeting on
Reconciling Anthropogenic Land Use Emissions

Report of IPCC Expert Meeting

9-11 July 2024, Ispra, Italy

Task Force on National Greenhouse Gas Inventories

INTERGOVERNMENTAL PANEL ON
climate change

The IPCC Expert Meeting on Reconciling Anthropogenic Land Use Emissions was organised by the IPCC Task Force on National Greenhouse Gas Inventories (TFI). It was held in a hybrid format at the European Commission's Joint Research Centre (JRC) in Ispra (Varese, Italy), from 9 to 11 July 2024.

The IPCC would like to thank the European Commission's Joint Research Centre for the generous support in holding this meeting.

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Preface

We are pleased to present this report of the IPCC Expert Meeting on "Reconciling Anthropogenic Land Use Emissions", held in a hybrid format at the premises of the European Commission's Joint Research Centre in Ispra (Italy) from 9 to 11 July 2024.

Global models and national GHG inventories use different methods to estimate anthropogenic CO_2 emissions and removals for the land sector. This difference has relevant implications for assessing collective climate progress of the remaining carbon budget and, more broadly, for the confidence on land use estimates under the Paris Agreement. Given the importance of this difference, the IPCC Panel decided, at its 60th Session in Istanbul, Türkiye in January 2024, to hold an Expert Meeting on reconciling anthropogenic land use emissions to establish stronger direct links between global modellers and GHG inventory compilers, develop a common understanding of the challenges in estimating land use GHG fluxes, and explore concrete steps to ensure a greater comparability of estimates.

The Expert Meeting provided a unique opportunity for 111 experts in global carbon modelling, Earth observation and national GHG inventories to come together to discuss their respective approaches to identify anthropogenic land GHG fluxes, the rationale for the approaches, and consider ways to reconcile the differences in the future. Discussion and conclusions of this Expert Meeting are described in this report. They are not to pre-empt the future work, but to initiate a constructive dialogue between the different communities to reconcile the differences in land emissions. We believe the outputs of this Expert Meeting will inform the scoping as well as the writing of the Assessment Report of the IPCC's 7th Assessment Cycle.

We would like to thank all those involved in this meeting, namely, the experts who participated, the members of the Scientific Steering Committee, the TFB, and the TFI Technical Support Unit, for their contribution, that enabled to make this meeting a success. We also extend our appreciation to the European Commission's Joint Research Centre for hosting this Expert Meeting.

Takeshi Enoki	Mazhar Hayat
Co-Chair	Co-Chair
Task Force on National Greenhouse Gas Inventories	Task Force on National Greenhouse Gas Inventories
Intergovernmental Panel on Climate Change	Intergovernmental Panel on Climate Change

Executive Summary

Land-based mitigation is a key element to reaching the Paris Agreement's temperature and net zero greenhouse gas (GHG) emissions goal. However, recent studies have revealed a significant discrepancy in global land-use CO_2 emissions between global models, used to determine the net-zero pathways in the IPCC Assessment Reports, and national GHG inventories as well as country climate pledges, used to assess compliance with the Paris Agreement. This gap, equal to about 6-7 billion tonnes CO_2 per year globally (equivalent to ca. 15% of global CO_2 emissions), mainly reflects differences in how anthropogenic CO_2 removals are defined, with countries using a broader definition than global models.

In other words, there are different communities working on the same topic but using different approaches, like different "languages", each valid in its context but incompatible in a dialogue without translation. While global models consider as "anthropogenic" only those emissions and removals associated to direct human-induced effects (e.g., land-use change, harvest, regrowth), national inventories include both direct and, often, most indirect human-induced effects (e.g., fertilization effect on vegetation growth due to increased atmospheric CO_2 concentration, Nitrogen deposition, changes in temperature and length of growing season) on land defined as "managed", i.e. subject to human influence. Specifically, managed land is where human interventions and practices have been applied to perform production, ecological or social functions, including conservation and fire protection activities. Emissions and removals for unmanaged lands are not reported in national inventories. The land areas considered by the different approaches are also different. Global models consider only the relatively small areas where the direct effects occur, while inventories consider a broader managed land area, often including the whole country.

Under the Paris Agreement's Global Stocktake, these differences have important implications for the assessment of where we are compared to where we should be.

To start addressing this problem, the IPCC Task Force on National GHG Inventories convened an Expert Meeting on "Reconciling Anthropogenic Land Use Emissions" at the European Commission's Joint Research Centre, Ispra (Varese, Italy), from July 9-11, 2024. The meeting gathered 111 experts (85 in person and 26 online) from 46 countries, representing the main communities involved in this topic: global carbon modelling, Earth observation, and national GHG inventories. The Expert Meeting was preceded by a preparatory Webinar (24 June 2024) attended by 80 experts, where the key concepts and methods used by the various communities were illustrated.

The Expert Meeting was structured around three questions:

- **Where are we?** Developing a shared understanding of the differences in land-use GHG estimates (with a focus on CO_2) between the communities that support the IPCC Assessment Reports and the National GHG inventories, including the origin of this difference, its magnitude and its implications.
- **Where do we want to go?** Establishing a foundation for enhanced understanding and collaboration across these communities to increase confidence and comparability in land use GHG estimates.
- **How do we get there?** Outlining concrete steps forward that each community can take to improve comparability in land use GHG estimates, thereby increasing confidence in the data used by future Global Stocktakes.

These questions were explored during the first one and a half days of presentations and plenary discussions, followed by one and a half days of discussions in three different Breakout sessions. In addition, 38 posters were prepared by participants and discussed in dedicated sessions.

The Expert Meeting offered participants a unique opportunity to engage - often for the first time - with experts from other communities, fostering a deeper mutual understanding of their respective 'languages' and the implications. It underscored the importance of increasing transparency across all communities, the need of communicating the implications of different definitions of anthropogenic CO_2 removals, and the necessity for 'translation' of estimates to ensure comparability.

A critical question concerns the direction and scope of this translation. For practical reasons, national GHG inventories are less flexible because they typically rely on verifiable observations that do not allow separating direct and indirect anthropogenic effects[1] as global models do, and follow IPCC methods and UNFCCC requirements agreed by all countries.

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[1] see IPCC (2009). Expert Meeting on Revisiting the Use of Managed Land as a Proxy for Estimating National Anthropogenic Emissions and Removals

In contrast, global models are more flexible and, in principle, can be operationally translated into the inventory approach. However, defining emissions as anthropogenic based strictly on identified drivers is deeply entrenched in the models' calculation of the remaining carbon budget and net-zero goals. For a more accurate assessment of collective progress under the Paris Agreement, it is thus crucial that both the original results from global models and their translated versions are available in future IPCC Assessment Reports, the Global Stocktake, and other relevant reports. This enables like-for-like comparisons between countries' and models' approaches, while highlighting the implications of differing definitions.

This translation, while improving comparability in land-use emission estimates from various communities, has significant implications at both global and national levels. At the global level, it reduces the remaining carbon budget as originally defined by global models and affects the timing and perception of net-zero emissions. In particular, the scientific formulation of net zero CO_2 emissions halts CO_2-induced warming only if the definition of removals excludes indirect CO_2 effects. While the inclusion of indirect effects does not diminish the importance of national mitigation efforts, it may reduce comparability between national commitments and global temperature goals as modelled by the IPCC, e.g. a country may appear climate neutral when indirect effects are included, but still emit significant fossil CO_2.

Therefore, we now know better where we are (different languages) and where we need to go (translation and communication of the implications). In addition, the Expert Meeting has outlined a number of strategic actions, i.e. how we can get there. These actions include:

- **Improving communication**, such as tailoring messages to specific audience (IPCC authors, government experts), avoiding a framing that pits "science vs. inventories" (as inventories are science-based), developing a shared glossary to improve understanding of concepts that are used by the two communities, and taking into account the differences between "reporting" in national inventories (following IPCC guidelines) vs. "accounting" towards the country climate targets. Furthermore, while the mismatch in estimates and their uncertainties should be communicated transparently, it should not distract from the urgency of continued mitigation efforts towards economy-wide net-zero emissions.
- **Improvements within each community**:
    - National GHG Inventories will continue to rely on the IPCC guidance and its "managed land proxy", where all emissions and removals from managed land are considered anthropogenic. The Biennial Transparency Reports to be reported by all Paris Agreement's Parties, which include the national inventories, represent an occasion to implement this proxy with greater transparency (definition, area, and where possible maps of managed land). Pending the availability of adequate resources, which are often lacking especially in developing countries, additional voluntary information would facilitate understanding and comparisons with global models. Such information may include: more detailed stratification of activity data (i.e., areas where different activities are happening, such as land use changes, forest harvest possibly disaggregated by intensity, and shifting agriculture if does not lead to land conversion); enhanced methodological information to help assessing the extent to which indirect effects are captured, which depends on the approach used (stock-difference or gain-loss), the Tier level, and variables such as growth rates and age classes; if and how disturbances are considered.
    - Global Models' results (from bookkeeping models, dynamic global vegetation models, integrated assessment models) can in principle be translated into the inventory framework, i.e. disaggregated to become conceptually more comparable to inventory results. Improvements that would help confidence in estimates and comparisons across communities include the following: enhanced accessibility to modelling assumptions/data for external users, including information on uncertainties; ensuring consistent estimations of the anthropogenic and natural components; better representation of forest demographics; improved integration of Earth observation data; better documentation of CO_2 fertilization effects; disaggregation of results consistently with national inventory categories; use of more detailed country-specific information.
    - The Earth Observation (EO) community already plays a key role in monitoring land use/cover change – providing independent data for other communities - and in estimating CO_2 fluxes. While EO-based fluxes do not align precisely with the definitions used in NGHGIs or global models, translating EO results to fit the NGHGI framework is feasible once the area of managed land is known. Specific improvements can include cross-comparisons of EO data, improving transparency/accessibility of data, standardizing land use/cover classes, enhancing time-series consistency, better monitoring of forest disturbances and regrowth rates, improved estimation of carbon stocks and carbon stock changes, better validation with ground-based data, enhanced guidance and capacity building on how EO data can be integrated into inventories using IPCC methods.

- **Strengthening collaboration across communities** is crucial to bridge existing gaps. This may involve: further developing the JRC-hosted “global land use carbon fluxes” hub[2] - an example of platform for comparing datasets with different methods -, including additional data products and more disaggregated comparisons and analyses; regular dialogues in workshops/task groups to advance mutual understanding and develop joint protocols for translation (to improve comparability), with the possible collaboration of and/or support from the IPCC TFI and the Global Carbon Project; improving data sharing and integration through shared repositories and enhanced interoperability of data; engaging experts from various communities in smaller groups at regional and national levels – possibly coordinated by the Global Carbon Project/RECCAP or similar initiatives - using joint protocols and leveraging local expertise and data. Lastly, collaboration between IPCC Working Groups and the TFI could be reinforced during the 7th IPCC Assessment Report (AR7) cycle by establishing a task group and developing common glossaries in order to secure consistent use of data and concepts across the AR7 products.

Furthermore, as part of efforts to foster mutual understanding, it is important for both the global models and EO communities to gain deeper understanding of the basic rules governing the Paris Agreement (e.g., the Enhanced Transparency Framework, Global Stocktake) and the basic methods in the IPCC guidelines. Conversely, it would be useful for the NGHGI community and policymakers to gain a better understanding of key concepts from the IPCC assessment reports that are relevant for Articles 2 and 4 of the Paris Agreement (e.g., the remaining carbon budget, net-zero emissions).

Feedback from experts shared informally during and after the Expert Meeting included a general sense of surprise at the magnitude of the differences in approaches for estimating land-use CO_2 emissions and removals. This was paired with some frustration due to the complexity of the task ahead, but also a strong motivation to tackle it. Feedback included remarks like: “the meeting was an eye-opener”, “there is so much work to do” and “we should have done this meeting 15 years ago.”

Overall, this Expert Meeting sowed important seeds of cooperation. A much-needed dialogue has begun among communities that had never truly interacted before at this scale, which is a historic achievement in itself. As an African proverb says, “If you want to go fast, go alone. If you want to go far, go together.”

In the coming years, there is a strong appetite for increased data exchange, enhanced dialogue, and fostering mutual understanding. Targeted collaboration, in particular at the level of component fluxes and countries, is a great opportunity to improve the accuracy of land-use emission estimates and enhance their comparability across different communities.

The first results of this effort will be evident in 3-4 years, through the IPCC AR7, countries’ Biennial Transparency Reports, and the 2nd Global Stocktake. Operationalizing the translation of global model results into national inventory definitions would help bridging the gap between the land-use estimates and scenarios in the IPCC Assessment Reports, which are based on global models, and the mitigation processes under the Paris Agreement, which rely on NGHGI data. This approach will also build confidence in land use as a viable mitigation option and strengthen the data and science available for the Global Stocktake process.

This report documents the results of these three days of intense discussion, which will inform the Scoping Meeting of the IPCC AR7 Reports and provide relevant background information to the Parties of the Paris Agreement.

The materials presented during the Expert Meeting, including all the presentations and the posters, are available at the TFI webpage https://www.ipcc-nggip.iges.or.jp/public/mtdocs/2407_EM_Land.html

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[2] https://forest-observatory.ec.europa.eu/

1. Introduction

Land-based mitigation is recognized as an increasingly important element to reach the Paris Agreement's temperature goal. However, recent studies[3] highlighted a large gap in global anthropogenic land use CO_2 estimates between the global models used in the IPCC 6th Assessment Report (bookkeeping models and integrated assessment models) and the national GHG inventories used to assess compliance with the climate targets under the Paris Agreement. This gap, equal to about 6-7 Gt CO_2/yr globally, mainly reflects differences in how anthropogenic GHG fluxes from forest and areas of managed land are defined (see section 2).

This difference has relevant implications for assessing collective climate progress, for the remaining carbon budget and, more broadly, for the confidence in land use estimates under the Paris Agreement. This issue has received the attention from the scientific and policy communities, including IPCC reports[4] and UNFCCC documents[5].

For these reasons, the IPCC Plenary LX mandated the IPCC Task Force on National GHG Inventories (TFI) to organize an Expert Meeting on "Reconciling land use emissions"[6], aimed at:

- Developing a common understanding of the gap in land use estimates between the communities that support the IPCC Assessment Reports and the National GHG inventories and its implications ("Where we are");
- Setting the basis for greater collaboration between the communities involved - global carbon modelling, Earth observation and national GHG inventories -, to increase confidence and comparability in land-related GHG estimates ("Where we want to go");
- Outlining concrete steps forward that each community can take to ensure greater comparability between future IPCC products and national GHG data prepared following the IPCC Guidelines ("How we get there").

The Expert Meeting, held on 9-11 July 2024 at the European Commission's Joint Research Centre in Ispra (Italy), gathered 114 experts (85 in presence and 29 online) from 46 countries. The Expert Meeting included one and a half day of presentations and plenary discussions, followed by one and a half days of discussion in three different Breakout Groups (BOGs). During the Expert Meeting, 38 posters prepared by participants, illustrating valuable information and results from the various communities, were presented and widely appreciated. The Expert Meeting was preceded by a preparatory Webinar (24 June 2024) attended by 80 experts, where the key concepts and methods used by the various communities were illustrated.

This report summarizes the material presented and the discussions held during the Expert Meeting, focusing on the three aims outlined above: "Where we are" (section 2), "Where we want to go and how to get there" (section 3, illustrating the outcomes of BOGs 1 and 2), followed by reflections on the communication challenges related to reconciling estimates among land-use emissions datasets (section 4, with the outcomes of BOG 3), and the Conclusions (section 5).

The report is complemented by the Expert Meeting agenda (Annex 1), the list of participants with statistics (Annex 2),), an overview of the UNFCCC's Global Stocktake process (Annex 3), a summary of the material presented to the plenary (Annex 4a: presentations; Annex 4b: presentations from the BOGs), and the Background paper (Annex 5). The Background paper includes a rich collection of the key concepts, data and evolving methods used by the three different communities involved, plus a list of terms used. Annex 6 includes all references used in other sections.

The materials presented during the Expert Meeting, including all the presentations and the posters, are available at the TFI webpage https://www.ipcc-nggip.iges.or.jp/public/mtdocs/2407_EM_Land.html.

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[3] E.g., Grassi et al. 2018, Grassi et al. 2021, Grassi et al. 2023, Gidden et al. 2023.

[4] IPCC AR6 Synthesis report (2023). Summary for Policymakers, footnote 40: "Global databases make different choices about which emissions and removals occurring on land are considered anthropogenic. Most countries report their anthropogenic land CO_2 fluxes including fluxes due to human-caused environmental change (e.g., CO2 fertilization) on 'managed' land in their national GHG inventories. Using emissions estimates based on these inventories, the remaining carbon budgets must be correspondingly reduced. {3.3.1}"

[5] UNFCCC Synthesis report for the Global Stocktake, para 31 (March 2022): "There is a difference in definition between the estimation of anthropogenic GHG emissions and removals from the LULUCF sector under the UNFCCC, and the estimation of emissions related to land-use change as part of the global emission estimates of the IPCC 6th Assessment Report. […] Such differences should be taken into careful consideration, and adjustments made accordingly, where any comparison between LULUCF emission data reported by Parties and the global emission estimates of the IPCC is attempted."

[6] The approved meeting proposal is contained in Annex 9 of Decision IPCC-LX-10.

2. Where are we?

According to the Global Carbon Project, which annually publishes the Global Carbon Budget (Friedlingstein et al 2023), anthropogenic CO_2 emissions have reached about 40 billion tons per year on average over the last decade (see Figure 1). Changes in land use and land management contribute around 12% of the total, mainly through deforestation. Simultaneously, terrestrial sinks absorb nearly a third of the total anthropogenic CO_2 emissions, mostly in forests.

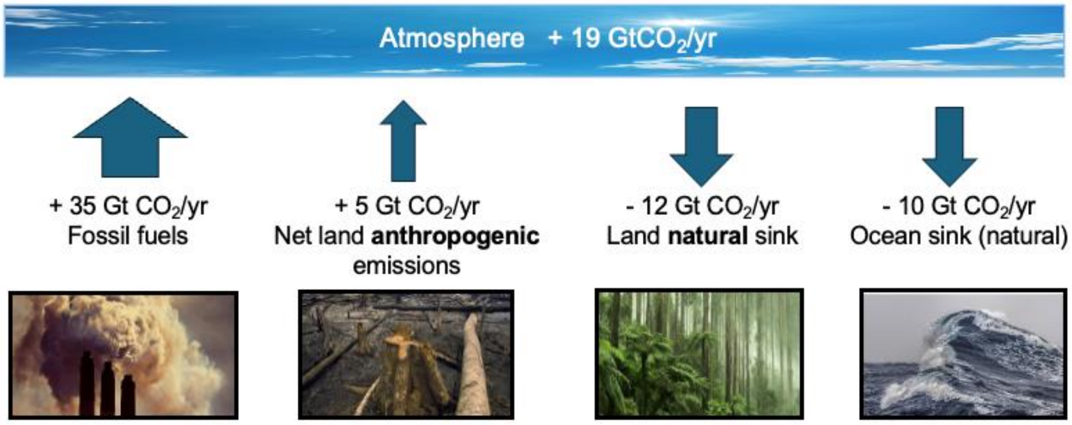

Figure 1. The global carbon budget (2013-2022): sources and sinks of anthropogenic emissions (Global Carbon Project, 2024). Numbers are from Friedlingstein et al. (2023), excluding the ‘budget imbalance’ required to make all numbers sum to zero.

Therefore, land currently plays a significant role on both the source and sink sides. This relevance is reflected also in the future mitigation potential, as it emerges from both scientific and policy documents.

According to the WGIII contribution to the latest IPCC Assessment Report (Nabuurs et al. 2022) the Agriculture, Forestry and Other Land Use (AFOLU[7]) sector can provide 20–30% of the global greenhouse gas (GHG) emissions mitigation needed for 1.5C or 2C pathways towards 2050, with the largest share from CO_2 emissions and removals within the Land Use, Land-Use Change and Forestry (LULUCF[8]) sector.

Similarly, LULUCF accounts for 25% of net emissions reductions pledged by countries in their nationally determined contributions (NDCs) to the Paris Agreement (e.g., Roman-Cuesta 2024). The focus of climate policy is now progressively shifting towards the implementation of these pledges, leading to greater interest in tracking progress at the country level. However, monitoring and assessing progress in the LULUCF sector is difficult due to the complexity of measuring land-based GHG emissions and removals, and specifically its anthropogenic component.

Despite unprecedented monitoring opportunities offered by new observation tools, striking differences remain between land-use CO_2 fluxes estimated by different approaches (Figure 2). For example, a comparison of global net LULUCF CO_2 flux estimates from diverse approaches show differences of several Gt CO_2/yr. Some on the differences among these datasets have been explored in depth in the scientific literature, while others have not.

The difference between the two country-based datasets, National GHG Inventories (NGHGIs) and FAOSTAT, can be mostly explained by a more complete coverage of NGHGIs, including for non-biomass carbon pools and non-forest land uses, and by different underlying data on forest carbon sink. The latter reflects the different scopes of the country-reporting to FAO, which focuses on area and biomass, and to UNFCCC, which explicitly focuses on C fluxes (Grassi et al. 2022).

A striking difference is the gap of about 6-7 Gt CO_2/yr between the global models from the Global Carbon Budget (Bookkeeping models and Dynamic Global Vegetation Models, DGVMs) and the NGHGIs. According to the available literature, this difference is largely explained by different definitions of anthropogenic CO_2 emissions and removals in

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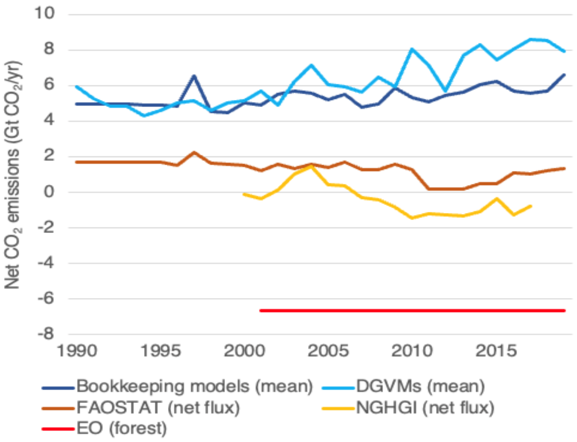
[7] AFOLU is the sum of the GHG inventory sectors Agriculture and LULUCF. See Glossary.

[8] LULUCF is a GHG inventory sector that covers anthropogenic emissions and removals of GHG in managed lands, excluding non-CO_2 agricultural emissions. See Glossary.

managed forests (e.g., Grassi et al. 2018, 2021, 2023, Schwingshackl et al. 2022, Gidden et al. 2023, Friedlingstein et al. 2023).

Figure 2. Global net LULUCF CO_2 flux in the WGIII contribution to the IPCC AR6 (redrawn from Fig. 7.4 in AFOLU chapter, Nabuurs et al. 2022), estimated using different methods: (i) Global models from the Global Carbon Budget (Friedlingstein et al. 2020): Dynamic Global Vegetation Models (DGVMs) and Bookkeeping models; (ii) Earth Observation data (forest-related fluxes only, Harris et al. 2021); and (iii) country-based data: National GHG Inventories (NGHGI, Grassi et al. 2021) and FAOSTAT (Tubiello et al. 2020). More updated data from global models and countries can be found in Friedlingstein et al. 2023.



Countries assume larger areas of forest to be managed than global models do, due to a broader definition of managed land in NGHGIs. Additionally, the fraction of the land net sink caused by indirect effects of human-induced environmental change (e.g., fertilization effect on vegetation growth due to increased atmospheric CO_2 concentration, Nitrogen deposition, changes in temperature and length of growing season) on managed lands is treated as non-anthropogenic by global models but as anthropogenic in most NGHGIs[9] (see Figure 3).

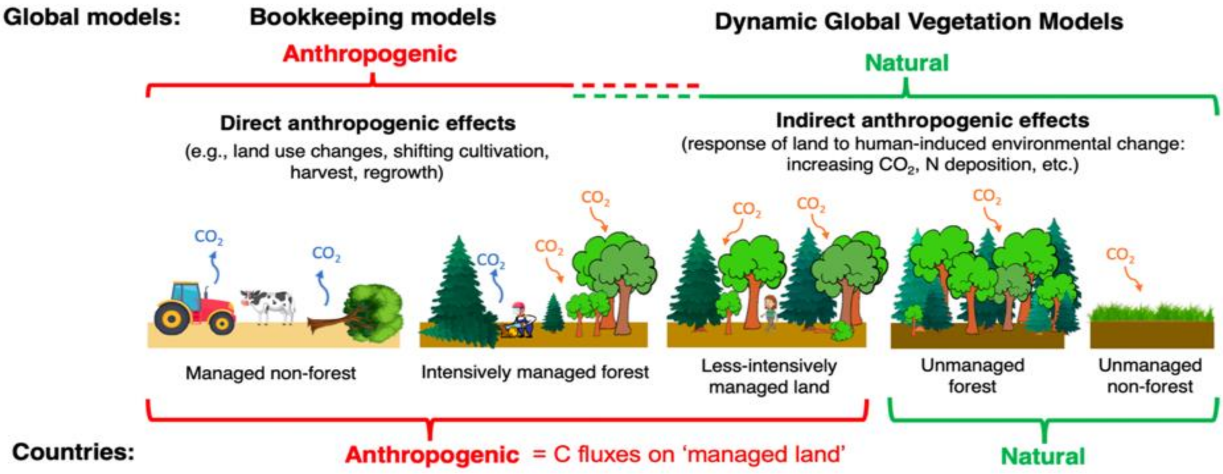


Figure 3. Conceptual illustration of the different approaches for estimating anthropogenic and natural land CO_2 fluxes by global models used in the Global Carbon Budget (Bookkeeping models and Dynamic Global Vegetation Models) and by countries' national GHG inventories. See Grassi et al. (2023) for details.

In other words, countries - by following the IPCC Guidelines for NGHGIs (IPCC 2006, 2019) and its 'managed land proxy' (see Annex 5.3) - consider a large part of the land sink to be anthropogenic, in contrast to global models where it is assumed to be non-anthropogenic (see Figure 4). This is because, especially in areas where land-use changes do not occur (e.g., forests that remain unchanged), it is often not possible to factor out direct and indirect effects using the observational data typically available from NGHGI and used for managing land resources, such as forest inventories (Canadell et al. 2007, IPCC 2009). This approach by NGHGI is what Parties of the Paris Agreement are required to follow under the Enhanced Transparency Framework.

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[9] Exceptions, where indirect effects are only partially included in the NGHGI, include Canada and Australia - see box 5.3.3, box 5.3.5 and Annex 5.3.8 for additional country-level details. The extent to which indirect effects are captured depends on many factors, including the approach (stock-difference or gain-loss) and the Tier level used (Tier 1 methods are not likely to fully include indirect drivers of emissions and removals).

It should be noted that there is no approach that may be considered superior to the other: due to differences in purpose and scope, the largely independent scientific communities that support the IPCC Inventory Guidelines (reflected in NGHGIs) and the IPCC Assessment Reports have developed different approaches to identify anthropogenic GHG fluxes. Both approaches - like two “languages” - are valid in their own specific contexts (and have their own shortcomings), but they are not directly comparable.

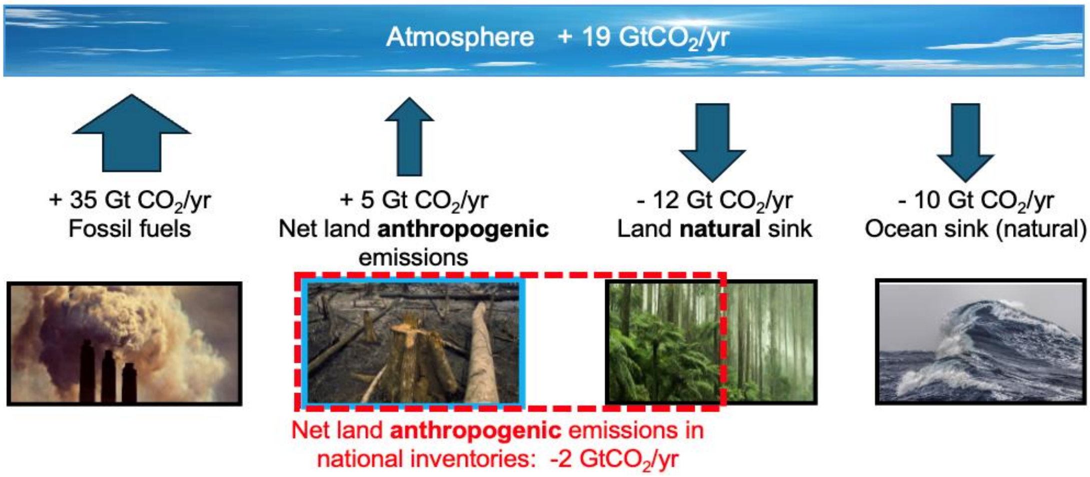

Figure 4. The global carbon budget, as in Figure 1, adapted to highlight the different system boundaries of net land anthropogenic emissions by global models (blue box) and national inventories (red box).

This lack of comparability is problematic. The global models’ approach forms the basis for the LULUCF estimates in the IPCC Assessment Reports - both for the historical period (using Bookkeeping models) and the future (emission scenarios by Integrated Assessment Models, IAMs). On the other hand, NGHGIs are the basis for assessing both the countries’ compliance with their climate pledges, and the collective climate progress against the IAMs-based emission benchmarks consistent with the Paris Agreement’s goal, as per the Global Stocktake mechanism.

A reconciliation between these approaches is needed, akin to a “translation” between two languages. While important steps in this direction have been taken (Grassi et al., 2021, 2023; Schwingshackl et al., 2023; Gidden et al., 2023; Friedlingstein et al., 2023), much work remains to be done. Since the reconciliation has impacts on the estimated remaining global carbon budget and the net-zero timing (IPCC 2023), future work will also need to explore how to best communicate this.

Among the other differences in Figure 2, the one between Earth Observation data and NGHGIs has not been explored in depth so far. However, it is clear that Earth Observation data, including integration with ground data and/or with various modelling approaches to estimate CO_2 fluxes (e.g., Harris et al. 2021, Xu et al. 2021, Deng et al. 2022), will play a key role both in supporting the countries’ reporting and verification needs under the Paris Agreement (e.g., Melo et al. 2023, Heinrich et al. 2023) and as a parametrization tool and benchmark for the land sink estimates from global models.

Overall, the above analysis reveals a worrying situation: the lack of agreement among different datasets on the sign and magnitude of the LULUCF CO_2 flux at global level – and for most regions and countries - may seriously jeopardize the assessment of the countries’ collective progress under the Global Stocktake and, more broadly, the confidence in land-use mitigation options.

At the same time, evidence indicates these discrepancies can be addressed through a joint cooperative effort across all the communities involved: global carbon models, Earth Observation and NGHGIs. The challenge is to achieve more comparable LULUCF estimates across communities, allowing the next IPCC Assessment Report and National GHG Inventories to assess the role of land use with more precision, while achieving consistency each other and so building confidence in the Global Stocktake.

3. Where do we want to go, how do we get there?

3.1 Discussion in BOG session 1

On **day 2 – BOG 1 session**, after one and a half days of presenations, three breakout groups (BOGs) with a balanced representation of the various communities discussed in parallel the following guiding questions:

- Remaining clarifications on presentations made at the plenary
- Wish list of information for understanding better what other communities do
- Wish list of data /information that other community could provide and improve your estimates
- Solutions for harmonization for other community

Below are the detailed summaries made by Co-Chairs of BOG session 1. The slides presented by the rapporteurs of each BOG are in Annex 4c below.

BOG 1A

Co-chairs: Sukumar Raman and Jo House. Rapporteur: Luis Panichelli

We need to be clear on the common goals of reconciliation and the purposes of different methodological approaches. What is the flexibility of each community to change? What incremental progress is feasible? Include all communities: inventories, models, EO, organisations that provide/compile/calculate data (e.g. FAO, EDGAR), policy users.

The group generally agreed that full alignment of different approaches would not be possible but that there is opportunity for better transparency and translation - Rosetta Stone approach. The basic steps of each approach need to be clear to other communities (including e.g. what information can be found in supplementary tables, what is freely available). It would be helpful to have direct comparisons regarding:

- Definition and terminology e.g. land use category definitions, management practices (including, where allowed by national circumstances, , forest harvest intensity, shifting agriculture, forest degradation, etc.) and natural disturbances.
- Resolution/scale, spatial & temporal: time period, is elevation considered
- System boundaries and baselines
- What is being measured/calculated/reported at each step and how do they relate to each other: Activity; change in activity; carbon stock; change in biomass; change in flux; climate impacts-natural disturbance (e.g., fire)
- Clarity on the methodological approaches

There is a lack of data/capacity in many countries to provide wall-to-wall information, also limited flexibility across all approaches to change (negotiated guidelines, country sovereignty vs global consistency, modelling juggernaut, data and methodological limitations). Keep a flexible approach to reconciliation going forward.

Specific Data wishes were discussed.

- Spatial as far as possible- (considering uncertainties and effects of different cartographies). Disaggregated area under different (1) cover types (2) activities
- Emissions from different activities e.g. industrial harvest, shifting cultivation
- Big data gaps: Soil carbon, degradation, disturbance, unmanaged forests

Practical approaches to moving forward include:

- Country based RECCAP type exercise with communities working together
- Stepwise exercise: First align key definitions and land areas as much as possible. Then go into detail country by country. Identify which tier/ methods countries using, whether spatially explicit. Next focus on carbon stocks, then on activities. Group countries using similar methods.
- Practical support for countries to move from net area change to spatial products, in line with move to higher IPCC tiers and approaches. Most countries use EO products but could be supported to improve further and to understand uncertainties e.g. accuracy, suitability and availability of cartographic products.
- Models to separate data in line with inventory land use categories (FL, CL, GL, WL, SL, OL).
- Non-inventory approaches could provide similar report to BTRs at the same time

BOG 1B

Co-chairs: Thomas Gasser and Mark Howden. Rapporteur: Roberta Cantinho

First, the group needed to clear up some misunderstandings:

- inventories cannot change drastically in one go,
- however, alternative/complementary approaches at the national level (by same or similar teams) could better compare with models,
- most of the reconciliation effort so far has been on the models' side,
- differences between communities and the results should be accepted and acknowledged, but we should aim for a common and clear narrative to explain them.

The group agreed that the task was therefore to find a minimum reporting requirement to enable translation between and comparison of approaches.

Ideally all approaches would report under a similar format/checklist that would include key information and data. Very tentatively, such a checklist would include:

- What is the forest definition?
- Where are the trees in "other land use"? And other biomass characteristics.
- Forest divided between area in production for wood supply and others.
- Which forest management practices are included and how are they represented (esp. in modelling studies)
- Distribution of growth rates or age classes (and how is this modelled in bookkeeping models and DGVM?)
- In models, report CO_2 fertilization, climate and other effects separately from direct anthropogenic effects.

Further considerations on reporting and definitions were discussed:

- It is fine if we do not agree on terms, but these should be clarified and more importantly be clear to policymakers as well as their implications.
- Disaggregation is often referred to as spatial, but it is important also at temporal scale and following finer land categories.
- Ideally, data collection should be done in a way that makes it available and usable by other communities.
- Clearly distinguish calculation, reporting and accounting, from the information collected.
- Transparency is the most important aspect.

From a modelling perspective, the (ideal) wish list for data from national inventories focused on:

- a definition of each country's managed land including management type and other details,

- historical data as far back as possible, even if less disaggregated (for the legacy effect),
- comparison with models is difficult if disturbances and indirect fluxes are treated differently by the countries: there is a need for a unified approach,
- integration of unified data from inventories into a public database would be key to improve comparison and model development,
- this would ideally include spatially-resolved data (for fluxes, but also all other key variables listed above, and especially managed land subcategories).

In terms of policy implications, some questioned how significant the misalignment really is: even if countries follow targets defined under the alternative convention, climate change will still be significantly reduced, and current actions are far from even reaching this point. It was answered that for some countries it matters more than at global level, as some countries could be already considered climate neutral under the national inventory convention in terms of anthropogenic emissions, despite emitting significant amounts of fossil CO_2. In addition, the relevant science community is accountable for the discrepancy and must be able to explain it and its implications to policymakers.

BOG 1C

Co-chairs: Sonia Seneviratne / Douglas MacDonald. Rapporteur: Clemens Schwingshackl

Initial discussions aimed to clarify aspects of the plenary presentations. Participants agreed that understanding and communicating the differences between the estimates by the different communities was critically important. However, they also sought clarification on the objective of the meeting and assurance that it would not result in changes to guidance on reporting emissions. It was noted that national capacities are very different and that should be considered in attempting to reconcile the estimates from the different communities. The question of who the meeting outcomes were targeting was also important to the participants, whether to better inform the authors of the next Global Stocktake or national policy makers.

The modelling community sought clarity on the underlying assumptions of NGHGIs, how emissions and removals are compiled and application of the managed land proxy in NGHGIs. Inventory compilers sought to better understand how uncertainty was considered in modelling analysis and questioned the concept of CO_2 fertilization. Inventory compilers noted that it was not possible to directly measure CO_2 fertilization and that the term may be misleading and represent a summation of a wide variety of processes. The communities agreed that knowledge gaps included lateral transport, belowground carbon and consideration of climate disturbance in projections.

The three communities developed a list of information that they required to better understand other communities estimates of emissions and removals. The communities agreed that a protocol was required that established mutually agreed definitions for specific terms used in analysis and sign conventions for communicating sinks and sources. Further the communities identified the need for; i) Improved information as to how countries define managed land, maps of managed land and why it is considered managed, ii) Improved transparency related to: calculations of uncertainty, iii) modelling assumptions, processes included and excluded and iv) management and fertilization history.

Participants identified the type of data that they could share to improve mutual understanding among the three communities including: i) the need for disaggregated data differentiating different types of management (e.g., intensive vs. extensive), ii) forest age classes and growth rates, iii) natural disturbances and iv) shifting cultivation. The need for a shared database for emissions and removals and disaggregated carbon flows and to share National Forest Inventory data (particularly for the remote sensing community) and gridded data on fluxes was expressed.

In summary, the BOG 1 participants highlighted as solutions the need for a common glossary and a protocol for the development of model estimates in parallel with NGHGIs. Further, they recognized the quantity of information already exists, but highlighted the importance to organize it and make it accessible for all. The TFI, IPCC, JRC, and the Global Carbon Project were mentioned as potential entities that could perform this organizational task. Finally, the communities identified the need for continued collaboration, suggesting small groups from different communities working together on smaller scale projects to improve the understanding of the differences between the different quantification tools and analyses.

3.2 Discussion in BOG session 2

On **day 3 – BOG 2 session**, three groups separating the communities (Global carbon modelling, Earth Observation, national GHG inventories) discussed challenges ahead and realistic concrete improvements that each community can realize in the next 3-4 years, to advance towards reconciliation for IPCC AR7 products and the 2nd Global Stocktake.

Below are the detailed summaries made by Co-Chairs of BOG sessions 2. The slides presented by the rapporteurs of each BOG are in Annex 4c below.

BOG 2A (National GHG inventories)

Co-chairs: Stephen Ogle, Yasna Rojas, Thelma Krug. Rapporteur: Rizaldi Boer

The BOG on NGHGI discussed issues related to reconciling differences between the LULUCF sector estimates from global models and greenhouse gas emissions inventories. Global models are periodically conducting a global stocktake of progress that Parties are making on their contributions to the Paris Agreement, and mismatch between LULUCF estimates between the two groups is problematic for evaluating progress.

Managed land is a central concept for the LULUCF inventory compilation. It assumes that all emissions and removals on that land are of an anthropogenic nature, including those that result from indirect and natural effects, such as CO_2 fertilization and nitrogen deposition. Inventory compilers estimate all GHG emissions and removals from managed land for which IPCC provide methodological guidance. In contrast, global models are tracking specific directly human-induced activities, such as logging, afforestation/reforestation and deforestation, and do not include indirect and/or natural effects in their estimates. The modelling community indicated that it would be helpful to understand which portions of the land are assumed to be managed and unmanaged, and it was acknowledged at the BOG that there are gaps in knowledge about the application of the proxy, but that continuous efforts are in place to improve national GHG reporting. Moreover, it is good practice to be transparent when reporting inventory results and methods, and this would include how the managed land proxy is applied even if all lands are managed.

One of the main conclusions of the break-out discussion is that there is a critical misunderstanding between the two communities about reporting emissions and removals and accounting. As noted above, inventories provide estimates of all GHG emissions and removals on managed land, and do not apply accounting rules, which are understood to be decided in a political forum. The Parties to the UNFCCC may agree upon accounting rules, which could lead to disaggregation of emissions between direct and indirect drivers of the C stock changes for the Paris Agreement reporting. However, this is beyond the scope of the IPCC National Greenhouse Gas Inventory Guidelines, which do not develop accounting rules While this may seem problematic, the purpose of the IPCC guidelines is to provide as accurate an estimate as possible of anthropogenic emissions and removals, and currently the managed land proxy is considered the best approach for meeting this objective in the LULUCF sector. Furthermore, the methods produced by the IPCC and applied by inventory compilers can only change if modifications are requested by the Parties and incorporated into a new methodology guidance.

During the BOG, it was acknowledged that inventories may not always be accurate. Inventory compilers are applying the best methods with good practice given resources available in each country for conducting the LULUCF inventory. There are often gaps in reporting that inventory compilers work to address as part of formal improvement plans. Such plans may even be discussed in national inventory reports, but implementing improvements can take time and may require resources that are not always available. An example is addressing illegal logging in LULUCF inventories for forest land that is difficult to estimate given the nature of logging without permits or tracking of these illegal activities. In countries where this is a gap, compilers work towards addressing this issue but as noted, it can take time and require resources that are not currently available.

In addition to gaps, inventory compilers apply methods with different levels of detail and specificity to national circumstances. Tier 1 methods are the simplest, relying on global or regional factors, which may or may not represent national circumstances. These methods require the least amount of activity data, and tend to have the largest uncertainties. Moreover, Tier 1 methods are not likely to fully address indirect drivers of emissions and removals, such as CO_2 fertilization of forests. The influence of fertilization continues to change over time, but the factors are based on data that have been collected in the past, sometimes from several decades ago. Tier 2 and 3 methods are more likely to incorporate the indirect effects and other non-anthropogenic drivers, particularly when using national forest inventories as the basis for reporting. These methods are likely more accurate for estimating all emissions and removals on managed land. Regardless, inventory compilers are following IPCC good practice when using Tier 2 and 3 methods, particularly if the source is a key category.

Disaggregation of inventory estimates into indirect/natural emissions and removals versus direct anthropogenic is not possible with the 2006 IPCC National Greenhouse Gas Inventory Guidelines, and may introduce ambiguity in the reported estimates. The one exception is in the 2019 Refinement to the 2006 IPCC National Greenhouse Ga Inventory Guidelines in which compilers may disaggregate anthropogenic emissions in the LULUCF sector from natural disturbances and inter-annual variability after estimating and reporting total emissions and removals from managed land. The group also discussed verification, and raised concerns that even if estimates could be disaggregated, it would be difficult to impossible for countries to verify the disaggregated estimates with observations.

The BOG also discussed regional engagement and sharing of results among Parties. Inventory compilers understand that inventory reporting should be confined to the methodologies and approaches provided in the IPCC reports and that no additional requirements should be added to facilitate the reconciliation between the inventory and modelling communities. Some participants also indicated that country estimates provided by models are sensitive since there is no direct engagement and involvement of country's experts, who may have access to better national-scale datasets and knowledge of national circumstances, and therefore global modelling estimates may not be representative. With this context, inventory compilers may choose to engage with the global modelling community, and work towards a resolution on this issue. This engagement could involve smaller groups that are clustered in regions with inventory compilers, global carbon modelers and experts on observations, possibly coordinated through RECCAP or another mechanism. These group would need to develop a joint protocol for assessing the differences and potential solutions, and the activity could be initiated with a 'report card' from each group identifying sources of data and methods, before proceeding with more in-depth evaluations of the differences.

BOG 2B (Earth Observation)

Co-chairs: Luis Aragão, Alessandro Cescatti. Rapporteur: Martin Herold

The BOG was attended by about 25 experts mostly from the field of Earth Observation (EO) with different regional and technical expertise. In general, the EO community understands the important role as provider of relevant data and estimates that serves both the modelling and GHG inventory communities. In particular, the community understands that EO information is useful for reconciling differences between models and NGHGI and between national and global numbers. In that context, the use EO data and community can be a key independent broker in comparing and reconciling definitions and concepts (i.e. related to aligning different forest definitions, managed land delineation, attributing drivers of forest degradation), and comparing and reconciling on level data and estimates that are used by different communities. In any harmonization and reconciliation process, issues of transparency, estimating and considering uncertainty, and the need for open source and open data is key. The EO community is fully committed to provide data in FAIR and open-source manner, and improve standardization and description of land use and land cover classes and products of interest for both models and NGHGI communities.

The EO community is already actively working to support countries and facilitate uptake of useful tools and techniques for national LULUCF and AFOLU monitoring and estimation. This includes the sharing of data, information and experiences, development of improved guidance on how EO data can be integrated in national monitoring and estimation using the IPCC methods. Moreover, the community agree on the need for intensifying capacity development, which EO community understands as a critical step for increasing the use of EO information in inventories and comparability among NGHGI information across nations, specially tropical countries. It is recognized that incorporating EO data and products in national monitoring has it challenges, i.e. which data to use and why, impact of uncertainties, time-series consistency and the need for consensus on suitable approaches.

There are several ongoing capacity building initiatives addressing these points (i.e. FAO, GFOI, NASA, CEOS) and they should be built upon to further enhance the uptake of EO data and products for national NGHGI efforts.

The EO community is also an active partner to support global and regional modelling with data for parameterization, calibration and validation. The EO engagement depends on the type of modelling but most promising areas include: (1) for bookkeeping models to improve the provision of land use change or activity data or regrowth curves, accounting for multiple disturbances processes that can lead to degradation; (2) for inversion modelling to develop top-down and bottom-up datasets providing spatio-temporal data covering the LULUCF/AFOLU flux (i.e. to become part of WMO's G3W) and (3) for DGVMs to provide additional model parameters emerging traits, on leaf biochemistry/water, or productivity (i.e. SIF), include more forest demography and explore how new EO-based land use can be transformed in long-term change history data. The EO community and modelling communities should discuss these opportunities so models can make better use of EO, i.e. for tropics (using hyperspectral and LIDAR etc.) and to establish robust scaling-up routines to make use of "supersites" (including networks of field plots, flux-towers, airborne photogrammetry and LiDAR) for comparison and benchmarking. There are also important developments to make use of AI or hybrid-data driven modelling to link data and prediction models for improving near-term predictions.

In terms of providing improved land change/activity data, the EO community expects important progress using the Landsat and Copernicus data archives and programs. This includes monitoring with greater detail the types of different forest disturbances and regrowth trajectories. Several initiatives are ongoing and a comparative analysis should be performed. Land use change data should be provided in the long-term for at least the 6 IPCC classes noting that differences in data change definitions/concepts exist that need to be considered and potentially harmonized. With different initiatives ongoing, an independent accuracy analysis for evolving global datasets for "land change" should be performed and specific national case studies can underpin how global datasets can be compared and integrated within national level efforts. There should also be a focus on providing more detail on land use change /management with the aim to provide more information i.e. on crops/rotations, pastures, or soil dynamics.

There are multiple ongoing EO efforts to move from EO monitoring from tracking of land changes to estimation of GHG emissions and removals. Several recent and upcoming satellite missions and programs are aiming at providing biomass/carbon stock estimates that can provide improved assessments, in particular, when integrated with ground monitoring efforts as part of national (i.e. NFI) or global network efforts (i.e. GEOTREES). These data combined with time series of EO data are already improving the derivation of emission and removal factors for both A/Reforestation and for forest disturbance/degradation and regrowth (i.e. space for time approaches). There are different approaches being developed for monitoring disturbance history/forest age data to estimate regrowth curves. Since carbon stocks, emission/removal factors and LULUCF sink and source estimate are produced by countries, models and EO – a coordinated comparison exercise should be facilitated as an important means to understanding differences in different approaches.

Issues to provide and make use of accuracy assessments and uncertainty layers for all products and estimates have been discussed as key point. It is important to consider both accuracy and precision while estimates should prioritize accuracy over precision. Further considerations are related to time-series consistency and the need for the EO community to be clear on general limitations: What is a "direct" observable and where EO is more of a proxy to support spatio-temporal extrapolation.

In terms of improving communication and engagement, the EO community fully supports the JRC-hosted land use flux hub as a key global platform to collect and compare datasets built with different methods and assumptions; noting that more data products will come and comparison will become more detailed and specific. The EO community is ready to support the further reconciliation process and community-consensus discussions, noting that transparency, open source and open data is a key underpinning of making joint progress.

To summarize the main EO-BOG outcomes on what could be done by 2028 – there are eight points of action:

- Provide data and expertise in reconciling definitions, concepts (i.e. forest definition, managed land) and on the level of data and estimates.
- Improve global activity data and some land management types, including country case studies.
- Carbon stocks, emissions and removals: facilitate a comparison to understand differences in stocks, factors, sinks and sources in models, EO and NGHGI.

- Invest in better EO-based, spatial LULUCF and/or AFOLU flux data/estimates.
- Provide and make use of accuracy assessments and uncertainty layers for all relevant products and estimates.
- Expand work with countries and LULUCF experts for the uptake of EO in national estimation and reporting.
- EO to support different (global) modelling – different pathways have been presented and discussed.
- Improve communication and engagement and act as (independent) partner for reconciling differences between models and NGHGI and between national and global numbers.

BOG 2C (Global carbon models)

Co-chairs: Julia Pongratz and Matthew Gidden. Rapporteur: Mike O'Sullivan

The BOG concluded from the previous discussions that both global carbon modelling and NGHGI approaches have their justification and recommends that the approaches should continue to be operationally translated and both type of data be presented in GST, IPCC and other reports. The BOG then identified key challenges and defined concrete steps towards a better reconciliation, which would improve and transform the (model) landscape (see figure in Annex 4C below), but require substantial communication effort and funding in addition to progress in individual tools:

- A lack of clear communication was perceived as the main issue, since much of the information that was requested from the modelling community already is available. E.g., many model codes are open source - but the models are still perceived as "black boxes". Next steps: provide glossaries, including TFI early on, and simple-language explanations of which publication covers what question; more it more accessible and traceable by external users the documentation on the assumptions, parameters and algorithms used. Ask TFI to provide a communications team.
- Requests for additional information (such as information on area (and maps) of managed land and further disaggregation of emissions in NGHGI): not everything can be made available (e.g., NFI data may only be distributed at non-localized scale), but in general there seems to be a high willingness to share data. Next steps: Communities to request data where needed, and to provide it as far as resources allow.
- The level of process understanding of the modelling community (e.g., on CO_2 effects) had been repeatedly questioned. Since there is substantial work on models' process representation and assessment of uncertainties, this seems to be again a matter of a lack of clear communication. Nevertheless, better estimates can be achieved through these next steps: (i) continue to improve model estimates (in particular, update the calculation of the GCB natural land sink to take out replaced sources/sinks; integrate Earth observation constraints on mortality); (ii) push forward country-level budgeting (-> RECCAP3): include more country-specific information and have stronger interaction with inventory teams; (iii) don't exchange only data, but also expertise, e.g. it seemed still unclear to what extent disturbances are included in NGHGIs, which complicates comparison with models.
- Substantial progress in more accurate flux estimates is expected if bookkeeping models (BMs) & IAMs implement country-specific information. Next steps: seek individual collaborations with NGHGI and other national actors. However, this is resource-intensive, so funding agencies need to be encouraged and a step change requires a dedicated funded project to do this across a substantial number of countries. Other promising pathways to progress were suggested to be (i) IAMs to simulate feedbacks endogenously; (ii) DGVMs (and BMs) to implement managements/policies; (iii) better linking CO2 removal (CDR) definitions and LULUCF emissions and removals.

4. Communication challenges

4.1 Discussion in BOG session 3

On **day 3 – BOG 3 session,** three groups with a balanced representation of the various communities discussed the 'communication challenge' through the following guiding questions:

- How to explain the implications of any reconciliation ?
- Clarifications if needed: How "big" is the problem? Which are the implications?
  - Effect on the remaining carbon budgets for various levels of warming,
  - Emission reduction rates needed (for various levels of warming)
  - The net zero CO_2 emission concept
  - The timing of global net zero CO_2 emission (for various levels of warming)
  - The need for globally net negative CO_2 emissions
- Who are we communicating this to? UNFCCC/COP/GST, IPCC, various scientific communities, national level policymakers, sub-national policymakers, other stakeholders. What are the risks of misunderstanding/misusing any reconciled estimates, from the scientific community and for countries?

Below are the detailed summaries made by Co-Chairs of BOG session 3. The slides presented by the rapporteurs of each BOG are in Annex 4c below.

BOG 3A

Co-chairs: Jan Fuglestvedt and Robert Matthews. Rapporteur: Joana Portugal-Pereira

The BOG aimed to:

- Understand the effects of reconciling land use emissions estimates on communication of global carbon budgets, emission reduction rates, and the concept of global net zero CO_2 emissions.
- Identify the different target audiences for communication, including the UNFCCC,COP delegates, IPCC WGs and TFI communities, overall scientific. inventories and modelling communities, national/sub-national policymakers
- Assess the potential risks associated with the misunderstanding or misapplication of reconciled land use emissions estimates within the scientific community and policymakers.
- Brainstorm strategies to address and mitigate miscommunication risks within IPCC to ensure accurate interpretation and effective use of the reconciled data.

<u>Recommendations</u>:

- The failure to effectively communicate the implications of efforts to reconcile land use emissions estimates may affect the credibility of scientific findings, as policymakers may lose trust in the reliability of the data presented. This can lead to increased confusion, as inconsistencies in the information create ambiguity and misunderstandings, and ultimately hinder progress in mitigation action.
- Clearly delineate the purposes and methodologies of different reporting mechanisms (such as GHGI reports and modelling exercises), and how they feed into the Global Stocktake and global temperature projections. This clarity helps in aligning expectations and interpreting results, and will reduce the potential for confusion or misinterpretation.

- Recognise the implications of discrepancies at diverse scales (global, national, and sub-national) and different time horizons. Tailor communication strategies to reflect the varying significance of these discrepancies and ensure equity for countries with significant land sinks or specific land use contributions. At the global level, differences may be minor, but at the national or sub-national level, they can have substantial policy implications. However, do not overstate the importance or seriousness of the discrepancies, particularly while there remains uncertainty over their existence, magnitude and source.
- Prioritise internal collaboration among scientific communities (national inventories and modelling teams) to reach a better understanding on the differences in estimates and ensure a clear understanding of these issues before external communication.
- Simplify complex modelling approaches while maintaining scientific accuracy. Use GHGIs and straightforward examples to bridge the gap between complex global models and more accessible reporting formats.
- Reinforce collaboration between IPCC WGs and TFI from the outset of AR7 by establishing a task group early on. Develop a common glossary across all reports of AR7 that integrates terminology from both WGs and TFI. Additionally, include cross-working group (x-WGs) and TFI-specific sections or boxes within AR7 to provide targeted insights and enhance coherence across different areas of expertise.
- Involve neutral communication specialists to develop a structured communication approach that effectively conveys the reconciliation process and its implications to various audiences (IPCC communities, scientific communities, UNFCCC, COP delegates, and policymakers).

BOG 3B

Co-chairs: Maria Sanz and Oliver Geden. Rapporteur: Keywan Riahi

Participants debated on how to best communicate within and beyond the research community the implications of any reconciliation (on remaining carbon budget, net zero, etc) as well as the uncertainty of estimates.

Despite the efforts been made already to reduce the uncertainty, land-based estimates are very uncertain from experimental studies and models provide a large range of results that need further considerations to fully grasp the reasons for discrepancy and progress more towards reconciling when possible. This challenge should not deviate from the urgent need to reduce emissions and reach the net zero as earlier as possible (earlier than 2050). It was acknowledged by all communities that collaboration needed to solve the issues, in the first place a translation across estimation approaches across communities to give confidence that the national targets are consistent with the science behind the Paris Agreement. Adequate communication is therefore fundamental within the research community (modelers in particular), and with inventory compilers and other stakeholders, by improving the common understanding across research communities and inventory experts we will be in a better position to convey that there is no 100% alignment, but that the "error" is not dominant compared to other uncertainties – e.g., uncertainties need to be incorporated in the budget. To achieve that it will be also fundamental to be more transparent and provide different parts of the flux (not only providing net values, but the individual components, including later fluxes) and explain them better.

How to structure and sequence the messages that we want to communicate is also important, as well as carefully assess and understand the risks of specific communications. On more concrete issues it was raised that:

- Communicate that communities need to talk to each other to answer the open questions
- Need to better understand the difference between flux and stock
- Communicate to the outside that large uncertainties are not a reason to not continue efforts to reconcile assumptions
- Uncertainties are high - take the difference and use that inform the propagation of uncertainty through a net zero target
- Need to be clear about the differences in what communities call managed land

- Different understanding of land, does not lead to different understanding of what it needs to get to the target?

On further thoughts on what to communicate:

- We need a research program to better understand and reduce uncertainties
- We need to address the issue of data sharing and interoperability of data

BOG 3C

Co-chairs: Thelma Krug and Andy Reisinger. Rapporteur: Jo House

Why: Policy makers don't understand fully why models/EO are showing something different from NGHGIs, and what the implications are. Lack of clarity could undermine the role of LULUCF in the Paris Agreement (diluting incentives for multiple land-benefits), or undermine the PA itself. Consider also the risk of ocean analogues (i.e. indirect effects on "managed" oceans areas). The "gap" is only an issue when different approaches are bought together in the context of the global stocktake. We should communicate better that different approaches exist for good reasons, none of them are right or wrong, all of them have inflexibilities to completely match the other, there likely will always be a discrepancy (even after reconciliation), but we can assess what, why and the implications for meeting targets/outcomes and future action.

Who we may communicate with:

- global policy makers/global stocktake
- national policy makers and practitioners developing NDCs, NGHGI compilers, national BTRs
- Independent data/support organisations –support countries to develop their NDCs, inventories, BTRs - improving data/methods towards higher tiers, spatial approaches and completeness.
- Carbon dioxide removal projects, markets, land managers e.g article 6.4, voluntary markets, emission trading schemes. Recognising different spatial and sectoral boundaries along lifecycle of projects, projects often use IPCC methods
- Scientists –research/assess scale of issue for IPCC AR7 and global stocktake.
- Publics need to have confidence in the credibility of the process.

What: Clearer communication of differences in language, definitions, methods, and purposes. Alternatives to "Reconcile" were discussed (eg. harmonise, map, align, translate, common understanding) but there was no consensus. Particular need for communicating "managed land", "disturbance" , benchmarks" between communities. Avoid saying "science" vs "inventories" as inventories are science-based.

How: To feed into AR7 scoping, AR7 Assessment and global stocktake:

- Common/adjacent glossaries
- "Rosetta Stone" approach to translation, in one place (see IPCC AR6 and SRCCL – build on this in more detail). Detailed descriptions are available in inventories and in published model/EO papers, all strive for "transparency", but different communities unfamiliar with each other.
- Communicate scale of problem in relations to specific issues e.g. compared to other aspects/sectors (fossil fuels /levels of countries ambitions globally)
- Reasons for the gap, its size and implications may change according to assumptions and time. Do analyses of including/excluding different processes (e.g. area/processes on "managed land", "natural disturbances") on flux (global, national) under different pathways. Be clear what the boundaries of these analyses are. eg current day vs future at net-zero, country vs global
- Mutual, respect, understanding, mapping + co-production are key.

5. Conclusions

As land-based mitigation is increasingly recognized as a crucial component in achieving the Paris Agreement's temperature target and individual national climate goals, building confidence in land-use GHG emission estimates is essential. However, the different estimation approaches developed by various communities - most notably, the global models underlying the IPCC Assessment Reports and NGHGIs used for assessing compliance with the Paris Agreement - lead to significant discrepancies in land-use emissions estimates at both global and country levels. This creates confusion, akin to a car driver (policy makers) having a navigation system (global models, providing the route) in miles and the car dashboard (national GHG inventories, assessing compliance with the route) in kilometres.

During the three-day IPCC Expert Meeting, experts from the global carbon modelling, Earth Observation (EO), and NGHGI communities engaged in intensive discussions on the different methods for estimating anthropogenic land-use CO_2 emissions and removals. The meeting was structured around three key questions:

1. Where are we? Developing a shared understanding of the discrepancies in land-use estimates between the communities, and of the implications for the remaining global carbon budget and net-zero targets.
2. Where do we want to go? Establishing a foundation for greater and more effective collaboration among these communities to enhance confidence and comparability in land-use GHG estimates.
3. How do we get there? Outlining actionable steps that each community can take to ensure greater comparability between future IPCC Assessments and NGHGIs guided by IPCC methodologies.

The first day and a half of the meeting was dedicated to exploring these questions through presentations and plenary discussions. This was followed by two half-days of breakout group discussions across three thematic groups and a final plenary session.

Where We Are

Have global emissions from deforestation increased or decreased between 2000 and 2020? Is land use globally a net source or sink of CO_2? These seemingly straightforward questions, posed to all participants at the start of the meeting, revealed striking differences among experts from various communities (see Annex 4a). This divergence came as a surprise to many and provided a clear picture of the starting point for discussions: despite working on similar topics, experts from different communities produced notably different answers to the same questions.

To this regard, the Expert Meeting offered a comprehensive overview of the current state of knowledge, emphasizing both the progress made and challenges ahead, including:

- Discrepancies: A significant mismatch exists between anthropogenic net emission estimates from global models and those reported in NGHGIs. This gap amounts to about 6-7 billion tonnes of CO_2 per year globally (equivalent to ca. 15% of total global CO_2 emissions). The primary cause of this discrepancy lies in how anthropogenic CO_2 removals are defined. Country inventories, following the IPCC Guidelines and the "managed land proxy," tend to classify larger areas of forest as "managed" compared to global models. Additionally, the land net sink resulting from indirect human-induced environmental changes (e.g., fertilization effect on vegetation growth due to increased atmospheric CO_2 concentration, Nitrogen deposition, changes in temperature and length of growing season) is categorized as natural in global models. However, in many NGHGIs, this sink is considered anthropogenic (depending on the methods used - see box 5.3.3, box 5.3.5 and Annex 5.3.8 for additional country-level details). This is because NGHGIs typically use observations, which do not distinguish between direct human-induced impacts and indirect or natural effects[10] (see Section 2, Annex 4b, and Annex 5.3).

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[10] E.g., suppose to have a managed forest plot where carbon stocks is measured at two points as 500 tC and 550 tC, respectively. The stock difference approach will suggest that over this particular time period this forest sequestered 50 tC, but there is no way one may know about how much of it came from CO_2 fertilization and how much came from human efforts. The same if the gain-loss approach is used. In both cases, the NGHGI will report it as an anthropogenic carbon sink.

- Reconciliation efforts and implications: The divergence in land-use emission estimates complicates efforts to assess the effectiveness of mitigation actions under the Paris Agreement's Global Stocktake. This is because the collective efforts from countries, which use a broad definition of CO_2 removals, are assessed against modelled pathways to net-zero that use a narrow definition of CO_2 removals. The need for improved reconciliation between these approaches has been widely recognized. Current reconciliation efforts have revealed important implications for the remaining global carbon budget, which is reduced by 12-18% when results from climate scenarios aligned with the Paris Agreement are adjusted to fit the inventory framework. To a lesser extent, this reconciliation also impacts the timeline for achieving global net-zero emissions, which need to occur 1 to 5 years earlier in those scenarios. At the country level, the differences may be more extreme. Crucially, when translating global model results into inventory frameworks, achieving "net zero" may no longer be sufficient to stabilize global temperatures. This is because achieving net zero CO_2 emissions only halts CO_2-induced warming if the definition of removals excludes indirect CO_2 effects. (see presentations in Annex 4b).

Where We Want to Go and How to Get There

To tackle the challenges highlighted and move reconciliation efforts forward, the following strategic actions are necessary:

Improving Communication. Different methods and terminologies often lead to confusion and misunderstanding between communities. Key communication challenges discussed during the Expert Meeting include:

- Terminology for addressing discrepancies in land-use CO_2 estimates. "Translating" was preferred over other terms (adjusting, reconciling, etc.), because it suggests that the two communities use distinct "languages," each valid in their own context but mutually incompatible in a dialogue without translation.
- Communicating the implications of the translation: translating global models' results into the inventory framework has relevant implications at both the global and country levels. At the global level, it reduces the remaining carbon budget and may modify the year of reaching net-zero emissions. Not all countries currently fully capture indirect effects in NGHGIs, due to data limitation. While the inclusion of indirect effects does not diminish the importance of national mitigation efforts, it may reduce comparability between national commitments and global temperature goals as modelled by the IPCC, e.g. a country may appear climate neutral when indirect effects are included, but still emit significant fossil CO_2. Risks exist in communicating the implications (potential misunderstanding), but also in not communicating them at all (continue with different communities essentially ignoring each other).
- Reporting vs. accounting of anthropogenic emissions and removals: Misunderstandings were clarified around these terms. Reporting refers to what countries include in their NGHGIs based on IPCC guidelines and the "managed land proxy". In contrast, accounting is used for assessing national obligations (Nationally Determined Contributions, NDCs) and it may include only a portion of GHG fluxes, following national legislation. In practice, most countries use the net land CO_2 flux *reported* in national GHG inventories for accounting purposes, i.e. to assess compliance with their NDCs and track progress towards their long-term (i.e. 2050) emission reduction strategies under the Paris Agreement.
- Common glossaries: developing a shared glossary would help align expectations and clarify terminology across communities. Some terms may require specification of the timing associated to their definitions, such as "afforestation" or "shifting agriculture."
- Tailoring messages to different audiences (IPCC authors, UNFCCC delegates, NGHGI compilers, carbon removal project manager, etc.) would improve understanding of the issue. Differences in approaches between communities should be accepted and acknowledged, but a common narrative is needed to explain the differences. The discussion should avoid framing it as "science vs. inventories", since both models and inventories are science-based.
- Communicating uncertainties: transparently addressing uncertainties in estimates is essential for managing expectations and guiding policy decisions. Discrepancies in land-use emissions should not be seen as undermining the need for continued mitigation efforts toward net-zero emissions.

Improvements within each community. Pending resource availability, improvements should focus on:

- National GHG Inventories cannot separate direct and indirect anthropogenic effects, and follow IPCC methods and UNFCCC requirements agreed by all countries. For these reasons, the "managed land proxy" was reaffirmed as the only widely applicable method for reporting anthropogenic emissions and removals to the UNFCCC, confirming previous IPCC work (IPCC 2006, 2009, 2019). However, the information on the application of the managed land proxy is often incomplete (e.g., no definitions, no area), especially in developing countries. With the forthcoming 1st Biennial Transparency Report (BTR) under the Enhanced Transparency Framework (due by the end of 2024), all countries will, for the first time, use standardized reporting tables that include information on managed land area by land use type. Depending on the widely different national capacities and resources, this and subsequent BTRs may provide opportunities to clarify the implementation of the managed land proxy, enhancing transparency on data, methods, and results. This would allow other communities to better understand what the NGHGI includes. Specific topics where additional voluntary information from countries, when possible, would further facilitate the understanding and the comparison with global models include: maps of managed land and explanations for why certain land is considered managed; disaggregation of fluxes by land sub-categories; time series of: forest harvest rates, including areas disaggregated by different harvest intensity classes, and any available data on illegal and informal logging; forest growth rates, forest biomass density and age structure (where applicable); CO_2 fluxes associated to natural disturbances (where applicable); whether and how shifting agriculture is included in the reporting; information to help assessing the extent to which indirect effects are captured, which depends on factors such as the approach (stock-difference or gain-loss) and the Tier level used (Tier 1 methods are not likely to fully include indirect drivers of emissions and removals)[11]; whether specific pools outside of managed land use transitions and areas with known anthropogenic disturbance history have been estimated to be in carbon equilibrium consistent with IPCC good practice (IPCC 2006, 2019) and supported by the required evidence. It is important to note that collecting and processing this information often requires significant time and resources, which are currently lacking, especially in developing countries.
- Global models (bookkeeping models, dynamic global vegetation models, integrated assessment models) are built around process understanding of vegetation growth. Given the flexibility of these models, their results can be operationally translated into the NGHGI approach. The translated results would not be inherently better or worse, but would ensure greater comparability with NGHGIs. For this community, it is crucial that both the original and translated results from global models are presented in future IPCC Assessment Reports, Global Stocktake, and other reports. This is useful to highlight the implications of different definitions. Specific improvements that could facilitate confidence in estimates and comparisons with NGHGIs include: enhanced accessibility of model data inputs and assumptions, including information on uncertainties: despite many model codes being open source, they are often perceived as "black boxes" by the NGHGI community due to the limited availability of modelling assumptions and data for external users; greater consistency in estimating anthropogenic and natural CO_2 fluxes across global models (BMs and DGVMs); Integrated Assessment Models (IAMs) simulating feedbacks endogenously; better integration of Earth Observation (EO) in BMs and DGVMs; improved representation of forest demographics and management in BMs/DGVMs, and of land-use policies in IAMs, using more detailed country-specific information; improved methodology for translation to the inventory approach; collection of more robust evidence on the effects of CO_2 fertilization and other indirect effects (which are disputed by some NGHGI expert), as well as of land-use legacy such as forest recovery, linking the in-situ knowledge from the inventory compilers to model representation; disaggregation of results to facilitate comparison with NGHGIs (e.g., providing results in formats consistent with BTRs); better linking of CO_2 removal (CDR) definitions and LULUCF fluxes between global models and NGHGIs; stronger interaction with NGHGI teams, including exchanging data and expertise, and more country-level budgeting efforts (e.g., RECCAP3).
- Earth Observation (EO): this community already plays a key role as a provider of relevant data on land cover /land-use changes and GHG fluxes, serving both the modelling and NGHGI communities. In this context, EO can act as an independent broker, facilitating the comparison and reconciliation of definitions and concepts (e.g., aligning different forest definitions, delineating managed land, and attributing drivers of forest degradation).

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[11] E.g., report information for each element on the source of data used, on the timeline of data and on the collection methodology of those data, to allow readers to derive for each element an estimate of the degree of the human-induced variability

While EO results do not align precisely with the definitions used in NGHGIs or global models, translating EO data to fit the NGHGI framework is feasible once the area of managed land is known. Specific improvements include the comparisons of different EO datasets to achieve a greater community consensus, transparency of methods and data, ensuring they are open-source and easily accessible; standardization of land use/cover classifications and products relevant for both models and NGHGI communities; better estimation of uncertainties (in terms of accuracy and precision); improved time-series consistency, allowing for better long-term analysis; utilizing increasing EO capacities to better monitor different forest disturbances and regrowth rates; improved estimation of carbon stock and stock changes, including integration and validation with ground-based data; enhanced guidance and capacity building on how EO data (including activity data and emission factors) can be integrated into NGHGIs using IPCC methods; continued support for global and regional modelling, with EO data used for parameterization, calibration, and validation.

Strengthening collaboration across communities is essential to bridge gaps between global models, Earth Observation (EO) data, and national inventories. This may involve:

- Maintenance and further development of the JRC-hosted global land use carbon flux hub, which is seen by participants as an example of important global platform for collecting and comparing datasets built with different methods and assumptions. As more data products become available, comparisons between products and with NGHGI data may need to become more detailed and specific. Analyses summarizing how different countries address specific topics (e.g., managed forest maps, natural disturbances, shifting agriculture, afforestation) will become increasingly useful for the modelling community;
- Regular dialogues in joint workshops, task groups, and online blogs to facilitate a deeper understanding of methodological differences. Develop joint protocols for translation to help align approaches. Potential support may be sought from the IPCC TFI and the Global Carbon Project.
- Improving data sharing and integration through shared repositories of data, enhancing interoperability between global models, EO data, and inventory estimates. This includes ensuring that data from various sources are compatible and comparable, and possibly using global models/EO data in the IPCC Emission Factor Database. Support may be sought from the IPCC TFI and Global Carbon Project.
- Engaging experts from various communities in smaller groups at regional and country levels, leveraging local expertise and data. This could involve the use of joint protocols for translation, potentially coordinated through the Global Carbon Project, RECCAP, or other mechanisms and research projects.
- Reinforcing collaboration between the IPCC Working Groups and the IPCC Task Force on GHG inventories during the AR7 process, by establishing a task group early on and developing common glossaries, taking into account the different national circumstances.

Overall, the Expert Meeting provided a unique opportunity for participants to interact (often for the first time) with experts from different communities, fostering a deeper mutual understanding of the “two languages” used for land-use estimates and their implications. Although issues related to the mismatch in land-use CO_2 flux estimates have not been fully resolved, the need to 'translate' between these two languages are now much better acknowledged.

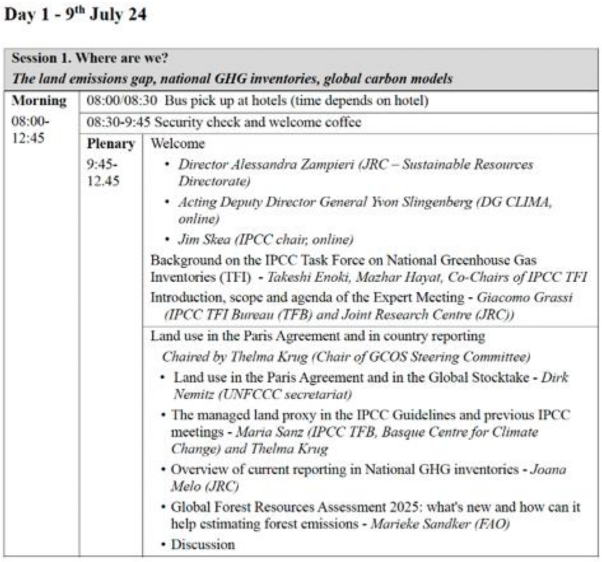
Feedback from experts shared informally during and after the meeting included a general sense of surprise at the magnitude of the differences in approaches for estimating land-use CO_2 fluxes between the communities. This was paired with some frustration due to the complexity of the task ahead, but also a strong motivation to tackle it, driven by the recognition of the topic's critical importance. Some of the feedback included remarks like: “the meeting was an eye-opener”, “there is so much work to do”, “I had the feeling that both communities did not want to move much”, “we need some kind of independent broker to lead the effort to compare and connect”, and “this meeting was extremely important – we just needed it 15 years ago.”

Many aspects still require clarification, including terminology, data, and methods used by the different communities, but a new dialogue has started, and there is a clear interest in continuing that conversation. While it is widely acknowledged that full alignment between different approaches is difficult, the importance of enhanced transparency from all communities and the translation of global models' results into the inventory approach has been clearly recognized.

By focusing on the strategic areas of improvement outlined above – enhanced communication, improvements within each community, and strengthening collaboration across communities – we can work towards achieving more credible and comparable LULUCF estimates across the various communities in the coming years. This will enable a more consistent and confident assessment of land use's role in climate progress at both global and country levels, particularly in the context of the next IPCC Assessment Report and Global Stocktake.

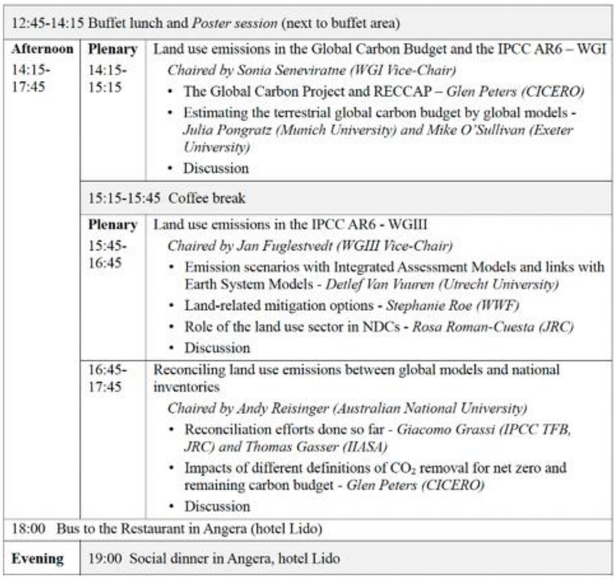
Annexes

Annex 1: Agenda

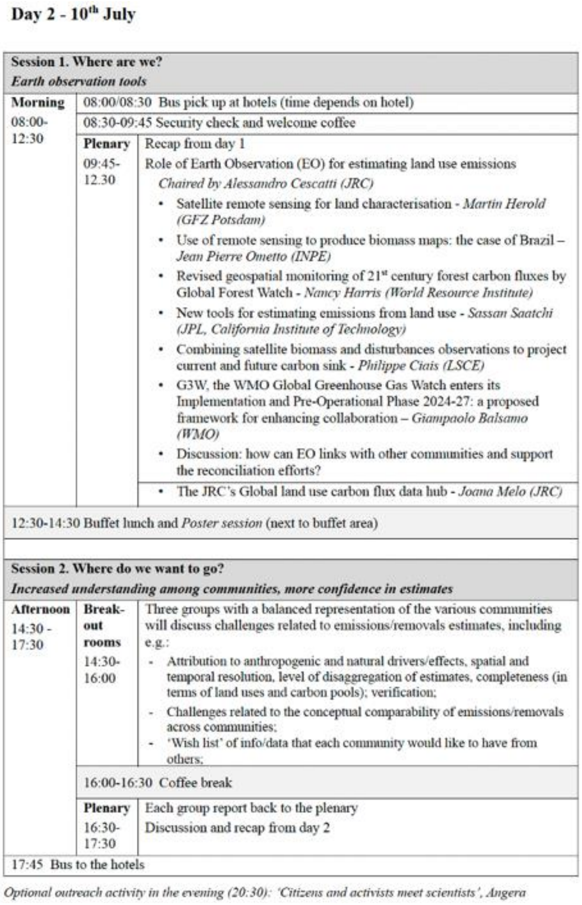


Day 1 - 9th July 24

Session 1. Where are we? ***The land emissions gap, national GHG inventories, global carbon models***		
Morning 08:00- 12:45	08:00/08:30 Bus pick up at hotels (time depends on hotel)	
	08:30-9:45 Security check and welcome coffee	
	Plenary 9:45- 12.45	Welcome • *Director Alessandra Zampieri (JRC – Sustainable Resources Directorate)* • *Acting Deputy Director General Yvon Slingenberg (DG CLIMA, online)* • *Jim Skea (IPCC chair, online)* Background on the IPCC Task Force on National Greenhouse Gas Inventories (TFI) - *Takeshi Enoki, Mazhar Hayat, Co-Chairs of IPCC TFI* Introduction, scope and agenda of the Expert Meeting - *Giacomo Grassi (IPCC TFI Bureau (TFB) and Joint Research Centre (JRC))*
		Land use in the Paris Agreement and in country reporting *Chaired by Thelma Krug (Chair of GCOS Steering Committee)* • Land use in the Paris Agreement and in the Global Stocktake - *Dirk Nemitz (UNFCCC secretariat)* • The managed land proxy in the IPCC Guidelines and previous IPCC meetings - *Maria Sanz (IPCC TFB, Basque Centre for Climate Change) and Thelma Krug* • Overview of current reporting in National GHG inventories - *Joana Melo (JRC)* • Global Forest Resources Assessment 2025: what's new and how can it help estimating forest emissions - *Marieke Sandker (FAO)* • Discussion



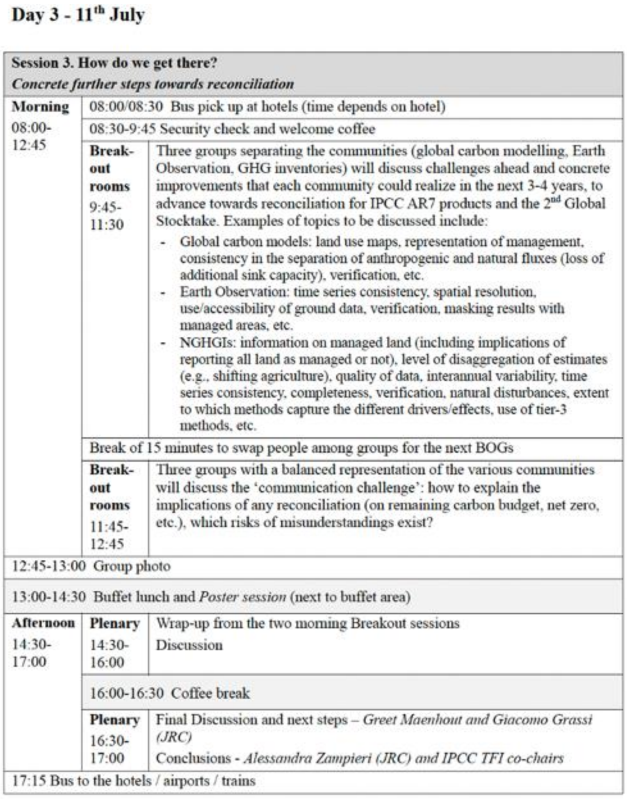
12:45-14:15 Buffet lunch and *Poster session* (next to buffet area)		
Afternoon 14:15- 17:45	**Plenary** 14:15- 15:15	Land use emissions in the Global Carbon Budget and the IPCC AR6 – WGI *Chaired by Sonia Seneviratne (WGI Vice-Chair)* • The Global Carbon Project and RECCAP – *Glen Peters (CICERO)* • Estimating the terrestrial global carbon budget by global models - *Julia Pongratz (Munich University) and Mike O'Sullivan (Exeter University)* • Discussion
	15:15-15:45 Coffee break	
	Plenary 15:45- 16:45	Land use emissions in the IPCC AR6 - WGIII *Chaired by Jan Fuglestvedt (WGIII Vice-Chair)* • Emission scenarios with Integrated Assessment Models and links with Earth System Models - *Detlef Van Vuuren (Utrecht University)* • Land-related mitigation options - *Stephanie Roe (WWF)* • Role of the land use sector in NDCs - *Rosa Roman-Cuesta (JRC)* • Discussion
	16:45- 17:45	Reconciling land use emissions between global models and national inventories *Chaired by Andy Reisinger (Australian National University)* • Reconciliation efforts done so far - *Giacomo Grassi (IPCC TFB, JRC) and Thomas Gasser (IIASA)* • Impacts of different definitions of CO_2 removal for net zero and remaining carbon budget - *Glen Peters (CICERO)* • Discussion
18:00 Bus to the Restaurant in Angera (hotel Lido)		
Evening	19:00 Social dinner in Angera, hotel Lido	



Day 2 - 10th July

Session 1. Where are we? ***Earth observation tools***		
Morning 08:00- 12:30	08:00/08:30 Bus pick up at hotels (time depends on hotel)	
	08:30-09:45 Security check and welcome coffee	
	Plenary 09:45- 12.30	Recap from day 1 Role of Earth Observation (EO) for estimating land use emissions *Chaired by Alessandro Cescatti (JRC)* • Satellite remote sensing for land characterisation - *Martin Herold (GFZ Potsdam)* • Use of remote sensing to produce biomass maps: the case of Brazil – *Jean Pierre Ometto (INPE)* • Revised geospatial monitoring of 21st century forest carbon fluxes by Global Forest Watch - *Nancy Harris (World Resource Institute)* • New tools for estimating emissions from land use - *Sassan Saatchi (JPL, California Institute of Technology)* • Combining satellite biomass and disturbances observations to project current and future carbon sink - *Philippe Ciais (LSCE)* • G3W, the WMO Global Greenhouse Gas Watch enters its Implementation and Pre-Operational Phase 2024-27: a proposed framework for enhancing collaboration – *Giampaolo Balsamo (WMO)* • Discussion: how can EO links with other communities and support the reconciliation efforts?
		• The JRC's Global land use carbon flux data hub - *Joana Melo (JRC)*
12:30-14:30 Buffet lunch and *Poster session* (next to buffet area)		
Session 2. Where do we want to go? ***Increased understanding among communities, more confidence in estimates***		
Afternoon 14:30 - 17:30	**Break-out rooms** 14:30- 16:00	Three groups with a balanced representation of the various communities will discuss challenges related to emissions/removals estimates, including e.g.: - Attribution to anthropogenic and natural drivers/effects, spatial and temporal resolution, level of disaggregation of estimates, completeness (in terms of land uses and carbon pools); verification; - Challenges related to the conceptual comparability of emissions/removals across communities; - 'Wish list' of info/data that each community would like to have from others;
	16:00-16:30 Coffee break	
	Plenary 16:30- 17:30	Each group report back to the plenary Discussion and recap from day 2
17:45 Bus to the hotels		

Optional outreach activity in the evening (20:30): 'Citizens and activists meet scientists', Angera



Day 3 - 11th July

Session 3. How do we get there? ***Concrete further steps towards reconciliation***		
Morning 08:00- 12:45	08:00/08:30 Bus pick up at hotels (time depends on hotel)	
	08:30-9:45 Security check and welcome coffee	
	Break-out rooms 9:45- 11:30	Three groups separating the communities (global carbon modelling, Earth Observation, GHG inventories) will discuss challenges ahead and concrete improvements that each community could realize in the next 3-4 years, to advance towards reconciliation for IPCC AR7 products and the 2nd Global Stocktake. Examples of topics to be discussed include: - Global carbon models: land use maps, representation of management, consistency in the separation of anthropogenic and natural fluxes (loss of additional sink capacity), verification, etc. - Earth Observation: time series consistency, spatial resolution, use/accessibility of ground data, verification, masking results with managed areas, etc. - NGHGIs: information on managed land (including implications of reporting all land as managed or not), level of disaggregation of estimates (e.g., shifting agriculture), quality of data, interannual variability, time series consistency, completeness, verification, natural disturbances, extent to which methods capture the different drivers/effects, use of tier-3 methods, etc.
	Break of 15 minutes to swap people among groups for the next BOGs	
	Break-out rooms 11:45- 12:45	Three groups with a balanced representation of the various communities will discuss the 'communication challenge': how to explain the implications of any reconciliation (on remaining carbon budget, net zero, etc.), which risks of misunderstandings exist?
12:45-13:00 Group photo		
13:00-14:30 Buffet lunch and *Poster session* (next to buffet area)		
Afternoon 14:30- 17:00	**Plenary** 14:30- 16:00	Wrap-up from the two morning Breakout sessions Discussion
	16:00-16:30 Coffee break	
	Plenary 16:30- 17:00	Final Discussion and next steps – *Greet Maenhout and Giacomo Grassi (JRC)* Conclusions - *Alessandra Zampieri (JRC) and IPCC TFI co-chairs*
17:15 Bus to the hotels / airports / trains		

Annex 2: List of participants with statistics

Participants to the Expert Meeting were selected following a process in accordance with IPCC policies and procedures, specifically Section 7.1 of Appendix A to the Principles Governing IPCC Work, Procedures for the Preparation, Review, Acceptance, Adoption, Approval and Publication of IPCC Reports. Criteria for selection were: (i) representation of a wide range of scientific, technical and socio-economic views and expertise; (ii) geographical representation; (iii) gender balance; and (iv) a mixture of experts with and without previous experience in IPCC.

On (i), experts were selected from three different communities: global carbon modelers, Earth Observation experts and national GHG inventory compilers.

After three rounds of invitations, a total of 129 individuals were invited to attend the workshop. Of these, a total of 111 attended the Expert Meeting (85 in person, 26 online), including 84 invited experts, 14 from the Scientific Steering Committee and 13 from Other categories (3 from IPCC TSUs, 6 from UN bodies, 4 from EC-JRC). See tables A.1 and A.2 for details.

Table A.1: geographical and gender balance of the 84 invited experts plus the 14 from the Scientific Steering Committee (SSC).

		Geographical balance								**Gender balance**	
		Developed countries	**Developing + EIT countries**	**World regions**							
				Africa	**Asia**	**South America**	**North and Central America**	**South-West pacific**	**Europe**	**Males**	**Females**
Invited experts only	**n.**	**49**	**38**	**10**	**15**	**9**	**17**	**11**	**25**	**54**	**33**
	%	*56%*	*44%*	*11%*	*17%*	*10%*	*20%*	*13%*	*29%*	*62%*	*38%*
Invited experts + SSC	***n.***	**56**	**45**	**11**	**19**	**11**	**17**	**12**	**30**	**63**	**38**
	%	*55%*	*45%*	*11%*	*19%*	*11%*	*17%*	*12%*	*30%*	*62%*	*38%*

Table A.2: full list participants: invited experts (IE), Scientific Steering Committee (SSC) and Other (Oth)

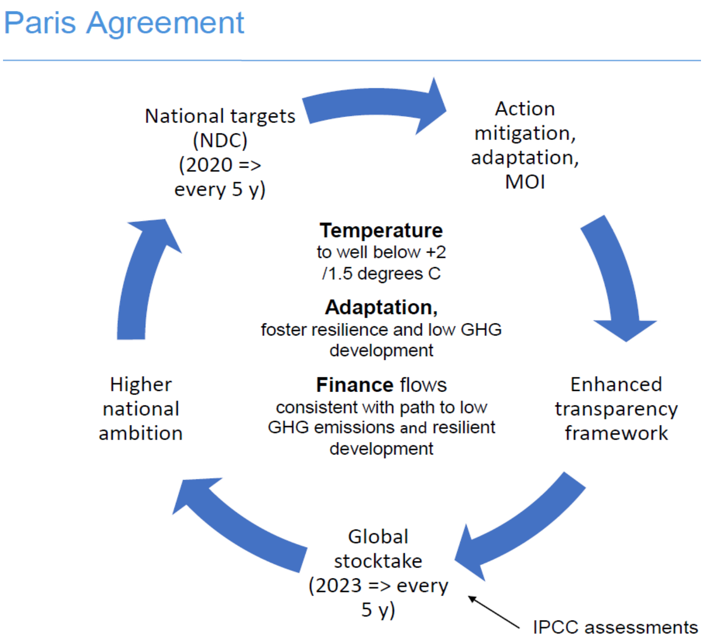
Last name	**First name**	**Country**	**Affiliation**	**presence/ online**	**Cat.**
AGYEI KYEI	Kwame	Ghana	Forestry Commission of Ghana	in person	IE
ARAGAO	Luiz	Brazil	National Institute for Space Research	in person	IE
BALSAMO	Gianpaolo	Switzerland	WMO	in person	Oth
Bastos	Ana	Portugal	Max Plank istitute	online	IE
BOER	Rizaldi	Indonesia	Int Res Institute for Env and Climate Change, IPB University, Bogor	in person	IE
BÖTTCHER	Hannes	Germany	Oeko-Institut	in person	IE
BRENDER	Pierre	Germany	UNFCCC secretariat	online	Oth
CABRERA QQUELLHUA	Nelly Berenice	Peru	Ministerio del Ambiente	in person	IE
Calvin	Kate	USA	NASA, IPCC WGIII	online	IE
CANTINHO	Roberta	Brazil	University of Brasília / The Nature Conservancy	in person	IE
Cescatti	Alessandro	Italy	JRC European Commission	in person	IE
CHATURVEDI	Rajiv Kumar	India	Birla Institute of Technology and Science, Pilani, K K Birla Goa Campus, Goa	in person	IE
CHINTALAPHANI	Shanti	Australia	CBR Data Analytics	in person	IE
Ciais	Philippe	France	LSCE	online	IE
COLLETT	Max	Australia	Australian Government Department of Climate Change, Energy, the Environment and Water	in person	IE
COWIE	Annette	Australia	NSW Department of Primary Industries	online	IE
DEN ELZEN	Michel	Netherlands	PBL Netherlands Environmental Assessment Agency	online	IE
DENG	Zhu	China	The University of Hong Kong	in person	IE
Domke	Grant	USA	USDA Forest Service	online	IE
Elhassan Mahmoud	Nagmeldin	Sudan	Independent Expert	online	IE
ENOKI	Takeshi	Japan	IGES, IPCC TFI	in person	SSC
FEDERICI	Sandro	Japan	IPCC TFI TSU	in person	SSC
FUGLESTVEDT	Jan	Norway	Cicero, IPCC WG III	in person	SSC
GASSER	Thomas	Austria	IIASA	in person	IE
GEDEN	Oliver	Germany	German Institute for International and Security Affairs	in person	IE
GIDDEN	Matthew	Austria	International Institute for Applied Systems Analysis	in person	IE
Grassi	Giacomo	Europe	JRC European Commission, IPCC TFI	in person	SSC
GREEN	Carly	New Zealand	Environmental Accounting Services	in person	Oth
HANSEN	Gerrit	France	IPCC WGI TSU	in person	Oth
HARRIS	Nancy	United States	World Resources Institute	in person	IE
HASEGAWA	Tomoko	Japan	Ritsumeikan University	in person	IE
HAYAT	Mazhar	Pakistan	Ministry of Climate Change & Environmental Coordination, IPCC TFI	online	SSC
HEINRICH	Viola	Germany	Helmholtz Centre Potsdam German Research Centre for Geosciences - GFZ	in person	IE
HEROLD	Martin	Germany	Deutsches Geoforschungszentrum GFZ	in person	IE
HOUGHTON	Richard	United States	Woodwell Climate Research Center	online	IE
HOUSE	Joanna	United Kingdom	University of Bristol	in person	IE

HOWDEN	Mark	Australia	Australian National University	in person	SSC
HUNKA	Neha	United States	University Of Maryland	in person	IE
ITO	Akihiko	Japan	The University of Tokyo	in person	IE
ITSOUA MADZOUS	Gervais Ludovic	Switzerland	IPCC WG III	in person	SSC
IVERSEN	Peter	Denmark	European Environment Agency	in person	IE
JONCKHEERE	Inge	Italy	ESA	in person	IE
K MURTHY	Indu	India	Center for Study of Science, Technology & Policy	in person	IE
KAIRE	Maguatte	Niger	Permanent Interstate Committee for Drought Control in the Sahel (CILSS)	online	IE
KONDO	Masayuki	Japan	Hiroshima University	online	IE
KRISNAWATI	Haruni	Indonesia	Ministry of Environment and Forestry	in person	IE
KRUG	Thelma	Brazil	National Institute for Space Research	in person	SSC
LUNDBLAD	Mattias	Sweden	Swedish University of Agricultural Sciences	online	IE
MACDONALD	Doug	Canada	Environment and Climate Change Canada	in person	IE
MATTHEWS	Robert	United Kingdom	Forest Research	in person	IE
Matthews	Damon	Canada	Concordia University	online	IE
Melo	Joana	Portugal	JRC European Commission	in person	Oth
Milandou	Carine	Congo	CNIAF	in person	IE
NATIFU	Bob	Uganda	Ministry of Water and Environment	in person	IE
NEMITZ	Dirk	Germany	UNFCCC	online	Oth
NGARIZE	Sekai	Zimbabwe	Self Employed	in person	IE
NYAWIRA	Sylvia Sarah	Kenya	International Centre for Tropical Agriculture	in person	IE
O'SULLIVAN	Mike	United Kingdom	University of Exeter	in person	IE
OGLE	Stephen	United States	Colorado State University	in person	IE
Ohrel	Sara	USA	NASA	online	IE
OLGUIN ALVAREZ	Marcela	Mexico	SilvaCarbon LAC / Climate Change Unit, USFS- IP	in person	IE
OMETTO	Jean	Brazil	National Institute for Space Research	in person	IE
OTT	Lesley	United States	NASA	in person	IE
PANICHELLI	Luis	Argentina	Climate Change Division - Secretary of Environment	in person	IE
PATRA	Prabir K.	India/Japan	RIGC-ESSR/IACE, JAMSTEC	online	IE
PENENGO	Cecilia	Uruguay	Ministry of Environment	in person	IE
PETERS	Glen	Norway	CICERO Center for International Climate Research	in person	IE
PETTA	Stephanie	Paraguay	Ministry of Environment and Sustainable Development	in person	IE
Philip	Elisabeth	Malaysia	FRIM	online	IE
Poba	Madhy	Gabon		in person	IE
PONGRATZ	Julia	Germany	Ludwig-Maximilians-Universität München	in person	IE
POPP	Alexander	Germany	PIK	in person	IE
PORTUGAL PEREIRA	Joana	Brazil	UFRJ	in person	IE
POUDEL	Mohan Prasad	Nepal	REDD Implementation Center	in person	IE
POULTER	Benjamin	United States	NASA GSFC	online	IE
RAKONCZAY	Zoltan	Belgium	EUROPEAN COMMISSION	in person	Oth
RAMAN	Sukumar	India	Centre for Ecological Sciences, Indian Institute of Science	in person	SSC

RANDERSON	James	United States	UC Irvine	in person	IE
REISINGER	Andy	New Zealand	independent consultant	in person	IE
RIAHI	Keywan	Austria	International Institute for Applied Systems Analysis (IIASA)	in person	IE
ROBAYO ROCHA	Lizet Jimena	Colombia	Instituto de Hidrología, Meteorología y Estudios Ambientales	in person	IE
RODRIGUEZ SANCHEZ	Roberto	Costa Rica	Instituto Meteorológico Nacional	in person	IE
ROE	Stephanie	United States	Worldwide Fund for Nature	in person	IE
Rogelj	Joeri	United Kingdom	Imperial College London	online	IE
ROJAS	Yasna	Chile	Instituto Forestal	in person	SSC
Roman	Rosa	Spain	JRC European Commission	in person	Oth
Romanowskaya	Anna	Russian Federation	*Izrael Institute of Global Climate and Ecology*	online	SSC
Rossi	Simone	Italy	JRC European Commission	in person	Oth
RUPAKHETI	Maheswar	Germany	Research Institute for Sustainability	in person	SSC
SAATCHI	Sassan	United States	Jet Propulsion Laboratory, California Institute of Technology	online	IE
SANA ULLAH	Muhammad	Pakistan	University of Agriculture Faisalabad	in person	IE
SANDKER	Marieke	Italy	FAO	in person	Oth
SANZ	Maria Jose	Spain	BC3 - BASQUE CENTRE FOR CLIMATE CHANGE	in person	SSC
SATO	Atsushi	Japan	Mitsubishi UFJ Research and Consulting Co., Ltd.	in person	IE
SCHWINGSHACKL	Clemens	Germany	LMU Munich	in person	IE
SENEVIRATNE	Sonia	Switzerland	ETH Zurich, IPCC WGI	in person	SSC
Sitch	Stephen	United Kingdom	University of Exeter	online	IE
SLIVINSKA	Valentyna	United States	EcoEngineers	in person	IE
Smyth	Carolyn	Canada	Canadian Forest Service	online	IE
SOEBANDI	Budiharto	Indonesia	Ministry of Environment and Forestry	in person	IE
SONWA	Denis Jean	Cameroon	CIFOR (Center for International Forestry Research)	in person	IE
SORIANO LUNA	Maria De Los Angeles	Mexico	National Forestry Commission (conafor)	in person	IE
STURGISS	Rob	Japan	IPCC TFI TSU	in person	Oth
SUSPENSE IFO	Averti	Congo	University of Marien N'GOUABI	in person	IE
TUBIELLO	Francesco Nicola	Italy	UN FAO	in person	Oth
VAN VUUREN	Detlef	Netherlands	PBL Netherlands Environmental Assessment Agency	in person	IE
VAUTARD	Robert	France	Centre National de la Recherche Scientifique, IPCC WG I	in person	IE
VITULLO	Marina	Italy	ISPRA	in person	IE
WANG	Xuhui	China	Peking University	online	IE
Wekesa	Anne	New Zealand	Ministry for the Environment	online	IE
Westphal	Michael I.	USA	IPCC WGIII TSU	online	Oth
YUE	Chao	China	Northwest A&F University	in person	IE
Zhang	Xiaoye	China	ChineseAcademy of Engineering, IPCC WG I	online	IE
Zhu	Jianhua	China	Chinese Academy of Forstry	online	IE

Annex 3: The Paris Agreement's Global Stocktake

The Paris Agreement[12] established four sequential elements/processes/mechanisms, within a cyclic path, to pursue its mitigation goal -i.e. to keep global average temperature increase to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels-.



The four elements/processes/mechanisms are all self-implemented by country Parties to the Paris Agreement and are implemented within a sequence of five-year cycles, in which each country Party acts singularly in designing and implementing its mitigation actions as well as jointly with all others in assessing mitigation progresses attained and mitigation needs in achieving the global mitigation goal. The sequence of elements/processes/mechanisms is:

1. Nationally Determined Contribution to the mitigation goal [NDC - Article 4], which is to be an economy-wide absolute emission reduction target -i.e. a net reduction of historical emissions, as reported in the National GHG Inventory (NGHGI)- for all Developed country Parties, while Developing country Parties have the flexibility to continue enhancing their mitigation efforts, eventually moving over time towards economy-wide emission reduction or limitation targets in the light of different national circumstances [*self-established mitigation target*].
2. Reporting of (a) National Inventory Report (NIR) of anthropogenic emissions by sources and removals by sinks of greenhouse gases, prepared using good practice methodologies accepted by the Intergovernmental Panel on Climate Change and agreed upon by the Conference of the Parties serving as the meeting of the Parties to this Agreement [NIR – Article 13.7.a]; and of (b) Information necessary to track progress made in implementing and achieving its nationally determined contribution under Article 4 [Article 13.7.b] [*self-assessed level and trend in net emissions, as compared to the NDC*[13]]. The NIR and the progress towards NDCs are included in the Biennial Transparency Report (BTR); the first BTR is required to be submitted at the latest by 31 December 2024. Least developed countries (LDCs) and Small Island Developing States (SIDS) may submit their first BTR later and at their discretion.

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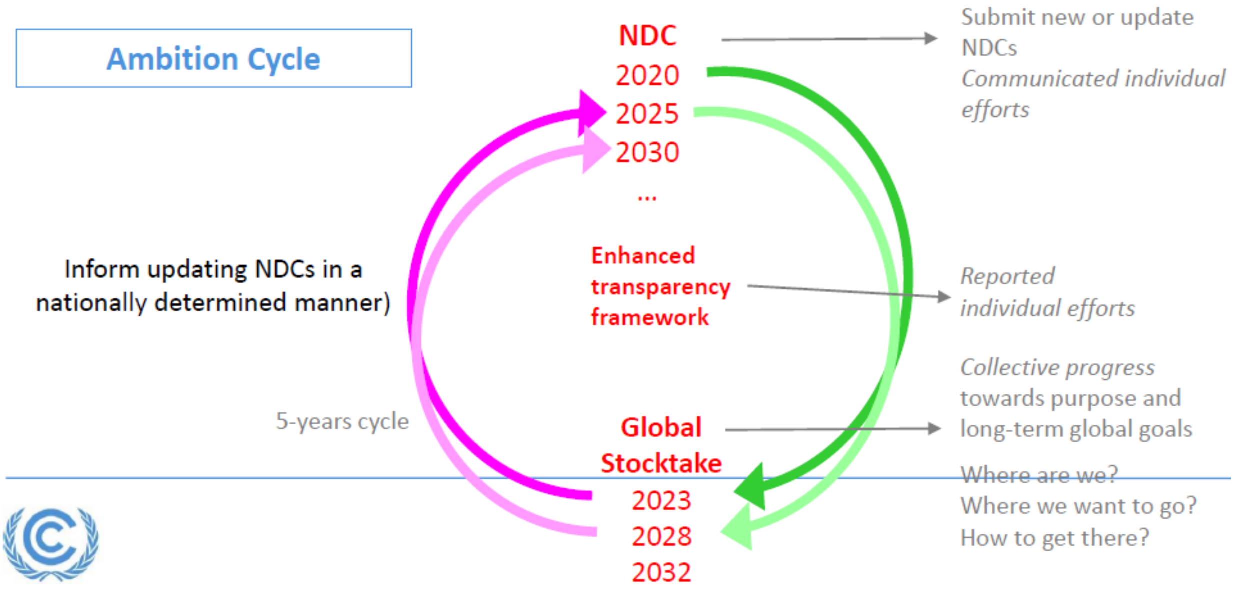
[12] http://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf

[13] Noting that for developing countries have the flexibility to use a different indicator than the absolute net emissions to track progress made in implementing and achieving its nationally determined contribution.

3. Review of information reported [Article 13.11/12], as conducted by experts nominated by country Parties to the Paris Agreement and furthermore considered by country Parties themselves [*self-implemented by Parties to the Paris Agreement*].
4. The Global Stocktake [GST – Article 14] where the Parties collectively take stock of the implementation of their self-established commitments to assess the collective progress towards achieving the global mitigation goal [*self-assessed level and trend in total (over the Parties) anthropogenic net emission, as compared to the global net emission level compatible with the mitigation goal*]. The result of the Global Stocktake informs the setting of the NDC for the following cycle.



First step of the GST is the collection of information from a number of sources including from voluntary submissions and the compilation of information in Synthesis reports[14] according to the themes.

In a second step, information is then discussed in technical Dialogues and Joint Contact Groups and further summarized in a Synthesis report[15].

The third step discusses the operative implications of the technical assessment through the Consideration of Outputs[16] with the aim to: i) Identify opportunities for and challenges in enhancing action and support for collective progress; ii) identify possible measures and good practices; iii) Summarize key political messages.

Finally, the Conference of the Parties to the UNFCCC serving as the meeting of the Parties to the Paris Agreement adopt a decision[17].

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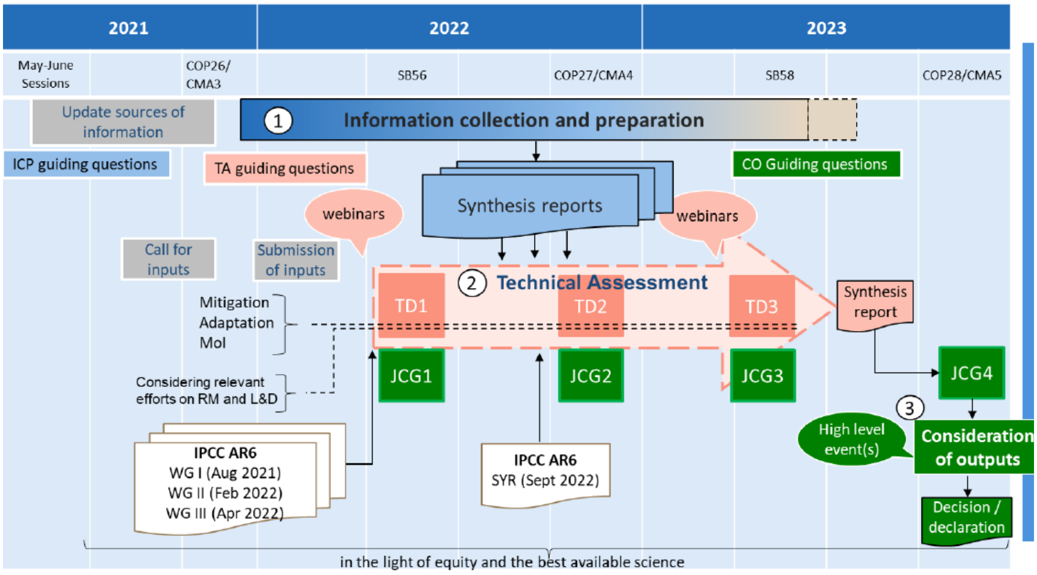
[14] https://unfccc.int/topics/global-stocktake/events-and-inputs/unfccc-and-constituted-bodies-synthesis-reports-and-webinar-for-the-technical-assessment-component

[15] https://unfccc.int/documents/631600

[16] https://unfccc.int/sites/default/files/resource/SYR_Views%20on%20%20Elements%20for%20CoO.pdf

[17] FCCC/PA/CMA/2023/16/Add.1 - Outcome of the first global stocktake

Timeline



The Global Stocktake of the Mitigation[18][19] targets the state of and trends in GHG emissions by sources and removals by sinks as a Parties' total aggregate emissions and removals by gas and by sector, examining their levels and trends across the time series. It is based on information received from Parties in their national GHG inventories, as reported in a number of documents. In the next future will be based on information in biennial transparency reports only (for both information: the NGHGI and the tracking of progress in achieving the NDC).

Such information compiled in global totals, is then compared[20] to two sets of information derived from the IPCC Assessment Reports on I. Carbon Budgets and associated II. Emissions scenario and pathways. In doing such comparison the discrepancy in the approach used to estimate anthropogenic GHG emissions and removals from land between NGHGIs and models used in the IPCC ARs causes a large bias in the estimate of the annual net CO_2 subtraction from the remaining atmospheric budget as projected according to emissions scenarios and pathways - i.e. a systematic underestimate of the annual consumption of the remaining carbon budget-; which means that the balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases is to be achieved before the second half of this century.

However, there is not a mechanism within the GST to reconcile the two different approaches to allow for an unbiased comparison, and thus an unbiased assessment of mitigation needs as well as of mitigation progress. Indeed, the Ambition Cycle constrains countries to the use of their NGHGIs to quantify level and trends of their anthropogenic emissions and removals, including from the land component; and Parties plan and quantify their nationally determined contributions accordingly, and track progress in their achievement, based on GHG estimates reported in their National GHG Inventories. It is therefore clear that such a reconciliation needs to be operated outside the GST so that the next GST can be fed with consistent information.

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[18] Mitigation themes are: 1. Overall effect of NDCs; 2. State of GHG emissions and removals and mitigation efforts undertaken by Parties

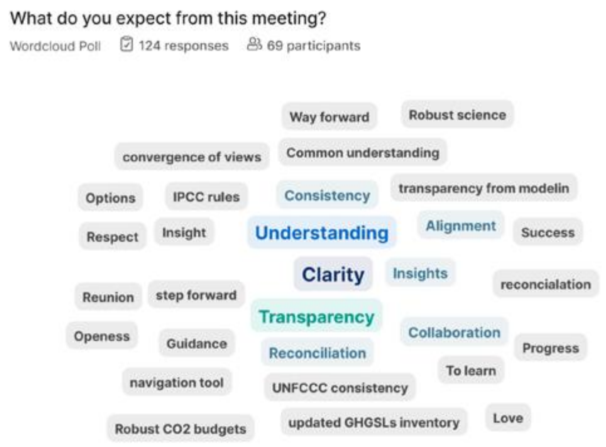
[19] https://unfccc.int/documents/461466

[20] https://unfccc.int/documents/461517

Annex 4: Material presented during the Expert Meeting

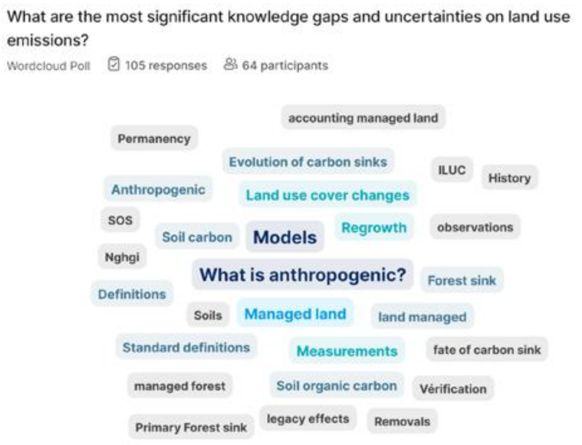
Annex 4a. Results of the polls

Initial polls (day 1)



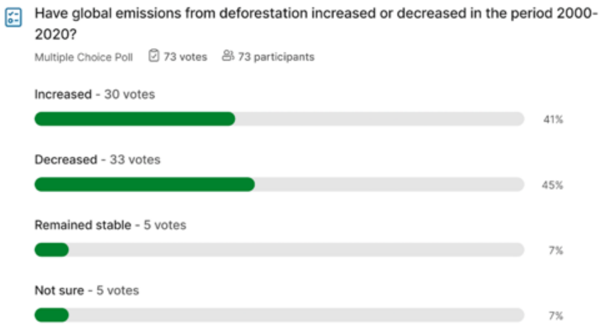
What do you expect from this meeting?

Wordcloud Poll 124 responses 69 participants



What are the most significant knowledge gaps and uncertainties on land use emissions?

Wordcloud Poll 105 responses 64 participants



Have global emissions from deforestation increased or decreased in the period 2000-2020?

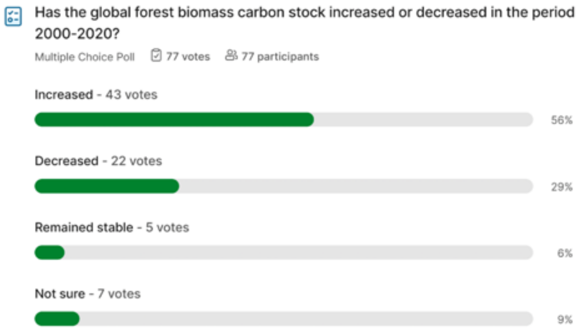
Multiple Choice Poll 73 votes 73 participants

Increased - 30 votes 41%

Decreased - 33 votes 45%

Remained stable - 5 votes 7%

Not sure - 5 votes 7%



Has the global forest biomass carbon stock increased or decreased in the period 2000-2020?

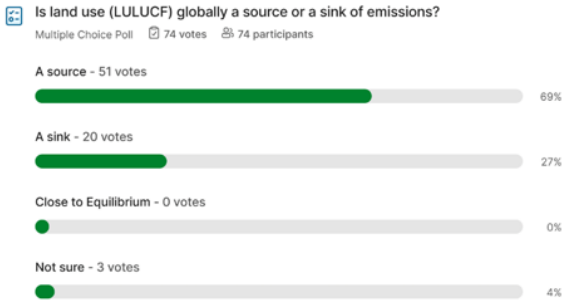
Multiple Choice Poll 77 votes 77 participants

Increased - 43 votes 56%

Decreased - 22 votes 29%

Remained stable - 5 votes 6%

Not sure - 7 votes 9%



Is land use (LULUCF) globally a source or a sink of emissions?

Multiple Choice Poll 74 votes 74 participants

A source - 51 votes 69%

A sink - 20 votes 27%

Close to Equilibrium - 0 votes 0%

Not sure - 3 votes 4%

Now imagine you are the policy maker that heard these answers from the experts. What do you do?

Multiple Choice Poll 65 votes 65 participants

Fire them all 😉 - 10 votes 15%

Lock them all in a room until they find consensus - 55 votes 85%

Final polls (day 3)

What did you learn from this meeting?

Wordcloud Poll 113 responses 65 participants

comparison in my country
grossreporting
Confustion
Translation
three sides of one coin
accounting / reporting
Worlds Apart
Models
Understanding
silos
Semantics
Talk to each other
Confusion
Homework
Complexity
better communication
plateform
it's complicated
unwillingness to move
more than fertilization
unknown knowns
Naming of parts
issue bigger than expect

What are the most significant knowledge gaps and uncertainties on land use emissions?

Wordcloud Poll 114 responses 64 participants

climate disturbance
declining sink
verification lack
legacy effects
CO2 ferilization
Soil carbon
treatment of MLP
Managed Land
Assumptions
Managed land proxy
CO2 fertilization
The future
NZE
Net zero
Definitions
Sinks
unknown
lateral fluxes
Natural disturbances
m8sattribution
future land sink
Climate disturbances
Lack Verification
future climate impacts

Which word do you think expresses better the attempt to address the discrepancies on land use emissions we discussed?

Multiple Choice Poll 61 votes 61 participants

Translation - 26 votes 43%
Mapping - 12 votes 20%
Adjustment - 2 votes 3%
Harmonization - 8 votes 13%
Alignment - 8 votes 13%
Reconciliation - 5 votes 8%

Annex 4b: Summary presentations

This section included the names of the actual presenters only. Other co-authors can be found in the slides online. All references are in section Annex 6

DAY 1: The land emissions gap, national GHG inventories, global carbon models

Morning:

a) Introduction

Introduction, scope and agenda of the Expert Meeting

Giacomo Grassi (Joint Research Centre, European Commission; IPCC TFI Bureau)

The Expert Meeting started with Slido polls asking participants their expectations and questions related to the topic under discussion. The answers to the questions highlighted a striking difference in the perception of the same topic by the participants (see Annex 4a). For example, about half of participants indicated that deforestation emissions are decreasing while half indicated that they are increasing.

To understand the implications of this mismatch, let us use an analogy between the functioning of the Paris Agreement and a car (figure below). There are three elements: the driver, that holds the steering wheel and decides the speed and direction, like the policy makers on climate policies; the car dashboard, which provides essential information to the driver, like the national GHG inventories (NGHGIs) do with policy makers and for assessing compliance towards country climate pledges; and then the navigation system, which provides an independent information on where the driver is and, crucially, allows to select routes for specific destinations, like the models that provide emissions mitigation pathways to limit warming to well-below 2°C. Similarly to the driver, that occasionally checks the navigation system against the dashboard, the Paris Agreement's Global Stocktake assesses every 5 years the collective climate progress, i.e. where countries are compared to what they would be expected to be. However, there is a problem that confuses the driver: the car dashboard uses kilometres while the navigation system uses miles. Similarly, due to differences in purpose and scope, the largely independent scientific communities that support the IPCC Guidelines (reflected in NGHGIs) and the IPCC Assessment Reports have developed different approaches to identify anthropogenic land use GHG fluxes. Both approaches - like two "languages" - are valid in their own specific contexts, and have their own shortcomings, but they are not directly comparable. This lack of comparability, and the associated disagreement among different datasets on the sign and magnitude of the land use CO_2 flux at global level, confuses the policy makers and has relevant implications for the assessment of the collective climate progress under the Paris Agreement, including on the remaining global carbon budget and the required timing for net-zero emissions.

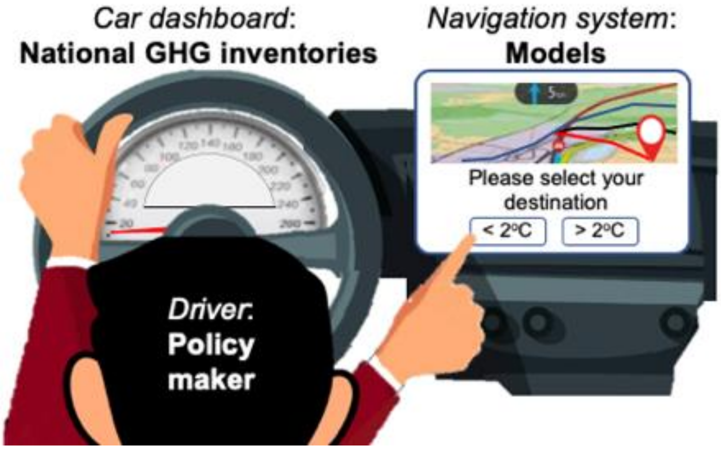
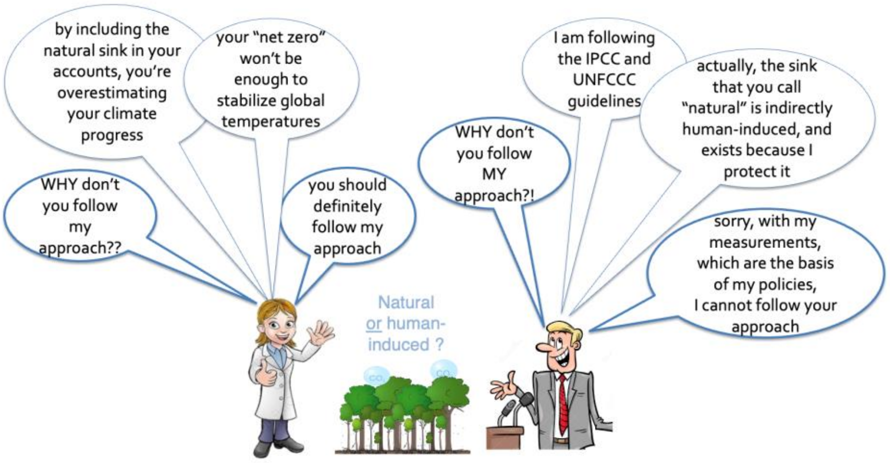


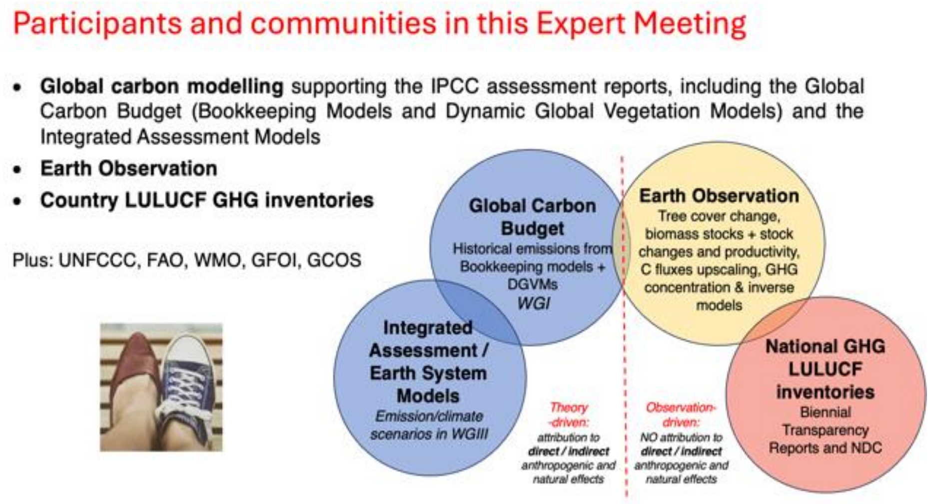
Figure: analogy between the functioning of the Paris Agreement and a car.

Figure: this is the starting point of the Expert Meeting ("where we are"): different communities that speak different language and, to some extent, blame each other (figure on the right).



At the same time, evidence indicates these discrepancies can be addressed through a joint cooperative effort across all the communities involved - global carbon models, Earth Observation and NGHGIs – which "translate" the two languages allowing to achieve more comparable LULUCF estimates across communities. This is the ultimate goal of the Expert Meeting: initiate a new dialogue and cooperation among the communities involved with the aim to see results in the next 3-4 years, allowing the next IPCC Assessment Reports and the next Paris Agreement's Global Stocktake to assess the role of land use with more precision, consistency and confidence.

Figure: to stimulate interaction, each participants from the different communities (figure on the right) was asked to select one or more colored dot to represent their expertise, and to prioritize interactions with other colors during the meeting.



Participants and communities in this Expert Meeting

- **Global carbon modelling** supporting the IPCC assessment reports, including the Global Carbon Budget (Bookkeeping Models and Dynamic Global Vegetation Models) and the Integrated Assessment Models
- **Earth Observation**
- **Country LULUCF GHG inventories**

Plus: UNFCCC, FAO, WMO, GFOI, GCOS

Global Carbon Budget
Historical emissions from Bookkeeping models + DGVMs
WGI

Earth Observation
Tree cover change, biomass stocks + stock changes and productivity, C fluxes upscaling, GHG concentration & inverse models

Integrated Assessment / Earth System Models
Emission/climate scenarios in WGIII

Theory -driven: attribution to ***direct / indirect*** *anthropogenic and natural effects*

Observation-driven: NO attribution to ***direct / indirect*** *anthropogenic and natural effects*

National GHG LULUCF inventories
Biennial Transparency Reports and NDC

b) Land use in the Paris Agreement and in country reporting

Land use in the Paris Agreement and in the Global Stocktake

Dirk Nemitz (UNFCCC secretariat)

Nationally determined contributions (NDCs) are at the heart of the Paris Agreement and the achievement of its long-term goals. NDCs embody efforts by each country to reduce national emissions and adapt to the impacts of climate change. NDCs are submitted every five years to the UNFCCC secretariat, with new NDCs being expected in February 2025. In order to enhance the ambition over time the Paris Agreement provides that successive NDCs will represent a progression compared to the previous NDC and reflect its highest possible ambition.

The Paris Agreement established an Enhanced Transparency Framework (ETF), a universal, robust framework for all Parties to report on progress and support, and for this information to undergo technical expert review. The ETF review process will ensure the credibility and accountability of global climate action and support and generate verifiable data and information, with a view to building trust and confidence that all countries are contributing their share to the global effort. The ETF requires all Parties to submit Biennial Transparency Reports (BTR), covering information on national inventory reports (NIRs), progress towards NDCs, policies and measures, climate change impacts and adaptation, levels of financial, technology development and transfer and capacity-building support, capacity-building needs and areas of improvement. The deadline for submitting the first BTR is 31 December 2024, and every two years thereafter. Small Island Developing States and the Least Developed Countries may submit information required for BTRs at their discretion.

The reporting and review of BTRs follows the Modalities, procedures and guidelines (MPGs) for the transparency framework for action and support referred to in Article 13 of the Paris Agreement (Decision 18/CMA.1). It is important to note that these contain different provisions for the National inventory report of anthropogenic emissions by sources and removals by sinks of greenhouse gases (section II, paragraphs 17-58) and Information necessary to track progress made in implementing and achieving NDCs (section III, paragraphs 59-103). For example, each Party shall use the 2006 IPCC Guidelines for its national inventory report, while the information to track progress shall include information on the IPCC guidelines used. Both sections contain limited sector-specific content, but include a few reporting provisions that are specific for the Land Use, Land-Use Change and Forestry sector. These are in relation to the approach used to address emissions and subsequent removals from natural disturbances on managed lands and the approach used to account for emissions and removals from harvested wood products. In addition, section III of the MPGs on tracking progress made in implementing and achieving NDCs also contains provisions on the approach used to address the effects of age-class structure in forests.

According to the Paris Agreement, Parties shall periodically take stock of its implementation to assess the collective progress towards achieving the purpose of the Agreement and its long-term goals. It enables countries and other stakeholders to take inventory, to see where they're collectively making progress toward meeting the goals of the Paris Agreement – and where they are not. The outcome of the first Global Stocktake finalized at COP28 in 2023 contains important provisions on efforts towards halting and reversing deforestation and forest degradation by 2030 (Decision 1/CMA.5, paragraphs 33-34). Each Party is expected to consider this outcome when preparing its 2025 NDC, and to report progress towards implementing and achieving its NDC in its BTRs. Two rounds of BTR submissions are expected in 2024 and 2026, followed by technical expert review, which will inform the next Global Stocktake scheduled to conclude in 2028.

The managed land proxy in the IPCC Guidelines and previous IPCC meetings

Maria Sanz (IPCC TFB, Basque Centre for Climate Change) and Thelma Krug (Chair of GCOS Steering Committee)

The Managed Land Proxy (MLP) arose from the challenge to separate anthropogenic and natural effects from emissions on land. IPCC provided a broad definition of MLP that Parties may use when developing their national greenhouse gas inventory, if appropriate. Parts of a country may not be managed due to remoteness, lack of access, low human population density and/or limited development in the region. So, estimating greenhouse gas emissions by sources and removals by sinks in unmanaged land may be seen as an unnecessary use of resources to compile information needed to estimate carbon stocks and associated changes rather than focusing the time and resources in areas that are directly influenced by human activity.

Brazil, for instance, includes in the managed land base natural forest land and natural grassland in Conservation Units and Indigenous Lands. The paper from Ogle et al. (2018) on Delineating managed land for reporting national greenhouse gas emissions and removals to the UNFCCC makes reference to the fact that the exclusion of unmanaged land may lead to scientifically incomplete understanding of the greenhouse gas fluxes between the land surface and the atmosphere. For instance, in the USA and Canada, much of the unmanaged land areas contain deep organic layers and permafrost that are susceptible to a range of climate change impacts from thawing, wildfires and other natural events. The associated emissions might be clearly not related to direct human-induced activities, and hence, not appropriate to be reported as anthropogenic emissions.

Transparency is the most important element when defining managed and unmanaged portions of the land, in particular due to the different approaches applied by the UNFCCC member governments to define managed and unmanaged lands, if so discriminated.

Overview of current reporting in National GHG inventories

Joana Melo (Joint Research Centre, European Commission)

Have global emissions from deforestation increased or decreased since the year 2000? Is the land use sector (LULUCF) globally a net sink or a net source? This presentation provides the answer from the National Greenhouse Gas Inventory (NGHGI) community to these fundamental questions posed at the beginning of the IPCC expert meeting on reconciling anthropogenic land use emissions.

We present a detailed analysis of data from NGHGIs communicated via a range of country reports to the United Nations Framework Convention on Climate Change (UNFCCC), which report anthropogenic emissions and removals based on the Intergovernmental Panel on Climate Change (IPCC) methodology. This data compilation of fluxes of carbon dioxide (CO_2) on managed land is an update of the dataset described by Grassi et al (2022). It now includes data from more recent submissions (85% of the data was submitted after 2020) for the period 2000-2022 for five land use categories (forest land, deforestation, other non-forest land uses, organic soils, and harvested wood products), and additional country-level methodological information.

From the aggregation of NGHGIs data, we show that LULUCF is an increasing net sink of on average -2.4 Gt CO_2/yr (see figure, panel a). This net sink has remained stable or has slightly decreased in developed countries (at -2.0 $GtCO_2yr^{-1}$ on average). Conversely, in developing countries the sector has moved from being a net source to a net sink (-0.4 Gt CO_2/yr on average) (figure, panel b). Global emissions from deforestation have remained stable or slightly decreased (4.1 Gt CO_2/yr on average) and are mostly occurring in developing countries. Most CO_2 removals are from Forest land (-0.4 Gt CO_2/yr on average) with an increasing sink in developing countries (-4.2 Gt CO_2/yr) and a decreasing sink in developed countries (-2.3 Gt CO_2/yr).

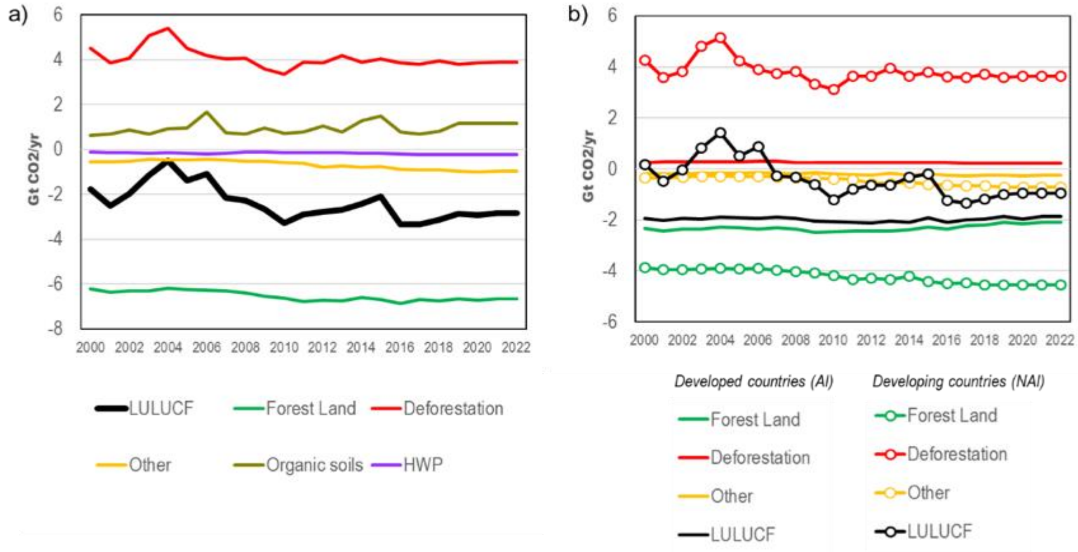


Figure: global trend 2000–2022 of CO_2 fluxes from the aggregation of NGHGI for the various land uses and land-use change categories (a) and CO_2 fluxes split by categories and by developed (Annex I, AI) and developing (non-Annex I, NAI) countries (b). Update of Figure 2 in Grassi et al. (2022).

Global Forest Resources Assessment (FRA) 2025. What's new and how can FRA help in forest emissions?

Marieke Sandker and Anssi Pekkarinen (Forestry Division, FAO)

FRA2025 will be launched at the end of 2025. Country reports have already been collected (countries can reach out to national correspondents for internal sharing and harmonization of reported data to Biennial Transparency Reports) and are currently undergoing data cleansing and analyses. Data collection has started for the FRA remote sensing survey (FRA-RSS); a global stratified area estimate involving >400 country experts and providing statistics per region and ecozone, not country-level. FRA-RSS results are expected to be published in 2026. FRA provides country reported statistics on forest area and forest area change (deforestation, afforestation/reforestation and other forest expansion) and many other variables. FRA does not provide statistics on harvested wood volumes (this is the Forest Products and Bioeconomy team) nor emissions/removals from forests. FAO uses nonetheless FRA data as input into its calculation of LULUCF emissions, with data disseminated annually in its corporate FAOSTAT database (https://openknowledge.fao.org/items/f1d26bec-8c1f-41b0-8f1c-ca4bef7f5c95). The FAO estimates of emissions and removals from forests, based on a stock change approach, have regularly featured in previous IPCC ARs and in the 2019 IPCC SRLCC. They will be updated in 2025 using the new FRA 2025 data. New features of FRA2025 comprise, among others, an Application Programming Interface for direct data transfer, voluntary updates within the 5-year cycle and more explanation in case different estimates are reported (e.g. to UNFCCC).

Afternoon:

a) Land use emissions in the Global Carbon Budget and the IPCC AR6 – WGI

Global and Regional Carbon Budgets

Glen Peters (CICERO, Center for Climate Research, Oslo, Norway) – on behalf of the Global Carbon Project

The Global Carbon Project (GCP, https://www.globalcarbonproject.org/) a project under Future Earth, has initiated numerous activities relevant for the carbon cycle and emission inventory communities. The most relevant of these activities are the preparation of 'budgets' of different greenhouse gases, at both the global and regional levels. These budgets estimate the sources and sinks of different greenhouse gases, tracks trends over time, and analyses the cause of changes and budget imbalances. The GCP compiles global budgets of CO_2, CH_4, and N_2O, and compiles regional budgets of all components (RECCAP1, RECCAP2, https://www.globalcarbonproject.org/reccap/index.htm).

The Global Carbon Budget (GCB, https://globalcarbonbudget.org/) has been published 18 times (first publication in 2006) and is now an annual output of the GCP with around 100 direct authors contributing each year. Since the publication is annual, there is constant improvements in methods and data used to estimate each budget component, and this holds true for the land-use change emissions (estimated with bookkeeping models) and the land sink (estimated with dynamic global vegetation models). The annual cycle and broad community effort helps push the science forward and makes the GCB a key input to scientific assessments (IPCC).

Regional budgets incorporate more diverse data sources and additionally include lateral fluxes (flows in carbon between regions such as in agricultural products, harvest, and river flows). Regional budgets link more closely to emission inventories and policy relevant outcomes, increasingly include remote sensing products, and represent the next frontier of scientific research. Regional budgets, and increasingly national budgets, are an area of active engagement of the carbon cycle community and where collaboration with the inventory community is most fertile.

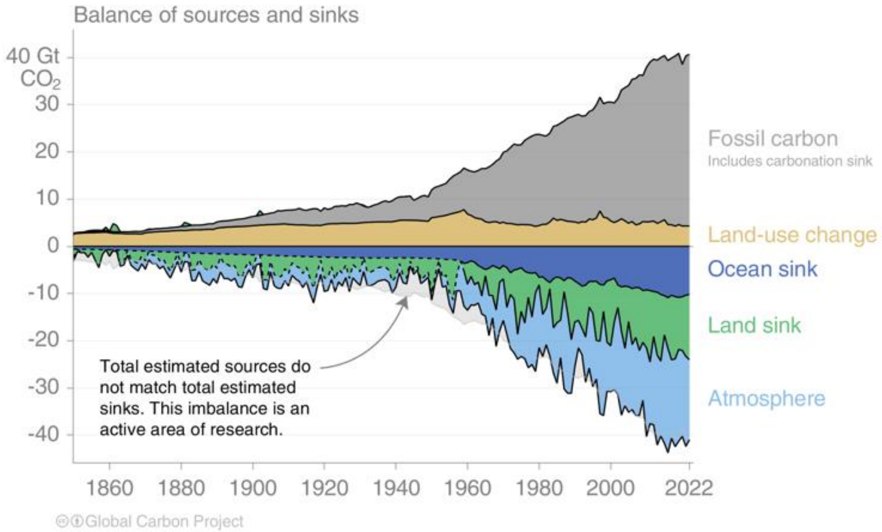


Figure: the global carbon budget over time.

Estimating the terrestrial global carbon budget by global models

Part 1: Bookkeeping modeling to estimate LULUCF emissions and removals

Julia Pongratz (Univ. of Munich) & Global Carbon Budget team

Bookkeeping models (BM) are used in the Global Carbon Project's annual Global Carbon Budgets (GCB) and IPCC Assessment Reports to estimate emissions and removals of CO_2 through LULUCF. This presentation provided detail concerning their uncertainties and treatment of indirect fluxes. For the basic concept of the semi-empirical BMs, see the background paper, Annex 5.1 "Global carbon models" below.

Models are used in the GCB to estimate LULUCF emissions and removals because observational data does not allow us to distinguish direct CO_2 fluxes caused by anthropogenic activities from indirect ones occurring in response to environmental changes. Like all model and observational approaches, BMs come with uncertainties. These have been extensively assessed and stem from the (equilibrium) carbon densities assumed for specific land-use types, response curves tracking evolution of carbon stocks after a land-use event, and how cleared material is allocated (slash, product pools) (Bastos et al., 2021). Further, estimates are very sensitive to the choice of land-use activity data (LUH2, HILDA+, FAO/FRA) (Gasser et al., 2020; Ganzenmüller et al., 2022), calling for better, higher-resolution activity data. For a routine assessment of the uncertainty range three largely independent BMs are used in the GCB (BLUE, OSCAR and Houghton&Castanho), with an additional uncertainty estimate around the BM average derived from dynamic global vegetation models (DGVMs). Estimates are continuously improved, including better use of remote-sensing data.

Global models provide net LULUCF flux estimate of direct activities, based on *drivers*, not *areas* (managed land proxy) like NGHGIs. GCB and NGHGI LULUCF flux estimates are operationally translated to each other (e.g., in GCB) to link country reporting to IPCC assessments and scenarios (TCRE, remaining carbon budget, net-zero years). The translation is based on Grassi et al. (2023) using DGVM's natural sink. It works well in particular on global level; it reveals important issues in one or the other method on national level (Schwingshackl et al., 2023; see figure). We see a large potential in the scientific communities joining up for a national-level comparison between global models, NGHGIs and Earth observations. BMs have recently been developed to integrate indirect effects on emissions and removals and to estimate the natural land sink (Gasser et al., 2020; Bultan et al., 2022; Dorgeist et al., 2024). This opens the way to a direct comparison to NGHGIs.

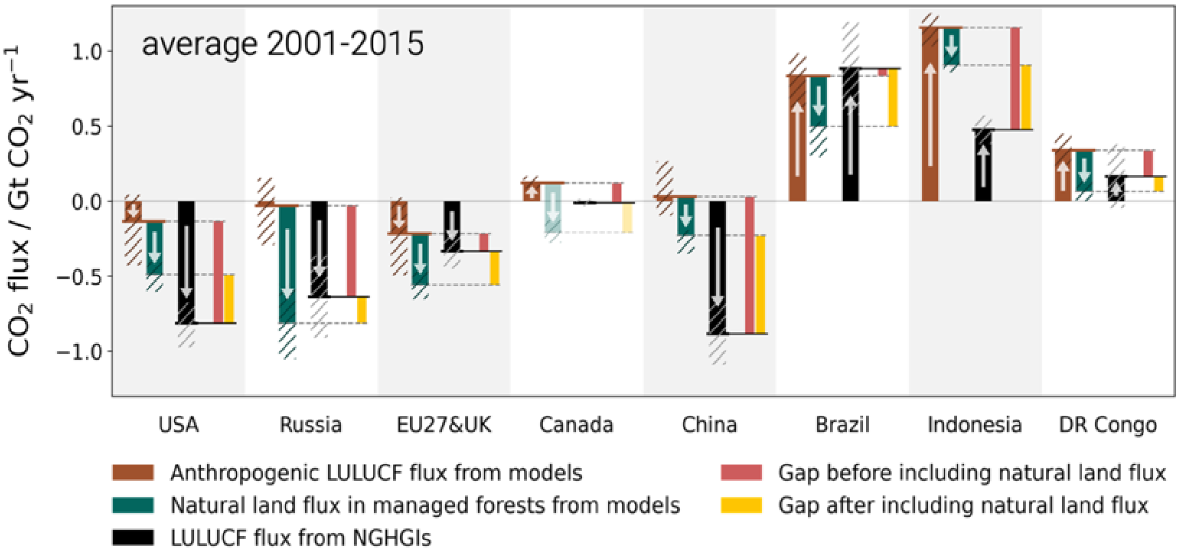


Figure: translation of bookkeeping models results to NGHGI approach (Schwingshackl et al., 2023)

Estimating the terrestrial global carbon budget by global models - Part 2: Dynamic Global Vegetation Models (DGVMs)

Mike O'Sullivan (Univ. of Exeter) & Global Carbon Budget team

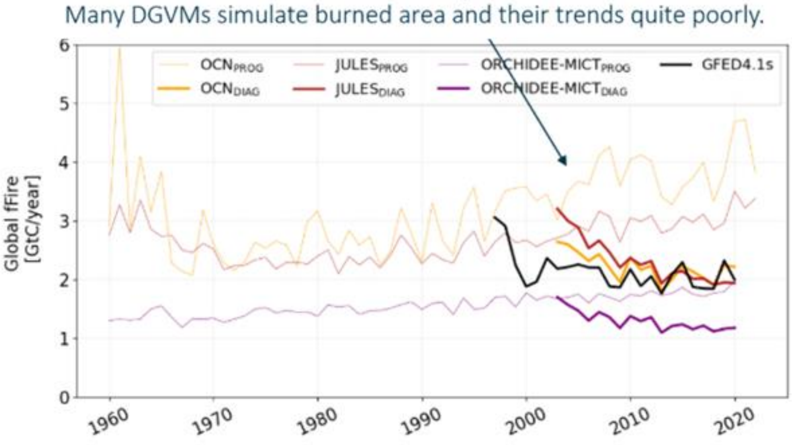
DGVMs are powerful, process-based models that simulate land dynamics across various scales and timeframes, enabling a detailed mechanistic understanding of the carbon cycle. These models are essential for distinguishing between direct human-induced carbon fluxes and natural or indirect fluxes, which is vital for accurately defining net zero emissions and quantifying the climate impact of human decisions.

The strengths of DGVMs lie in their explicit representation of many interacting processes, enabling the simulation of vegetation dynamics, prediction of carbon and water cycles, and analysis of feedback mechanisms between ecosystems and the climate. With 20 models integrated into the Global Carbon Budget (GCB), DGVMs provide robust global-scale estimates of carbon fluxes. These models start simulations at equilibrium in the year 1700, allowing for precise attribution of changes to human activities.

A significant advancement in the field is the integration of Earth Observation (EO) data, which substantially enhances the accuracy of DGVMs. EO data, such as the ESA CCI Land Cover, is used to spatially allocate country-level FAO data, leading to corrected emission trends and reduced uncertainties in land-use change emissions (ELUC). The use of Mapbiomas data in Brazil and Indonesia has refined ELUC estimates, making the models more reliable. Further, satellite-derived fire disturbance data is now used to constrain fire carbon emission estimates.

Despite their strengths, DGVMs face challenges, particularly in regional carbon budget estimations and interannual variability. The continuous improvement in these models is vitally important, especially through the incorporation of near-real-time EO data to better capture large climate impacts with low latency. These enhancements are crucial for providing accurate, region-specific data that support national greenhouse gas inventories and global climate mitigation efforts.

In conclusion, DGVMs are invaluable tools for understanding and managing the carbon cycle, particularly in the context of land-use definitions and national inventory compilation. Ongoing improvements through EO data integration are essential to reducing uncertainties and enhancing the precision of these models, thereby strengthening their role in global climate policy and mitigation strategies.



Many DGVMs simulate burned area and their trends quite poorly.

Figure: global fires emission from selected DGVMs.

b) Land use emissions in the IPCC AR6 – WGIII

Integrated assessment models and representation of land use change

Detlef van Vuuren (PBL), Thomas Gasser (IIASA) and Elke Stehfest (PBL)

General description and types of IAMs

Integrated assessment models (IAMs) are used to develop scenarios about the co-evolution of the economy, society, and the environment to support environmental policymaking. The most common use of IAMs is in the field of climate mitigation, through the generation of scenarios representing climate action (from no action to the 1.5°C goal) under a broad range of assumptions about future socio-economic, institutional, and technological developments. Land cover and land use form important elements of most IAMs, given their roles in climate change (as a cause, solution, and impact sector) and biodiversity loss. The land use component of IAMs describes how land is used to meet the demand for producing food, fibers, timber, and energy, as well as providing space for shelter and nature. The representation of these processes can be at either the regional or gridded scale. The land use categories specified by IAMs typically include cropland, pasture, built-up area, forests, and other land. The description of all other land cover classes is based on biome distribution maps, either static or dynamic, distinguishing vegetation into at least forest and non-forest natural vegetation that can potentially be converted to agriculture, as well as other lands.

IAMs calculate both CO_2 emissions from land-use change and non-CO_2 emissions from agricultural activities. Conceptually, the calculation of land-use change related CO_2 emissions aligns with the approach used in bookkeeping models, defining anthropogenic emissions only in cases of land use changes and sometimes additional forest management. Still there are also some key differences across IAMs, for instance in relation to whether a regional or grid based approach is used.

Linkage with other climate research communities

From IAMs to climate models. ESMs and DGVM require patterns of land use and land cover change to simulate carbon fluxes caused by these perturbations in an internally consistent manner. There is a harmonization process that connects historical land-use reconstructions with future projections from IAMs in a format suitable for ESMs (Hurtt et al., 2020). As part of the process, IAM data is adjusted to be consistent with historical emissions used in complex models. By design, this ensures that the land use CO2 emissions provided as input to SCMs align with bookkeeping emissions.

From IAMs to UNFCCC**.** IAM estimates are aligned with emission inventories, which typically use a bookkeeping approach. The UNFCCC, however, uses a different definition in which the net uptake of CO_2 in managed forests can be accounted for as an additional sink. The difference between these definitions is quite substantial. Recently, both Grassi et al (2021) and Gidden et al (2023) used methods (either using IMAGE/LPJml or a simple climate model) to calculate land use emission data that is consistent with the bookkeeping models and the national inventory conventions. In mitigation scenarios, the difference between the two estimates decreases over time as the CO_2 stored in forests starts to reach equilibrium with atmospheric CO_2. As a result, the conversion has a strong impact on annual emissions and carbon budgets, but only a small influence on, for instance, the net zero year.

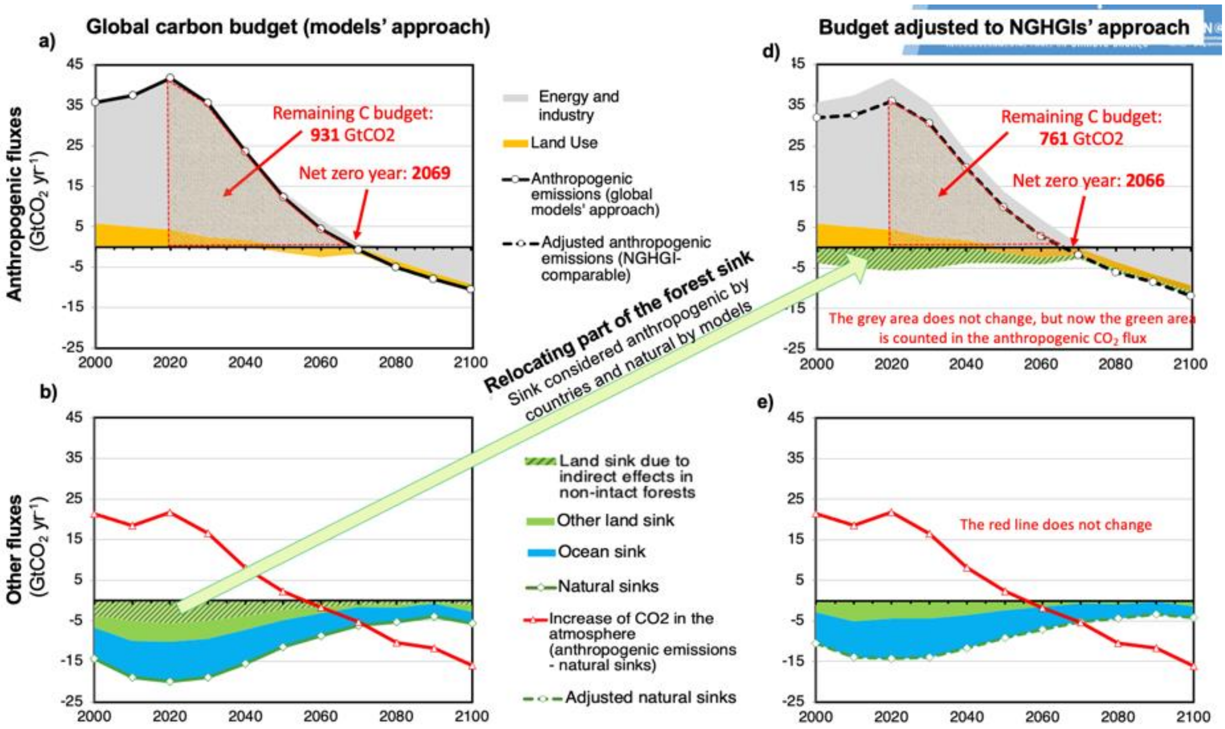


Figure: Indication of how the data from global models (left) can be made consistent with UNFCCC reporting by redefining some of land sink in forest area from natural (models) to anthropogenic (UNCCC), Grassi et al (2021).

Role of the land use sector in NDCs

Rosa Roman-Cuesta (Joint Research Centre, European Commission)

Due to their capacity to both emit and remove CO_2 to/from the atmosphere, carbon fluxes from the land use sector (understood as forests, wetlands, grasslands, croplands, settlements and other land) are at the core of the Paris Agreement (PA). Land use models that align with well-below 2 °C by 2100 rely on deforestation reductions and large future removals, while countries depend on it for a quarter of global mitigation commitments, as reported in the first round of Nationally Determined Contributions (NDCs-2015). Under worsening climatic scenarios, the role of the land use sector is becoming more uncertain. The First Global Stocktake (GST) was an opportunity to track NDC-2020 progress against 2030 modelled emission pathways that align with the PA temperature goals, and the future reliance of countries on their land carbon fluxes to meet their climate neutrality goals. The First GST, however, has fully excluded the mitigation commitments of the land use sector, as presented by countries under their second NDC submission (NDC 2020). Hence, the values reported under the Assessment Report (2030) of 55.4 and 51.9 GtCO2e/yr in 2030 under unconditional and conditional mitigation pledges, fully exclude carbon fluxes from the land. This exclusion relates to well-known conceptual differences between the modelling community and countries' greenhouse gas (GHG) Inventory teams, on the definition of anthropogenic direct emissions. It has however resulted in a knowledge gap, and countries remain blind on 1. how the land use sector performed under the NDC 2020, 2. what the global GHG budget is under country's reporting of GHG including the role of committed additional sinks and removals, and 3. how the tracking of progress between NDC and models would differ between models and countries' pledges in 2030, with a future aim to offer data translations.

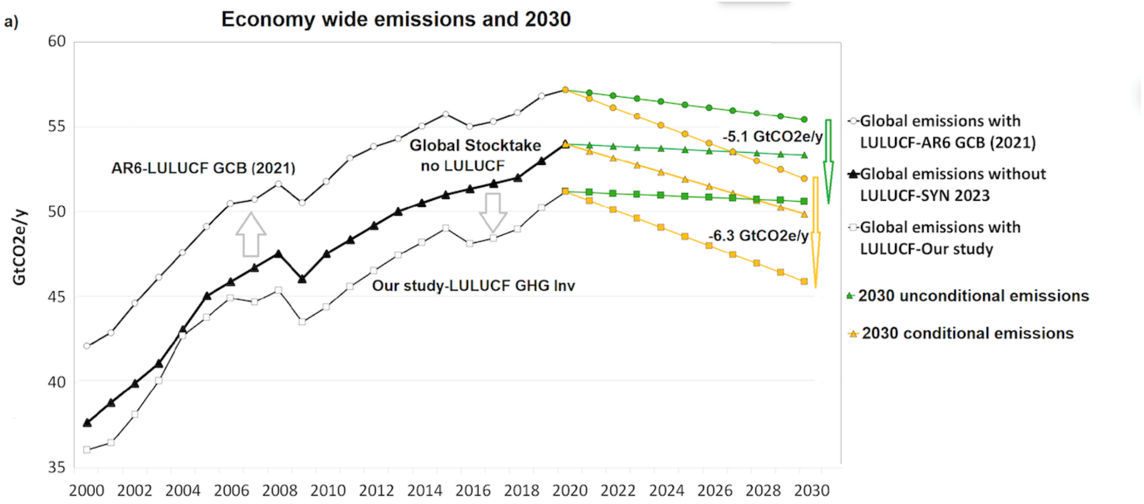


Figure: Economy-wide historical emissions including and excluding the LULUCF sector (2000-2020), and 2030 projections under three different scenarios. i) Historical and 2030 emissions excluding LULUCF in the Global Stocktake (SYN2023). Including LULUCF: i) historical emissions using data from the Global Carbon Budget (2021), and AR6 SSP1.1.9 for 2030, and ii) country-based LULUCF data from GHG Inventories and NDCs (Our study). Conditional and unconditional scenarios are presented for the three scenarios, leading to differences between -6.3 and -5.1 GtCO2e/y.

To cover this GST gap, we assessed land use commitments under countries' and found that 1. the land retains a quarter of global mitigation pledges in 2030, mostly through conditional support (-1.5±1.1 GtCO2e/y), failing low on domestic action (-0.2±0.5 GtCO2e/y). Under the full implementation of the pledges, the estimated additional sink in 2030 (-0.6 GtCO2e/y) remains close but yet insufficient to remain aligned with emission pathways under the PA goals (Carbon Dioxide Removal (CDR) Gap). 3. GHG projections for the land use sector in 2030 differ between countries and models by -6.3 and -5.1 GtCO2e/y, depending on countries commitments under unconditional and conditional support, respectively.

The well-known net emission difference observed in the historical period is retained in 2030 projections, but is influenced by countries commitments. Different 2030 emission scenarios for the land use sector has consequences on fulfilling the goals of the PA, affecting the timing of net zero and the available remaining carbon budget. Further data harmonization, and downscaling sectoral and regional analyses would be needed in future GSTs to support countries to raise their ambition in future rounds of the NDCs.

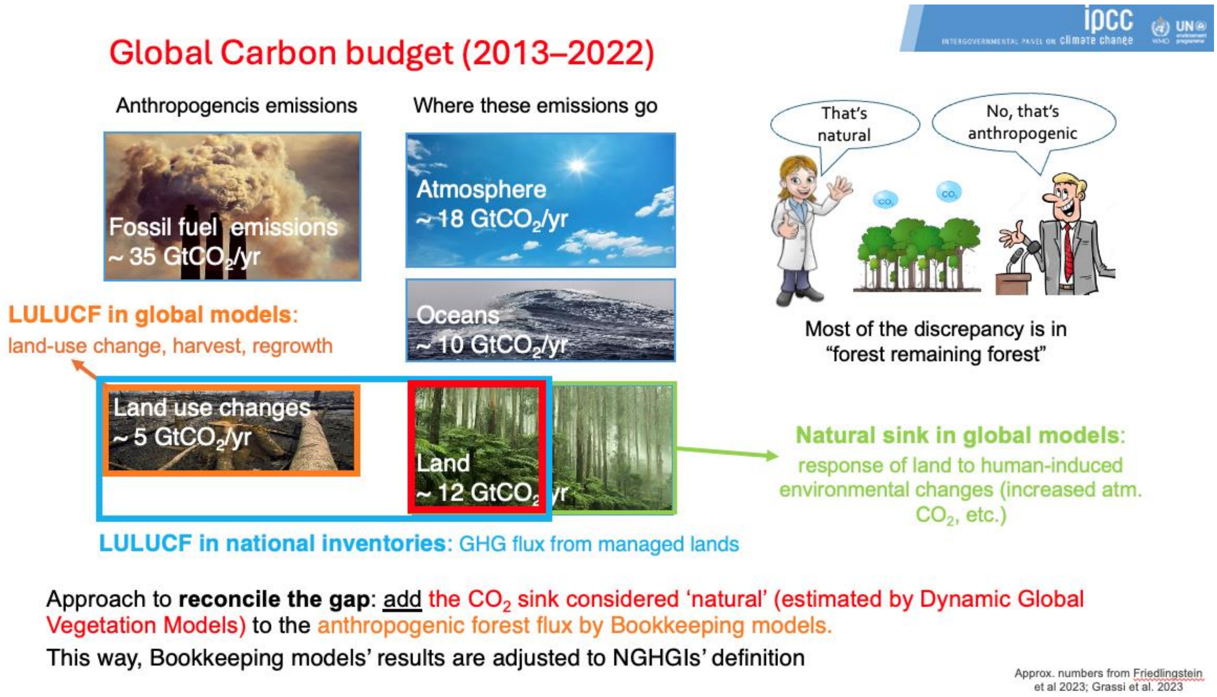
c) Reconciling land use emissions between global models and national inventories

Reconciling land use CO_2 fluxes, Part 1

Giacomo Grassi (Joint Research Centre, European Commission; IPCC TFI Bureau)

The first half of the talk on reconciling land use emissions illustrated an approach to “translate” Global models’ results to make them more comparable with GHG inventories (figure below). This approach has been implemented for the historical period (Grassi et al. 2023) and for future emissions scenarios (Grassi et al. 2021), proving in both cases encouraging results.

When this approach is applied for future emission scenario, it has relevant implications for the remaining carbon budget and net zero years (see figure in the presentation summary from Van Vuuren, above).



Global Carbon budget (2013–2022)

Anthropogencis emissions

Where these emissions go

Fossil fuel emissions ~ 35 $GtCO_2$/yr

Atmosphere ~18 $GtCO_2$/yr

Oceans ~10 $GtCO_2$/yr

LULUCF in global models: land-use change, harvest, regrowth

Land use changes ~ 5 $GtCO_2$/yr

Land ~ 12 $GtCO_2$/yr

LULUCF in national inventories: GHG flux from managed lands

Most of the discrepancy is in “forest remaining forest”

Natural sink in global models: response of land to human-induced environmental changes (increased atm. CO_2, etc.)

Approach to **reconcile the gap**: add the CO_2 sink considered ‘natural’ (estimated by Dynamic Global Vegetation Models) to the anthropogenic forest flux by Bookkeeping models.

This way, Bookkeeping models’ results are adjusted to NGHGIs’ definition

Approx. numbers from Friedlingstein et al 2023; Grassi et al. 2023

Figure: approach to reconcile land use emissions between global models and national inventories.

As a conclusion, this presentation noted that the main reason of the LULUCF gap between countries and global models is understood and can be largely reconciled. However, a lot of work is still to be done. From the side of the countries, the aim is to achieve greater transparency on data/methods, greater completeness of estimates, information on definitions/area of managed lands, more clarity of LULUCF within climate targets.

From the Global models’ side, future work will include better representation of land use areas and land management, greater consistency between anthropogenic and natural fluxes, and more disaggregated results to increase comparability to countries. In addition, further work will need to include the operationalization the comparison and the careful communication of implications (remaining carbon budget, net zero).

Reconciling land use CO_2 fluxes, Part 2

Thomas Gasser (IIASA)

This second half of the talk presented a recent analysis, published by Gidden et al. in 2023 in *Nature*, of the implications for global climate policies of the reconciliation approach suggested by Grassi et al. and introduced in the first half of the talk.

The core motivation of this analysis was that high-level mitigation benchmarks provided for policy advice in the IPCC AR6 used the scientific model convention for land use CO_2 fluxes (i.e. the reported historical LULUCF flux is an emission). These mitigation benchmarks are key for high-level international discussions, as they provide global mitigation targets such as emissions levels in 2030 that are compatible with the Paris agreement temperature targets. The study investigated how these benchmarks are affected by aligning the land CO_2 fluxes with the national inventory convention, as a prerequisite for a consistent Global Stocktake. Two key results were reported.

First, all benchmarks shift under the new accounting convention. In the case of pathways compatible with the 1.5 °C target, compared to what was reported in the AR6, net-zero CO_2 emissions need to be reached 1 to 5 years earlier, emissions reductions in 2030 need to be 3.4 to 5.9 % more, and cumulative CO_2 emissions until reaching net-zero need to be lower by 54 to 95 Gt CO_2.

Second, because the indirect effect that environmental changes have on the land carbon cycle are included under the national inventory convention (whilst they are not under the model convention), a future decrease in the sink provided by the indirect effect, such as caused by a decrease in CO_2 fertilization or by an increase in climate-induced mortality, could mask a country's increased efforts to preserve or increase carbon stocks through direct intervention such as reforestation.

As a conclusion, we suggested that mitigation targets should be separately formulated for CO_2 emissions from LULUCF and for other sectors. We also requested more detailed information from IAM teams and national inventories, regarding their estimates of the direct and indirect effects, as well as their land management classification.

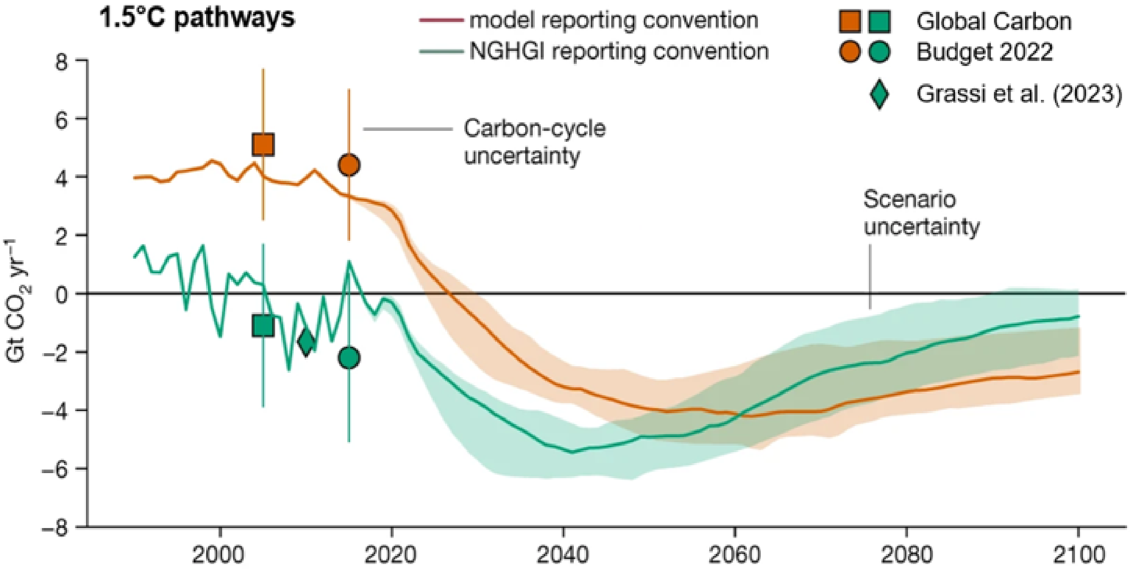


Figure: Illustration of the future land use CO2 fluxes under both conventions in 1.5°C compatible scenarios. The difference between the two curves is the indirect effect over managed land. The masking effect appears when the two curves cross: the indirect effect becomes a source of CO_2 despite intense afforestation and reforestation efforts to keep the direct effect a sink of CO_2.

Impacts of different definitions of removals

Glen Peters (CICERO)

The problem. There are mathematical reasons why the carbon cycle community separates 'direct' and 'indirect' effects. The carbon cycle is modelled by separating '*active'* emissions (fossil fuels and *direct* land use change) from '*passive'* removals (e.g., *indirect* CO_2 fertilization). The net emissions are an input into the system, while the passive removals are a response of the system. *The two can't be mixed*. Models of the carbon cycle show that if active emissions go to zero (black lines in figure below), the CO_2 concentration declines, and the temperature stabilises. The passive uptake declines as emissions and concentrations decline, but it does not reach zero. If active net emissions are balanced with passive removals (dotted lines), then the CO_2 concentration stabilises and temperature rises. This analysis is detailed in Allen et al 2024 (in press; see also poster 'MAllen').

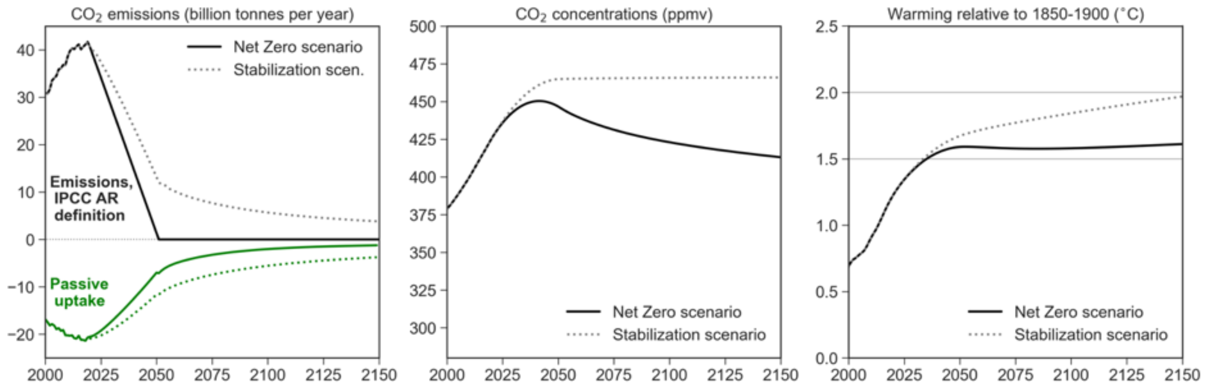


Figure: Impact of ambiguity in the definition of removals in net zero. Achieving net zero CO_2 emissions only halts CO_2-induced warming if the definition of removals excludes 'passive' CO_2 uptake (i.e. *indirect* CO_2 effects).

A practical solution? The current mapping from active and passive emissions to emission inventories via global models mixes active emissions and passive removals, which changes the meaning of net zero emissions. However, it may still be possible to separate active and passive fluxes through better disaggregation of forest land. Bookkeeping models and inventories already disaggregate re/afforestation, deforestation, HWPs, and bioenergy (via a memo). However, definitions differ. If 'forest land remaining forest land' was further disaggregated into lands that are in active forestry activities (regrowth from harvest), re/afforestation for periods beyond 20 years (default), then this would help separate active and passive uptake in inventories. 'Anthropogenic' emissions could then be defined primarily as active removals but allowing some passive removals to be practical. Global models (DGVMs) should be able to provide results at the same level of disaggregation, which will help comparisons with bookkeeping models and inventories. This disaggregation approach could retain land areas as a proxy for active uptake but requires tighter definitions of 'managed land' to those where active management occurs and direct effects dominate.

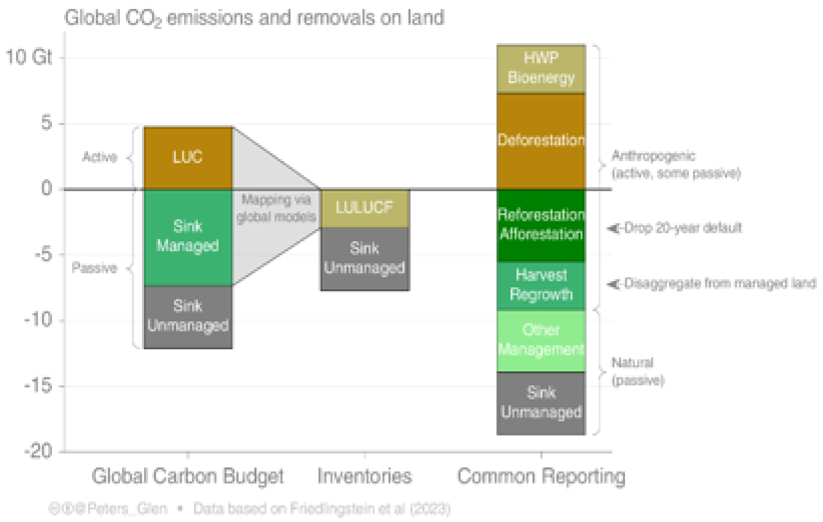


Figure: disaggregation of land emission and removals

DAY 2: Role of Earth Observation (EO) for estimating land use emissions

Satellite remote sensing for land characterisation

Martin Herold (GFZ Potsdam)

The presentation emphasized the role of Earth Observations as key data source underpinning climate and Earth system science, modelling and services for many years. This also includes the capabilities to track spatial distribution of land use changes, carbon stocks, sinks and sources is an important baseline for underpinning policy decisions. Another critical aspect is the timeliness of satellite data to provide information rapidly to regularly assess performance and compliance, and adjust polices if needed. Due to recent operational availability satellite data streams (i.e. as part of the Copernicus program), we do see and increasing use of such information to support the implementation of climate actions (i.e. improved land management) by providing locally-relevant data and information on land use and GHG impacts and enhance the transparency and accountability of the different stakeholders involved in climate actions. Many Earth Observation are available open-source.

For the purpose of reconciling estimates from global modeling and national monitoring efforts, it is important to note that Earth Observation data have been used for both global and national monitoring efforts; hence often time similar satellite data are employed for different LULUCF uptakes – as shown in Table 5.2.1 (See Annex 5.2)

Because of the their wide-spread use, Earth Observation data can play an important role in linking national estimates (i.e. those from NGHGI) and the global level in the context of the UNFCCC global stocktake. Estimates can be provided following different (forest) definitions, covering different periods, regions and at different levels of land types and classes.

Use of remote sensing to produce biomass maps: the case of Brazil

Jean Pierre Ometto (INPE, Brazil)

The Amazon Rainforest, the largest tropical forest in the world, stores a significant portion of Earth's terrestrial carbon. As climate change and land-use practices evolve, continuously updating carbon stock estimates is essential, especially given the dynamic nature of the forest. Current forest inventory data only cover a small part of the Amazon, limiting their reliability for broad regional assessments. This study introduces a new high-resolution (250-meter) above-ground biomass map for the Brazilian Amazon, based on satellite data from 2016, while accounting for uncertainty. The study integrates multiple scales of data to estimate biomass across both intact and degraded forest areas affected by fire and selective logging.

The project utilized the largest airborne LiDAR dataset ever collected in the Amazon, covering 360,000 km² through transects that represent all major vegetation categories. In two field campaigns (2016/2017 and 2017/2018), 901 LiDAR transects were collected across the Brazilian Amazon. Of these, 613 were randomly distributed over primary and secondary forest areas, 133 over the deforestation arc, and 155 overlapped with field plots for model calibration. Each transect spanned at least 375 hectares (12.5 km by 300 m) and was surveyed using a Trimble Harrier 68i airborne sensor aboard a Cessna 206 aircraft. LiDAR data were integrated with Landsat OLI images, resulting in accurate biomass estimates. Vegetation indices and texture images also proved useful, particularly for assessing biomass in areas impacted by forest degradation.

The biomass map was produced using airborne laser scanning (ALS) data, calibrated with field inventories, and extrapolated regionally using machine learning techniques. Inputs included Synthetic Aperture Radar (PALSAR), vegetation indices from the MODIS satellite, and precipitation data from the Tropical Rainfall Measuring Mission (TRMM). A total of 174 field inventories, geolocated with Differential GPS (DGPS), were used to validate the biomass estimates. The new multi-scale approach proved effective in estimating biomass even in areas degraded by forest fires and selective logging, showcasing the ability of the method to provide detailed and accurate estimates for a variety of forest conditions.

The biomass results of this study revealed significant variability across the region. The new map captured various vegetation types, with above-ground biomass values ranging from a maximum of 518 Mg ha-1 to a mean of 174 Mg ha-1, with a standard deviation of 102 Mg ha-1. Biomass stocks were found to be lower in degraded forest areas compared to intact regions, reflecting the impacts of forest degradation. This unique dataset offers a comprehensive view of the Amazon’s biomass distribution and structure, aiding in conservation planning, carbon emission assessments, and mechanisms for reducing emissions.

The new biomass and uncertainty maps (see figure below) serve as an important reference for both the scientific community and policymakers. Developed using the largest LiDAR dataset obtained from flights over the Brazilian Amazon, this map supports research on carbon fluxes, projections of atmospheric CO2 concentrations, and the development of mitigation strategies. The map also contributes to UNFCCC reports, IPCC assessments, and REDD+ efforts to curb emissions from deforestation and forest degradation. Moreover, this map and its dataset provide essential support for models estimating carbon losses and gains driven by human activities and climate change.

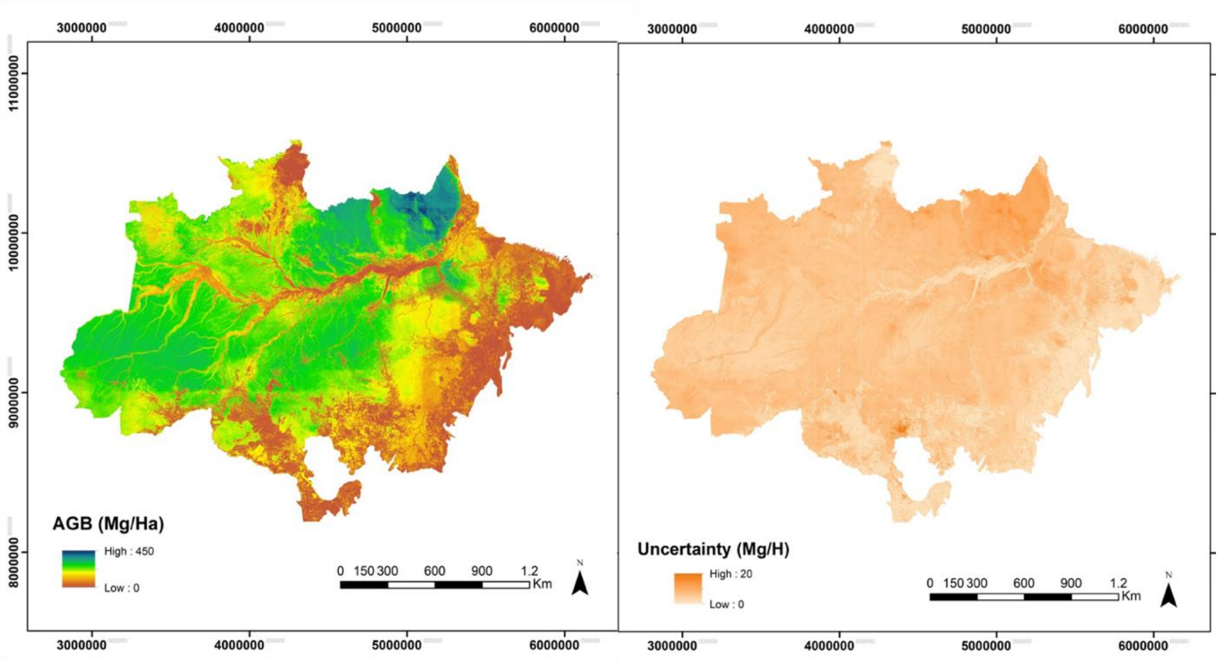


Figure: Above-ground biomass map at 250-m resolution for the Brazilian Amazon (left panel) with corresponding uncertainty (right panel).

Revised geospatial monitoring of 21st century forest carbon fluxes by Global Forest Watch

Nancy Harris (World Resource Institute)

Maps of forest greenhouse gas fluxes on Global Forest Watch (GFW) are the product of an operational geospatial monitoring framework that integrates ground, airborne, and satellite data. The framework reports gross emissions and removals and does not differentiate between fluxes from anthropogenic and non-anthropogenic activities like countries do in their national greenhouse gas inventories (NGHGIs). To facilitate the complementary use of Earth observation-based fluxes with NGHGIs, GFW's estimates of gross emissions and removals were translated into categories that are more comparable with the land use categories used by countries to report anthropogenic (net) forest fluxes in their NGHGIs, following the Guidelines of the Intergovernmental Panel on Climate Change (IPCC). After assigning GFW's forest carbon fluxes to these inventory reporting categories, GFW's provisional estimates of average deforestation emissions and the anthropogenic sink in forests, which reflect several updates and improvements to data used in the original framework, aligned well with aggregated NGHGIs at the global scale. Through this work, the potential for Earth observation-based flux estimates was illustrated to be translatable into the language of NGHGIs, which can help to build consensus around the Global Stocktake and evaluate progress towards Paris Agreement goals.

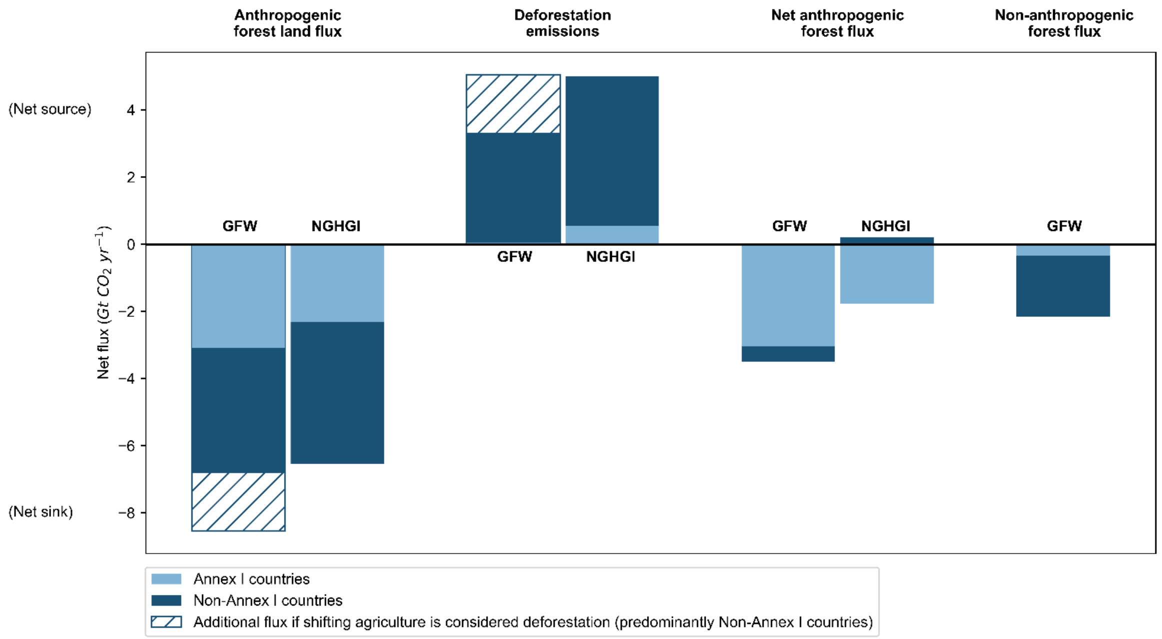


Figure: comparison of average annual forest carbon fluxes (2001–2022) between national greenhouse gas inventories (NGHGI) and the updated GFW flux model.

New tools for estimating emissions from land use

Sassan Saatchi (Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA)

Accurately assessing net carbon dioxide emissions from global land carbon changes and understanding the role of land in climate mitigation are critical yet challenging tasks, fraught with significant uncertainties. These uncertainties are evident in two primary aspects of land carbon flux data: (1) the considerable difference (exceeding 6 Gt CO_2/yr) between national greenhouse gas inventories (NGHGIs) reported to the UNFCCC and the LULUCF (Land Use Land Use Change and Forestry) book-keeping models used by the IPCC and assessed by the Global Carbon Project (GCP), and (2) the substantial variation (over 3 Gt CO_2/yr) among the three book-keeping models employed in GCP's land use emissions estimates.

As climate policy shifts from commitments to implementation, reconciling these differences before the next global stocktake in 2028 is imperative. Furthermore, establishing a reliable jurisdictional Measurement, Reporting, and Verification (MRV) system for land carbon is crucial to enable countries to effectively evaluate their progress towards national climate targets under the Paris Agreement.

Our team at JPL, in collaboration with international researchers, has developed new techniques and tools over the past decade based on a combination of ground inventory measurements and satellite observations of land use, forest structure, and biomass for long-term (2000-present) monitoring of land carbon stock changes. This brings a systematic observation-based approach, along with uncertainty assessments, to localize and provide precise estimations of emissions and removals of carbon from land use activities, to better quantify land sinks and sources. The geospatial data and estimates are integrated into a jurisdictional MRV system to significantly improve the global stocktake, inform national carbon management policies, and bolster climate mitigation efforts, including initiatives like REDD+ and nature-based solutions.

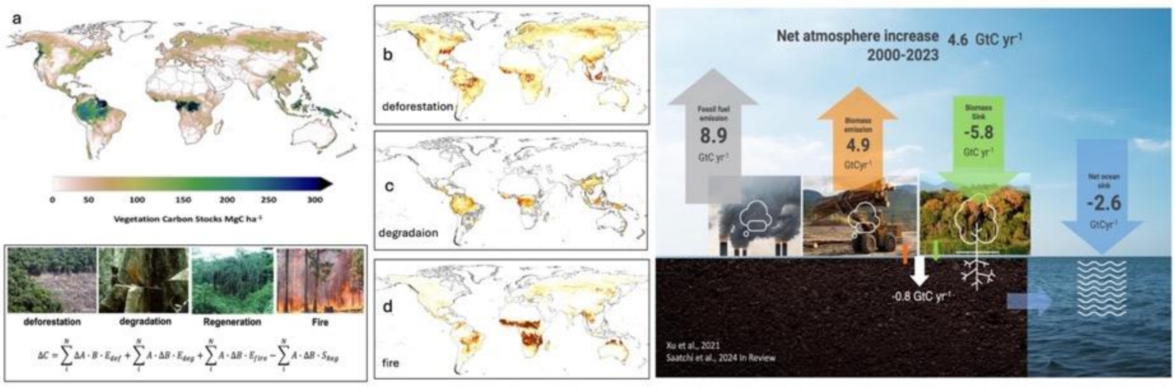


Figure: The new tools integrated in the jurisdictional MRV system include (a) carbon stocks at 100 m spatial resolution from 2000-2023, (b) estimates of deforestation and forest clearing, (c) forest degradation, (c) forest and savanna fires all at 30 m resolution to calculate the stock changes and emissions and removals from land use activities. The MRV system can contribute to improve balancing global carbon budget (right panel).

Combining satellite biomass and disturbances observations to project current and future carbon sink

Philippe Ciais (LSCE)

EO based data are increasingly used for assessment of land cover and biomass carbon changes, but they have also issues and differences related to coverage, accuracy and systems boundaries for these data to be useful for NGHGIs. The situation is also country specific with some countries already using EO data in their inventories and others not, in compliance with IPCC guidelines and land use / sectors / carbon pools change definitions. The presentation illustrated examples of results for above ground biomass changes estimated from EO at different spatial and temporal resolutions including L-VOD, machine learning models and new deep learning maps of height and above ground biomass changes available globally. Two approaches are distinguished between stock change methods and gain loss methods where disturbance data, recovery of biomass stocks after disturbances and biomass loss consecutive to disturbances are combined together for providing carbon budgets of secondary forests, at high spatial resolution.

G3W, the WMO Global Greenhouse Gas Watch

Giampaolo Balsamo (WMO)

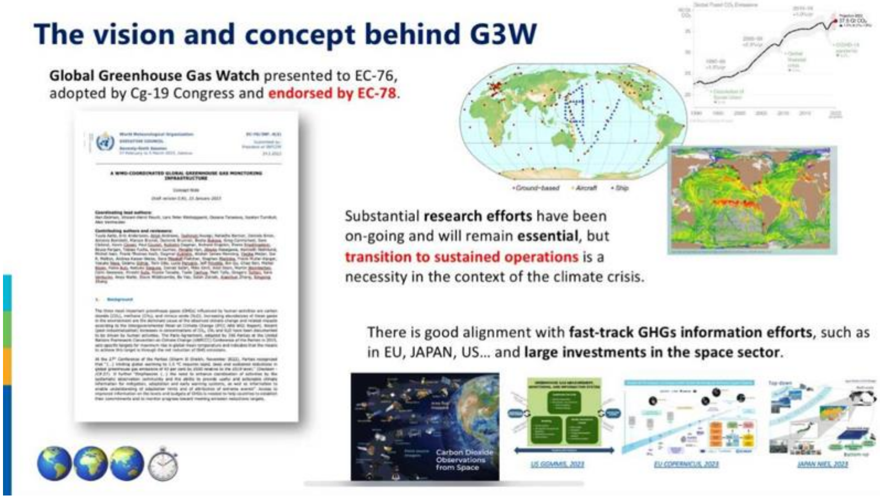
The G3W aims to establish and support a coordinated global operational greenhouse gases (GHGs) observation network of space-based (i.e. satellites) and surface-based sensors (i.e. in situ stations) that can accurately estimate GHGs fluxes, focusing on carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), the top three gases that are responsible for global warming and the associated impacts that manifest in extreme weather.

By integrating several sources of quality-controlled observations in earth system models that consider physical, chemical, and biological processes reaching far beyond physical atmospheric and oceanic processes, the natural and anthropogenic sources and sinks of GHGs can be better monitored and provide support to existing efforts.

The integration of observations and modelling (also leveraging Artificial Intelligence) is coordinated within G3W, and count on well-established operating centres to produce consolidated and continuous global information on the total fluxes and concentrations of GHGs, with guidance on the accuracy of the data and their interoperability all along the value-chain. The G3W implementation plan has outlined a staged approach, beginning with the G3W-IPP, the Implementation and Pre-Operational Phase from 2024 to 2027, followed by the G3W-IOP Initial Operational Phase from 2028 to 2031, and finally, transitioning to the G3W-EOP Enhanced Operational Phases from 2032 to 2050.

The Implementation and Pre-Operational Phase focus on the Research to Operation transition including the necessary standardisation and benefit from the World Meteorological Organization's (WMO's) long-term efforts in coordinating greenhouse gas GHG observations and research under the Global Atmospheric Watch (GAW) Programme, the Intergovernmental Panel on Climate Change (IPCC), and the Global Climate Observing System Programme, as well as on the experience of the intergovernmental commissions for infrastructure and services that benefit from expertise and collaboration of the 193 Members of WMO.

The goal of G3W is to ensure that key observation-based information is available with agreed standards, following the principle of joint contribution and shared benefits, supporting all Nations in the implementation of the Paris Agreement climate targets, and serving the Enhanced Transparency Framework processes of the United Nations Climate Change UNFCCC.



The vision and concept behind G3W

Global Greenhouse Gas Watch presented to EC-76, adopted by Cg-19 Congress and **endorsed by EC-78**.

Substantial **research efforts** have been on-going and will remain **essential**, but **transition to sustained operations** is a necessity in the context of the climate crisis.

There is good alignment with **fast-track GHGs information efforts**, such as in EU, JAPAN, US… and **large investments in the space sector**.

Figure: vision behind the G3W

The JRC’s Global land use carbon fluxes data hub

Joana Melo (Joint Research Centre, European Commission)

Land use is increasingly recognized as key to achieving the goals of the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC). However, a lack of clarity and consensus on the magnitude and trend of land use emissions and removals (LULUCF) jeopardises the assessment of global progress. National Greenhouse gas (GHG) inventories (NGHGI) prepared and reported by Parties to the UNFCCC form the basis for designing and implementing climate policies at national level. The aggregation of GHG fluxes reported in NGHGIs is also the main source of information for assessing collective progress towards the long-term goals of the Paris Agreement under the Global Stocktake.

Here we present CO_2 fluxes from LULUCF in a living interactive data-hub hosted by the EU Forest Observatory (European Commission 2024, https://forest-observatory.ec.europa.eu). The maps show the 2000-2022 average land use CO_2 fluxes from NGHGIs. CO_2 fluxes are allocated to the classes Forest (excluding organic soils), Deforestation, Other non-forest land uses, Organic soils, and harvested wood products, with data gaps filled without altering the levels and trends of the reported data (see Grassi et al., 2022). In the graphs with annual CO_2 fluxes for 2000-2022, we further compare NGHGI estimates with independent global emission datasets at global and country level:

(i) Global Carbon Budget (GCB) data from Friedlingstein et al. (2023), using three bookkeeping models to estimate CO_2 fluxes from Forest, Deforestation and Other transitions, and external datasets to estimate CO_2 emissions from Organic soils. Forest fluxes from the GCB are adjusted to the NGHGI definition of human-induced CO_2 sink using the methodology described by Grassi et al. (2023).

(ii) Global Forest Watch (GFW) data from Gibbs et al. (in review, update of Harris et al., 2021) include provisional CO_2 fluxes from forests and deforestation (including organic soils) from 2001 onwards, estimated by integrating Earth observation data into a geospatial GHG monitoring framework. Here, CO_2 fluxes linked to shifting agriculture are allocated either to the Forest or Deforestation classes for comparability with NGHGIs.

Aligned with the conclusions of this IPCC expert meeting, the LULUCF hub will continually update information on the CO_2 fluxes reported by Parties to the Paris Agreement in their NGHGIs. The objective is to facilitate the understanding of other scientific communities about the data and methods used in NGHGIs at the country level. Furthermore, the LULUCF hub aims to provide updated information on ongoing efforts from the global modelling and earth observation communities to handle and present their land use CO_2 estimates in a conceptually similar way to how countries measure and report using IPCC guidance. Ultimately, it will stimulate further work to increase the confidence on carbon fluxes from land use and forest ahead of the next UNFCCC Global Stocktake.

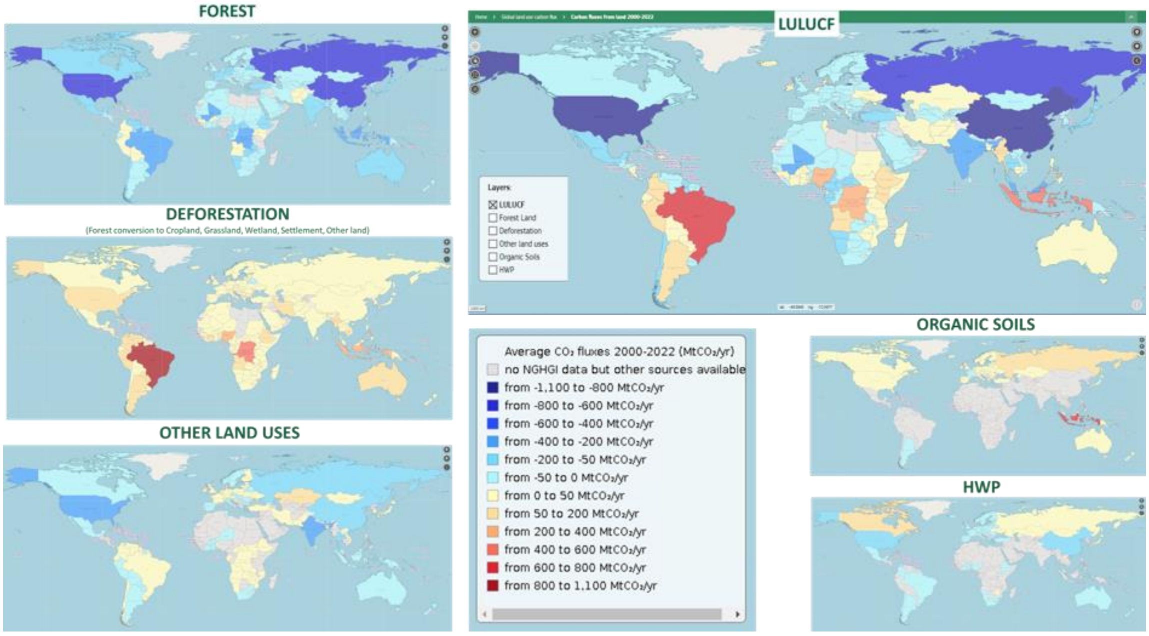


Figure. Spatial distribution of the 2000–2022 average of CO_2 fluxes from the aggregation of National GHG inventories (NGHGI) for the various land uses and land-use change (LULUCF) categories: Forest, Deforestation, Other land uses (cropland, grassland, wetlands, settlements, other land), organic soils and harvested wood products (HWP). European Commission (2024).

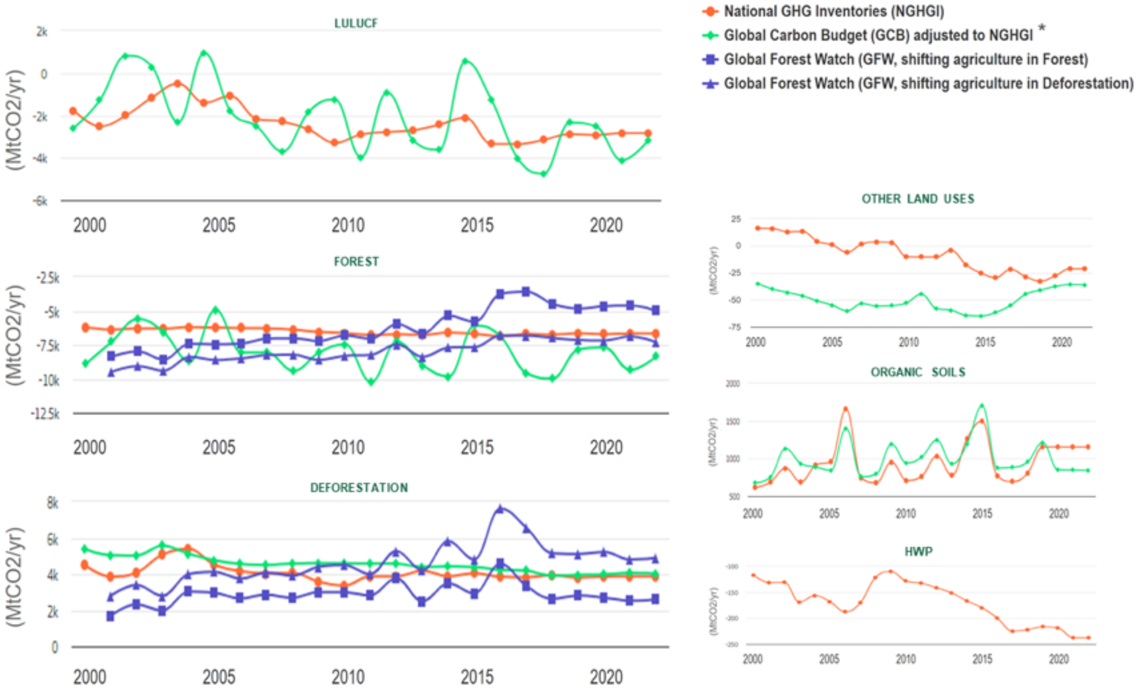


Figure. Global trend for the period 2000–2022 of CO_2 fluxes for the various land uses and land-use change (LULUCF) classes (Forest, Deforestation, Other land uses, organic soils, harvested wood products) from: 1) the aggregation of NGHGIs (orange); 2) the Global Carbon Budget (GCB, green, * Forest fluxes from the GCB are adjusted to the NGHGI definition of human-induced CO2 sink using the methodology from Grassi et al. (2023), which adds the natural sink from dynamic global vegetation models occurring on managed lands to the Forest CO_2 flux from bookkeeping models - only in classes Forest and LULUCF); and 3) the Global Forest Watch (GFW, blue, with gross emissions from forest disturbances and gross removals by standing and new forest recombined into Forest and Deforestation (including organic soils), and the allocation of CO_2 fluxes due to shifting agriculture either shown in the Forest or Deforestation class for comparability with NGHGIs). European Commission (2024).

Annex 4c: Slides from BOGs

Below is the text from the BOGs slides presented in the plenary.

DAY 2 – BOG 1

BOG1 consisted of three groups with a balanced representation of the various communities.
The following guiding questions were provided to stimulate the discussion:

- Remaining clarifications on previous 1.5 day
- Wish list of information for understanding better what other communities do
- Wish list of data (and timelines) that other community could provide and improve your estimates
- Solutions for harmonization for other community

BOG 1A

Co-chairs: Sukumar Raman and Jo House. Rapporteur: Luis Panichelli

Points of clarification

- How models are including indirect (natural) effects
- Carbon budget: historical vs. remaining
- Net vs. Net CO_2 estimates in models
- Communities: Include Statistics

Solutions for what? What is the common goal?

- Identify sources and sinks to further mitigation action
- Is there flexibility in each system to change and what is it? What incremental progress is feasible?

Translation between models, inventories, EO, Statistical approaches

- What is the purpose of different approaches?
- Full alignment not possible BUT opportunity for Rosetta Stone / transparency
- Basic steps of each approach
- Direct comparison of approach to:
  - Definition and terminology, e.g., forest, activity, managed land, shifting agriculture
  - Scales, spatial and temporal. If considered, what resolution and what time periods
  - System boundaries
  - Change in activity vs. biomass vs. flux
  - Methodological approaches by countries and models and EO, etc.

Data wishes

- Spatial as far as possible
- Area of land under different cover types—different cartographies and uncertainties
- Area of land under different activities
- Contribution of different activities to flux on forest land remaining forest land, e.g., industrial harvest or other activities

Practical approaches to moving forward

- Country-based RECAAP-type exercise with modelers, RS, and inventory compilers working together

- Stepwise exercise: UNFCCC help identify which tier of methods a country is using and whether spatially explicit. Next focus on carbon stocks. Next focus on activities
- Models/EO/statistical approaches—provide similar report to BTRs at the same time

BOG 1B

Co-chairs: Thomas Gasser and Mark Howden. Rapporteur: Roberta Cantinho

Points of clarification

- What questions are we trying to answer?
    - We could all move together to improve data (Definition of forest/Managed land...)
- What are the risks if we don't reconcile?
    - Wrong impression to decision-makers and our targets (clear narrative across communities would help to improve communication)
- The National Inventory is not supposed to change its methodology; but the models could bring information to compare as they could be more flexible.

Wishlist

- Identify overlaps that could benefit each other
- Translation between the different communities to better comprehension and integration
- Producing diversity data that could be combined to generate comparable results
- Difference between anthropogenic and natural
- Publicly available database (for all communities)
- Metadata available (for all communities)
- Availability on spatial-specific information of the NGHGIs
- Permanent plots to have more information (age distribution, growth, difference from wood production to managed)
- Template/Checklist for all communities

BOG 1C

Co-chairs: Sonia Seneviratne / Douglas MacDonald. Rapporteur: Clemens Schwingshackl

Points of clarification

Initial discussions aimed to clarify aspects of the plenary presentations. Participants agreed that understanding and communicating the differences between the estimates by the different communities was critically important. However, they also sought clarification on the objective of the meeting and assurance that it would not result in changes to guidance on reporting emissions. It was noted that national capacities are very different and that should be considered in attempting to reconcile the estimates from the different communities. The question of who the meeting outcomes were targeting was also important to the participants, whether to better inform the authors of the next Global Stocktake or national policy makers.

The modelling community sought clarity on the underlying assumptions of NGHGIs, how emissions and removals are compiled and application of the managed land proxy in NGHGIs. Inventory compilers sought to better understand how uncertainty was considered in modelling analysis and questioned the concept of CO_2 fertilization. Inventory compilers noted that it was not possible to directly measure CO_2 fertilization and that the term may be misleading and represent a summation of a wide variety of processes. The communities agreed that knowledge gaps included lateral transport, belowground carbon and consideration of climate disturbance in projections.

Wishlist

The three communities developed a list of information that they required to better understand other communities estimates of emissions and removals. The communities agreed that:

- A protocol was required that established mutually agreed definitions for specific terms used in analysis and sign conventions for communicating sinks and sources.
- Improved information as to how countries define managed land, maps of managed land and why it is considered managed,
- Improved transparency related to: calculations of uncertainty,
- Modelling assumptions, processes included and excluded and
- Management and fertilization history.

Participants identified the type of data that they could share to improve mutual understanding among the three communities including the need for:

- Disaggregated data differentiating i) different types of management (e.g., intensive vs. extensive), ii) forest age classes and growth rates, iv) natural disturbances and iv) shifting cultivation.
- A shared database for emissions and removals and disaggregated carbon flows and to share National Forest Inventory data (particularly for the remote sensing community) and gridded data on fluxes was expressed.

Solutions

In summary, the BOG 1C participants highlighted as solutions the need for a common glossary and a protocol for the development of model estimates in parallel with NGHGIs. Further, they recognized the quantity of information already exists, but highlighted the importance to organize it and make it accessible for all. The TFI, IPCC, JRC, and the Global Carbon Project were mentioned as potential entities that could perform this organizational task. Finally, the communities identified the need for continued collaboration, suggesting small groups from different communities working together on smaller scale projects to improve the understanding of the differences between the different quantification tools and analyses.

DAY 3 – BOG 2

BOG2 consisted of three groups separating the communities (GHG inventories – BOG2A; Earth Observation – BOG2B, and global carbon modelling – BOG2C) to discuss challenges ahead and realistic concrete improvements that each community can realize in the next 3-4 years to advance towards reconciliation for IPCC AR7 products and the 2nd Global Stocktake.

Examples of topics were provided to help stimulate the discussion:

- NGHGIs: information on managed land (including implications of reporting all land as managed or not), shifting agriculture, transparency on methods and coverage, tier-3 methods to separate effects? etc.
- Earth Observation: time series consistency, spatial resolution, use/accessibility of ground data, validation, masking results with managed areas, etc.
- Bookkeeping models / DGVMs and IAMs: better representation of management, forest maps, harmonization anthropogenic and natural fluxes (loss of additional sink capacity), etc.

BOG 2A (National GHG inventories)

Co-chairs: Stephen Ogle, Yasna Rojas, Thelma Krug. Rapporteur: Rizaldi Boer

General points

- Information on managed land
- Level of disaggregation of estimates

- Interannual variability
- Natural disturbance extends to which methods capture the different drivers/effects
- Use of tier 3 method
- Verification

Main points of the discussion

- Misunderstanding between the two communities
    - GHGI does estimation, not accounting
    - It is important to have a brief summary of the GHG Inventory, IPCC Guidelines, and process of the UNFCCC in the report of this meeting
    - Accounting of emissions and removal rules for commitment to achieve the NDCs target is done by UNFCCC
- Limitations in the data, limitations of the assumption, and process in GHGI and in the modelling
    - Tier 1, Tier 2, and Tier 3 are different with increasing complexity and country's specificity
    - Tier 3 may use a processes-based approach which is similar to the global carbon modelling community
- Level of disaggregation
    - What kind of disaggregation (e.g., by process, by land cover depends on Tier)
    - Indirect/natural versus direct anthropogenic emissions and removals are not possible to be disaggregated generally in the GHG Inventories, particularly when using emission factors
    - Emissions from natural disturbances may be disaggregated from the total, but the total must be reported. Decisions about accounting are made in the UNFCCC process, not in the IPCC Guidelines
    - If we could disaggregate, how could we verify the direct human-induced and indirect/natural emission with observations?
- Improve transparency on the criteria used to define the managed land, including the implication for selecting the criteria for defining the managed land on the emission and removals
    - Broad definition of managed land across countries may include production, ecological, and social functions (e.g., conservation areas may be considered as managed land for ecological purposes). This is potentially a grey area in treating lands in the global carbon model
- GHGIs are not always complete, but Inventory compilers do improvements over time to address limitations and gaps in the operational system (e.g., harvested wood may not be captured by the current data compilation system, such as illegal logging and also changes of the EF from Default into more CS, etc.)
- A smaller group among the three communities to discuss the approaches in more detail to gain a better understanding
- Regional studies to do more in-depth comparison between the global model and GHGI possible through RECCAP or new mechanisms
    - May involve joint protocol and provide basic information by *report card* to share between the communities about their approaches
    - This needs to take into consideration confidential data and how it can be shared
- Participants from the BOG-A do not expect changes to the IPCC GLs from this meeting as it will require a request for a change from parties to UNFCCC

BOG 2B (Earth Observation)

Co-chairs: Luis Aragão, Alessandro Cescatti. Rapporteur: Martin Herold

General points

- EO community - important role in linking between models and GHG-I, between national and global etc.
    - Reconciling definitions/concepts (forest definition, managed land,...)
    - Reconciling on level of data and estimates
- In any harmonization and reconciliation process - transparency, estimating and considering uncertainty, and open source and open data is key and EO community fully commits to that
- We proposed eight areas of work by 2028

EO community to engage with countries

- Support countries and facilitate uptake of useful tools and techniques for national LULUCF monitoring and estimation in countries, sharing information and experience, improved guidance, capacity development
- Incorporating EO data and products in national monitoring has its challenges (which data/why, impact of uncertainties, need for consensus) -> several ongoing capacity building initiatives that can be built upon (i.e. FAO, GFOI, NASA ...)
- We had limited country representation in our session

EO to support (global) modelling

- Bookkeeping models: activity data, regrowth curves ...
- Inversion modelling: EO-based spatial AFOLU flux to link with inversion models, i.e., become part of G3W
- DGVMs:
    - Additional model parameters that could be provided, emerging traits, leaf biochemistry/water, productivity (i.e. SIF),...
    - How new EO-based land use can be transformed in long-term change history data?
    - Need to better discuss opportunities so models can make better use of EO, i.e., for topics (using hyperspectral and LIDAR etc.) – make use of "supersites" (i.e., flux-towers) for benchmarking
- Include forest demography in modelling
- Make use of data-driven modelling (AI) to link data and models (potential black box)

Provide land change/activity data

- Progress is expected for the Landsat/Sentinel era
- Different forest disturbance (and regrowth?) products – needs a comparative analysis
- Land change (6 IPCC classes):
    - Understand different data change definitions/concepts and needs to harmonize (for our purposes)
    - Independent accuracy analysis for evolving global datasets for "change"
    - National case studies
- Land use change vs. land management – aim to provide more detail (crops/rotations, pastures, soil dynamics) but there will be limits
    - There are trade-offs for different temporal precision/timing of change: land use change vs. land management

From land change to emissions and removals

- Biomass/carbon stocks estimates – many new/recent sensors and improve quality, issues to go back in time when the quality of EO sensors were not there
- Make use of new opportunities to engage with ground monitoring community
- Emission and removal factors:
    - For both A/Reforestation and for forest disturbance/degradation and regrowth (i.e., space for time approaches)
    - Make use of disturbance history/forest age datasets to develop regrowth curves – different approaches are developing
    - Dialog with bookkeeping models in particular

- Carbon stocks, emission/removal factors and LULUCF sink and source estimate are produced by countries, models and EO – facilitate a comparison as important means to understand differences

Uncertainties

- Provide and make use of accuracy assessments and uncertainty layers for all products and estimates
- Independent verification (i.e., fake AI)
- Accuracy vs. precision – prioritize accuracy over precision?!
- Time-series consistency
- Be clear on general EO limitations: What is a "direct" observable and where EO is more of a proxy to extrapolate? – we cannot help much with monitoring CO2 fertilization effects

Improve communication and engagement

- Full support the JRC-hosted land use flux hub – key global platform to collect and compare – noting that more will come and comparison will become more detailed and specific
- Support and community-consensus discussions and work more as community to provide "one voice"
- Transparency, open source and open data throughout

Key activities until 2028

1. Provide data and expertise in reconciling definitions, concepts (forest definition, managed land,...) and estimates
2. Improve (global) activity data (6 IPCC classes) and "some" land management types, including national case studies
3. Carbon stocks, emissions and removals: facilitate a comparison to understand differences in stocks, factors, sinks and sources in models, EO and GHGI
4. EO-based, spatial LULUCF and/or AFOLU flux data/estimation
5. Provide and make use of accuracy assessments and uncertainty layers for all relevant products and estimates
6. Expand work with countries and LULUCF experts for the uptake of EO in national estimation and reporting
7. EO to support (global) modelling – different pathways
8. Improve communication and engagement

Feasible improvements in the next 3-4 years to advance towards reconciliation for IPCC AR7 products and the 2nd Global Stocktake

- Improving communication
    - Transparency (codes, comparison, assumptions)
    - Robustness of time series
    - Limitations (retrieved vs. derived with models)
    - Uncertainty/consistency (precision accuracy). Related also to accessibility to ground data
    - Improve consensus within EO community
    - Platform to improve communication and bi-directional exchange with Inventory and model communities (training, discussion etc., connected with EUFOR at JRC/GEO)
    - Dialogue with other communities (bookkeeping models, inventory, DGVMs) to understand needs/will/capacity to uptake EO products.
- Use/accessibility of ground data (role of WMO), verification
- Masking results with managed areas
- New possibilities/risks from emerging technologies (fake AI)
- EO to play an increasingly important role
- EO to help reconcile definitions (e.g., forest area, managed area)
- EO to parameterise models (growth and mortality)

- EO to improve inverse modelling
- EO to facilitate access to technology for countries (EO, AI models)
- Improved ingestion of EO in the production of data for and with other communities
- Activity data (land cover/land use/change IPCC categories) — Harmonisation, definitions
- Robust change detection (area, biomass, disturbance)

BOG 2C (Global carbon models)

Co-chairs: Julia Pongratz and Matthew Gidden. Rapporteur: Mike O'Sullivan

Underlying agreement

- We continue with different definitions (including in IPCC AR), each approach has their justification - but operationally translate, improve and evaluate at the national level.
- (A key next step will be to ensure the country's ambitions align with both definitions - but this was not part of this week's meeting.)
- The BOG aims at defining concrete steps forward on better communication and understanding.

Requests for additional information that should be available

- NGHGI:
    - (Disaggregated) information on area (and maps) of managed land
    - Disaggregate forest remaining forest flux
    - Report harvest (in addition to HWP)
- NFI data available at a non-localised scale
- NFI community has resources to respond to data requests (at aggregated levels)
- Create taxonomy of reporting and accounting across countries - clear definition of what is/isn't included → for us to implement in models
    - Ongoing activities (like map of which countries use MLP)
- Next steps: everyone to (seek)/provide the information!

Transparency & communication.

Much of the information requested already exists - communication is the main issue!

- Examples: GCB provides national level data and component fluxes matching NGHGI definitions. Many model codes are open source - but remain "black boxes." Information on model's activity data is published.
- Next steps:
    - Common protocols where they do not already exist, but working with certain data/models will always require the author's help - resource issue. Try to alleviate by…
    - … glossaries, simple-language explanations of which publication cover what question
        - and keep to them to provide exactly the same variables for comparison
        - and make sure this time TFI is included early on
    - TFI to provide a communications team

Process understanding

- Does CO2 fertilization fully explain the discrepancy? Is it that simple?
    - Model development a continuous process -> We know it is uncertain - again can we better communicate these uncertainties?
    - Forest mortality. Below ground. Litter representation (impacts for fire regimes).
    - LASC

    - Climate disturbance. To include or exclude? In reality, we cannot separate climate change and natural variability. Which indirect effects to include and why? -> Need clear information on what each country does.
- Next steps:
    - Update calculation of “indirect” sink in Global Carbon Budget - corrected land cover - “S2.5”
    - RECCAP3 - Toward country level budgeting. Rely on country specific information and interactions with inventory teams
    - Not just data exchange required, but expertise and communication
    - EO constraints on disturbances (and regrowth)
    - Use the “S3” simulation - all drivers included - but need greater disaggregation from DGVMs

Requests for additional progress

- Bookkeeping models (BMs) & IAMs to implement country-specific information (e.g., regional BMs/IAMs)
    - Next steps: Seek individual collaborations - high willingness, but requires funding
- Models and NGHGI to compare and improve at the national level
    - Successful collaborations exist, incl. RECCAP, Norway - funding agencies to encourage this interaction
    - Next steps: Step change requires a dedicated funded project to do this across a substantial number of countries
- IAMs to simulate feedbacks endogenously
- DGVMs (and BMs) to implement managements/policies
- DGVMs to take out replaced sources/sinks
- NGHGI to provide more complete reporting of disturbances (or do they already?).
- Linking CO2 removal (CDR) definitions and LULUCF fluxes
    - E.g., time of removal through photosynthesis (LULUCF flux) does not match transferral to durable HWP pool (CDR definition)
    - Next steps: Trust CDR task force to get it right

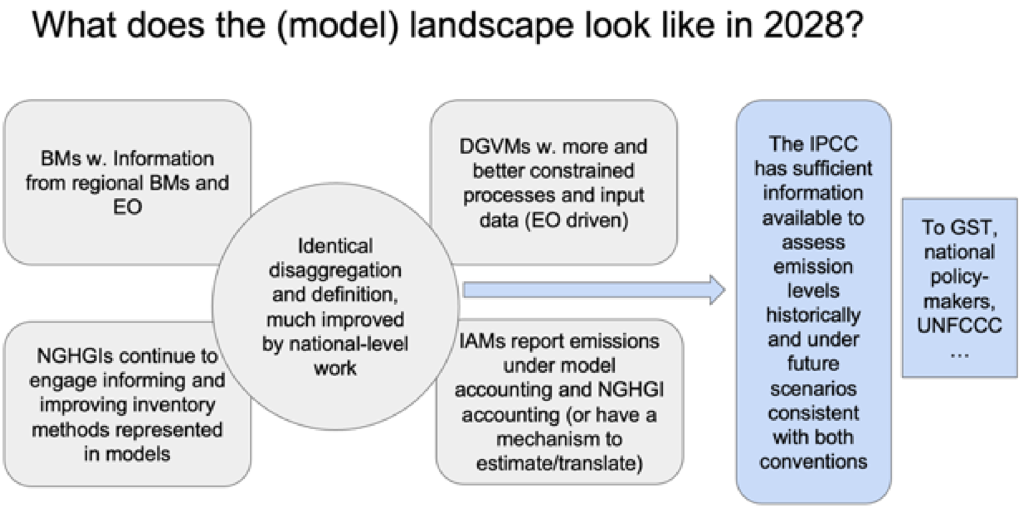


Figure: What does the (model) landscape look like in 2028? (BOG2C: Global Models)

DAY 3 – BOG 3

BOG3 consisted of three groups with a balanced representation of the various communities. The following guiding questions were provided to stimulate the discussion on the “communication challenge”:

- How to explain the implications of any reconciliation ?
- Clarifications if needed: How “big” is the problem? Which are the implications?
    - Effect on the remaining carbon budgets for various levels of warming,
    - Emission reduction rates needed (for various levels of warming)
    - The net zero CO2 emission concept
    - The timing of global net zero CO2 emission (for various levels of warming)
    - The need for globally net negative CO2 emissions
- Who are we communicating this to? UNFCCC / COP /GST, “IPCC communities”, various scientific communities, national level policymakers, sub-national policymakers, other stakeholders.
- What are the risks of misunderstanding/misusing any reconciled estimates, from the scientific community and for countries?

BOG 3A

Co-chairs: Jan Fuglestvedt and Robert Matthews. Raporteur: Joana Portugal-Pereira

More work is needed to better understand different communities (NGHGI, various modelling communities) before communicating to policymakers

- Improve transparency in reporting, definitions and assumptions (natural/climate disturbances) to better understand the magnitude of the issue
    - NGHGI: Eg: Reporting exercises in national BTIs (reporting tables) will feed into the GSTs; Be clear about the purposed of the reporting
    - Modelling: 1. More disaggregation of data inputs and results; 2. Adopt clear strategy to explain modelling results and its boundaries -> “simple but not simplistic” 3. Report explicitly remaining C budget as FF/land
    - IPCC bureau: reinforcing WGs communities & TFI since the early start of the cycle; Common glossary in AR7, including TFI; x-WGs/TFI boxes
- Some of the proposed actions are already being addressed, but there could be better dissemination

We need to seriously consider implications for climate negotiations

- Global level:
    - Might not be very significant: NZE CO_2 emission target may shift slightly ~5 years onward
- National Level:
    - May be very large, especially in parties with large land sinks
    - Implications are time dependent (risks related to fragility of sinks)
    - Equity issues

We need to avoid miscommunication

- We need more clarity about the size of the issue and *if there is an issue at all*
- We need to get the language right
- At national level, may raise equity issues
- If we are not careful, we may gridlock global climate negotiation efforts
- Risks of non-communication:

    - Lack of credibility
    - More confusion
    - Hinder progress
- Bring Communication Experts onboard to support in passing the right message in a positive way to avoid miscommunication and misinterpretation of scientific findings
    - Immediately -> GCP (?)
    - Short-term -> IPCC AR7 products
    - Can this expert meeting report be a good starting point and feed into the AR7 scoping meeting?

BOG 3B

Co-chairs: Maria Sanz and Oliver Geden. Raporteur: Keywan Riahi

- Communication needs to carefully consider risks and avoid misunderstanding and misinterpretation
    - Efforts have been made already to reduce the uncertainty – now, need to further reconcile estimates
    - Communicate that despite uncertainties, there are a number of issues that are robust and would not change: *CO_2 Emissions need to drop (and reach net zero), budget remains tight for keeping warming to well below 2°C, etc…*
- Communicate to the modelling community to report emissions outcomes that would be as close as possible to the inventories
    - Critical now as the next generation of scenarios developed for AR7
    - Does not mean that models need to be recalibrated, but reporting needs to improve with alternative assumptions
    - Uncertainties need to be incorporated and quantified: e.g., carbon budget under different assumptions
- Collaboration needs to continue to solve the issues → important to enable translation across approaches → increase confidence that the national targets are consistent with the science behind the Paris Agreement
- Communicate to all communities the data reporting needs to make things comparable
- Need to improve our understanding, but at the same time uncertainties seem not dominant compared to other uncertainties
- Communicate better different parts of the flux (not only the aggregated net flux, but decompose into the components: direct and indirect sink, deforestation, thinning/management, different types of disturbances,…)

BOG 3C

Co-chairs: Thelma Krug and Andy Reisinger. Raporteur: Jo House

- Communicate to who, why?
- Discussed language (no particular consensus): Reconcile, harmonise, map, align,…
- Common/adjacent glossaries and translations and clearer communication of different communities' methods/approaches/purpose
- Stop saying "science" and "inventories" as inventories are science based, use science, produced by scientists. E.g. Global methods/approaches (models EO) vs country reporting methods/approaches

Communities we may communicate with

- global policy makers/global stocktake

- national policy makers and practitioners developing NDCs, NGHGI compilers, national BTRs
- Inventory support organisations – e.g., that support countries to do develop their NDCs, do inventories, do BTRs and supporting countries to improving their methods towards higher tiers, and towards spatial approaches and completeness.
- Carbon dioxide removal projects and markets (article 6.4, voluntary markets, emission trading schemes) – recognising different spatial and sectoral boundaries along lifecycle of projects, often use the IPCC guideline methods, need to have confidence of markets, publics etc. Consider in context of ocean analogues.

How big is the problem and how to communicate it?

- Helpful to communicate scale of problem e.g. compared to other aspects/sectors e.g. fossil fuels /levels of countries ambitions globally
- Do analyses of including/excluding different processes and its influence on the outcome of the flux at different scales (global, national). IPCC can then assess these in AR7. Important when we are communicating around gap – to be clear what the boundaries of these analyses are. E.g., current day vs future at net-zero, country vs global
- Natural disturbances may change from source to sink in future, so reasons for the gap and size of gap may change according to assumptions/inclusion of climate/carbon feedbacks
    - Implications for “reconciliation” methods,
    - Helpful information to communicate to countries (and others)

Annex 5: Background paper

Annex 5.1. Global carbon models

Section 5.1.1: by Julia Pongratz and Clemens Schwingshack (LMU München), Stephen Sitch (University of Exeter); Section 5.1.2: by Detlef van Vuuren and Elke Stehfest (PBL Netherlands) and Thomas Gasser (IIASA).

5.1.1 Estimating the terrestrial carbon budget by global models

5.1.1.1 The global carbon budget

Accurate assessment of anthropogenic carbon dioxide (CO_2) emissions and their fate in the natural sinks of the atmosphere, ocean, and terrestrial biosphere is critical to understand the global carbon cycle, support the development of climate policies, and project future climate change. The global carbon budget contains five components. Sources include fossil CO_2 emissions (EFOS; estimated from energy statistics and cement production data) and the net flux of emissions and removals from land-use change and land management (ELUC; estimated by bookkeeping modelling, BM). The fate of CO_2, or the sinks are composed of the growth rate in atmospheric CO_2 concentration (GATM; measured directly), the ocean CO_2 sink (SOCEAN; based on global ocean biogeochemistry models and observations), and the terrestrial CO_2 sink (SLAND; based on dynamic global vegetation models (DGVMs)). The remaining difference between sources and sinks is termed the carbon budget imbalance (BIM), which is a measure for the current understanding of the global carbon cycle:

$$B_{\mathrm{IM}} = E_{\mathrm{FOS}} + E_{\mathrm{LUC}} - (G_{\mathrm{ATM}} + S_{\mathrm{OCEAN}} + S_{\mathrm{LAND}})$$

The Global Carbon Project presents estimates of all carbon budget terms updated to the current year as its “global carbon budget” (GCB) each year at the COP (Friedlingstein et al., 2023). A more detailed analysis is performed every few years under the REgional Carbon Cycle and Processes (RECCAP) project (Ciais et al., 2022).

The terrestrial carbon balance includes the two components ELUC and SLAND. ELUC comprises emissions from deforestation (including permanent deforestation and deforestation in shifting cultivation cycles), emissions from peat drainage and peat fires, removals from forest (re)growth (including forest (re)growth due to afforestation and reforestation and forest regrowth in shifting cultivation cycles), fluxes from wood harvest and other forest management (comprising slash and product decay following wood harvest, regrowth after wood harvest, and fire suppression), and emissions and removals related to other land-use transitions. Overall, the emission terms exceed the removal terms, such that net ELUC contributes about 10-15% of total anthropogenic CO_2 emission (fossil and land-use). The GCB estimates of ELUC are used widely, e.g., in the IPCC Assessment Reports of WG1 and WG3, the UNEP gap reports, and the State of CDR reports.

SLAND includes CO_2 fluxes in all – managed and unmanaged – ecosystems that result from environmental changes, such as rising CO_2 levels, climate variability and change, e.g. resulting in wildfires, or drought. It thus includes an “indirect” effect of human activity. A major difference between the GCB and NGHGI reporting is that in SLAND on managed land is classified not as natural, but as an anthropogenic flux in NGHGI, based on the managed land proxy (see section 5.2.2.4). Another source of frequent confusion arises from the term “natural land sink”, which refers to SLAND in the scientific community, but in the political language often refers to carbon dioxide removal options, i.e. direct anthropogenic activity. SLAND has been a strong sink globally in the past decades, taking up one quarter to one third of all anthropogenic CO_2 emissions.

In reality, ELUC and SLAND cannot easily be separated (three quarters of the ice-free land surface are under some type of use, and environmental changes are ubiquitous); their sum is termed “net land-atmosphere exchange”. Models need to be employed to separate ELUC and SLAND from each other. The rationale behind the definitions of SLAND and ELUC, which differ from NGHGI (see section 5.2.2.4), is to be able to separate carbon fluxes by drivers. The separation into drivers is necessary for process understanding and makes it possible to identify the individual levers for reducing emissions and increasing natural sinks, which are both important for guiding land-use decision-making towards net-zero emission goals. In a carbon cycle model, ELUC is treated as an input into the system (like fossil CO_2 emissions), while SLAND is a feedback (response) of the system. Thus, as the human drivers change (EFOS and ELUC), the carbon cycle responds (SLAND changes). This separation leads to important scientific findings, such as the near linear relationship between temperature and cumulative emissions and the concept of net zero CO_2 emissions.

5.1.1.2 ELUC from bookkeeping models

CO_2 emissions and removals from land-use change are often calculated by bookkeeping modelling. These models follow a semi-empirical approach with the advantage of high traceability of results that makes attribution of fluxes to drivers easily possible, a high level of possible disaggregation into component fluxes, and the opportunity to include observation-based information. The bookkeeping approach was developed by Houghton (1983) and keeps track of the carbon stored in vegetation and soils before and after a land-use change event (transitions between various natural vegetation types, croplands, and pastures) (Fig. 5.1.1). Literature-based response curves describe the decay of vegetation and soil carbon, including transfers to product pools of different lifetimes, as well as carbon uptake due to regrowth of natural vegetation. In addition, bookkeeping models can represent long-term degradation of primary forest, and include forest management practices such as wood harvests. In the current approach, carbon densities remain fixed over time to exclude the additional sink capacity that ecosystems provide in response to environmental changes (Pongratz et al., 2014).

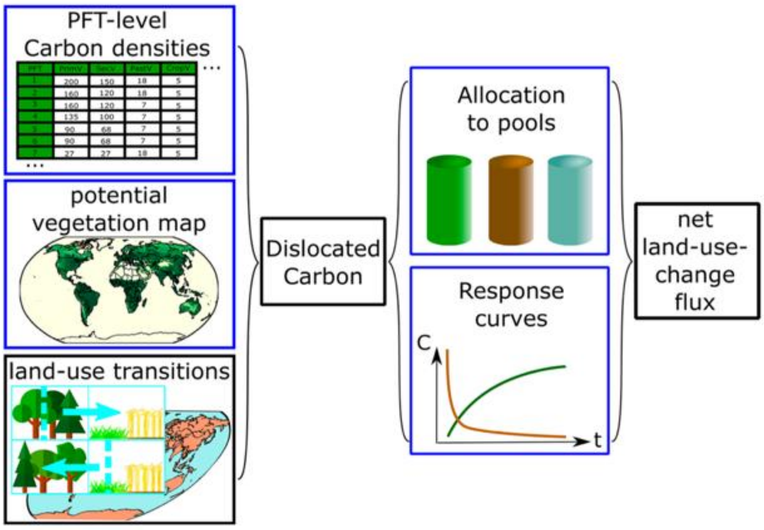


Figure 5.1.1: Schematic description of a typical bookkeeping model, using here the bookkeeping model BLUE as an example (figure from Bastos et al., 2021). Plant Function Type (PFT).

Three bookkeeping estimates are used in the latest GCB: one based on the Bookkeeping of Land Use Emissions model BLUE (Hansis et al., 2015), one using the compact Earth system model OSCAR (Gasser et al., 2020), and an estimate published by Houghton and Castanho (2023; hereafter H&C2023). The bookkeeping models differ in (1) computational units (spatially explicit treatment of land-use change at 0.25° resolution for BLUE, country-level for H&C2023 and OSCAR), (2) which and how land-use processes are represented (e.g., shifting cultivation), and (3) carbon densities assigned to vegetation and soils for different types of vegetation (literature-based for BLUE and H&C2023, calibrated to DGVMs for OSCAR).

To run their simulations, the bookkeeping models use information on changes in land use and land management from two different datasets. The harmonized land-use change dataset LUH2 (Hurtt et al., 2020; Chini et al., 2021) provides data at 0.25° spatial resolution. LUH2 expands the time series of agricultural (cropland and pasture) area from the History Database of the Global Environment HYDE3.3 dataset (Klein Goldewijk et al., 2017a, 2017b; which itself is based on Food and Agriculture Organization (FAO) agricultural areas) by including information on sub-grid scale transitions. Additionally, LUH2 uses wood harvest data from the FAO. To estimate ELUC for the GCB, BLUE uses LUH2, H&C2023 uses FAO directly, and the OSCAR estimate is an average of simulations based on LUH2 and FAO. Fig. 5.1.2 shows GCB2023 results for ELUC component fluxes.

The usage of land-use change datasets (LUH2 and FAO) allows tracking of changes in area and the state of natural ecosystems, facilitating a separation between the driver of change and the response. If observations were used directly, e.g. forest inventories or changes in biomass stocks observed by satellites, indirect effects from environmental conditions would be included, and it would not be possible to clearly distinguish anthropogenic from natural drivers.

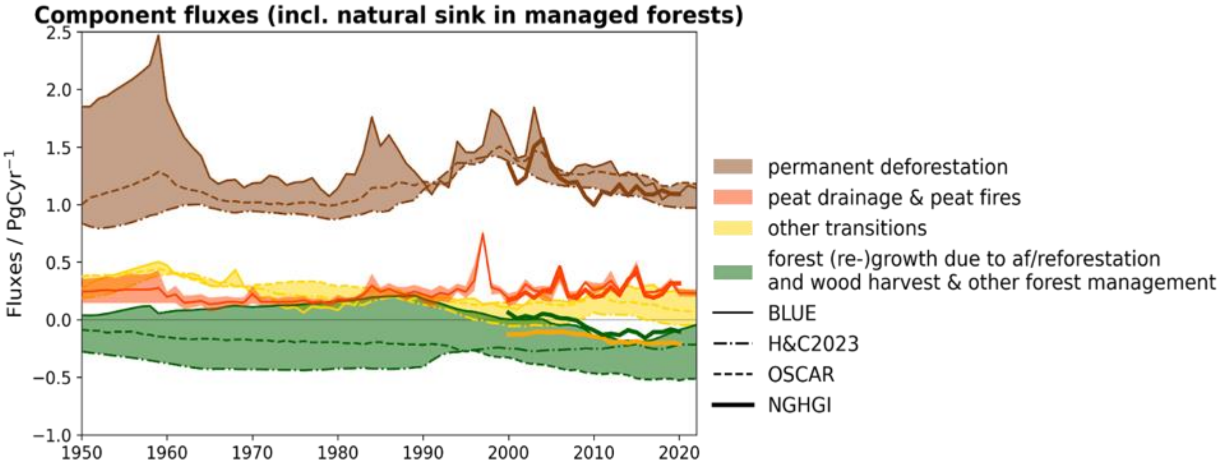


Figure 5.1.2: Various ELUC component fluxes for the three GCB2023 bookkeeping models (shown since 1950, but data available from 1850 onwards). Emissions from peat drainage and peat fires are added from external datasets (see Friedlingstein et al. 2023). The NGHGIs are shown for comparison, for the period 2000-2020. Net ELUC estimated by bookkeeping models amounts to 4.7±2.6 $GtCO_2$ (1.3±0.7 GtC) per year for 2013–2022. © C. Schwingshackl.

5.1.1.3 SLAND from DGVMs

DGVMs are process-based models that estimate terrestrial CO_2 fluxes. They consider vegetation growth and mortality, as well as decomposition of dead organic matter associated with natural cycles. Most DGVMs explicitly simulate the coupling of carbon and nitrogen cycles, but the representation (and level of detail) of other processes strongly varies across models (Blyth et al., 2021; Friedlingstein et al., 2023). Many DGVMs also act as land surface schemes of Earth system models used for weather prediction and climate projections.

A key purpose of DGVMs is to simulate the response in vegetation and soil carbon, expressed as the net biome productivity (NBP), to trends and variability in environmental conditions. To this end, DGVM simulations require environmental forcing data. Typically, they are driven by observation-based data on atmospheric CO_2 concentration, climate variability and change (including spatial-temporal fields of temperature, precipitation, radiation), and nitrogen deposition. For a realistic simulation of the terrestrial carbon balance, changes in land-use also need to be taken into account (usually using the LUH2 dataset). However, in this simulation it is impossible to separate anthropogenic and natural fluxes. Thus, SLAND is derived from a simulation without land-use change using a pre-industrial vegetation distribution from the year 1700. This has the caveat that the natural land sink is overestimated because the pre-industrial forest cover was substantially higher than it is today (Dorgeist et al., subm.). The difference between the two simulations with and without land-use change is used to derive an uncertainty estimate around the ELUC estimate of the bookkeeping models. DGVM data are not directly used to quantify ELUC because of the confounding effect of the “loss of additional sink capacity” (of 0.4±0.3 GtC yr-1 in the last decade; for details see Obermeier et al., 2021). Fig. 5.1.3 shows the GCB2023 estimates for SLAND.

An international ensemble of DGVMs under the ‘Trends and drivers of the regional scale terrestrial sources and sinks of carbon dioxide’ (TRENDY) project quantifies each year carbon fluxes for the GCB and for RECCAP, with all DGVMs following a common protocol (Sitch et al., in press). A set of factorial simulations allows attribution of spatio-temporal changes in land surface processes to three primary global change drivers: changes in atmospheric CO_2 concentration, climate change and variability, and land-use change. Only models that simulate a positive ELUC during the 1990s are included in GCBs.

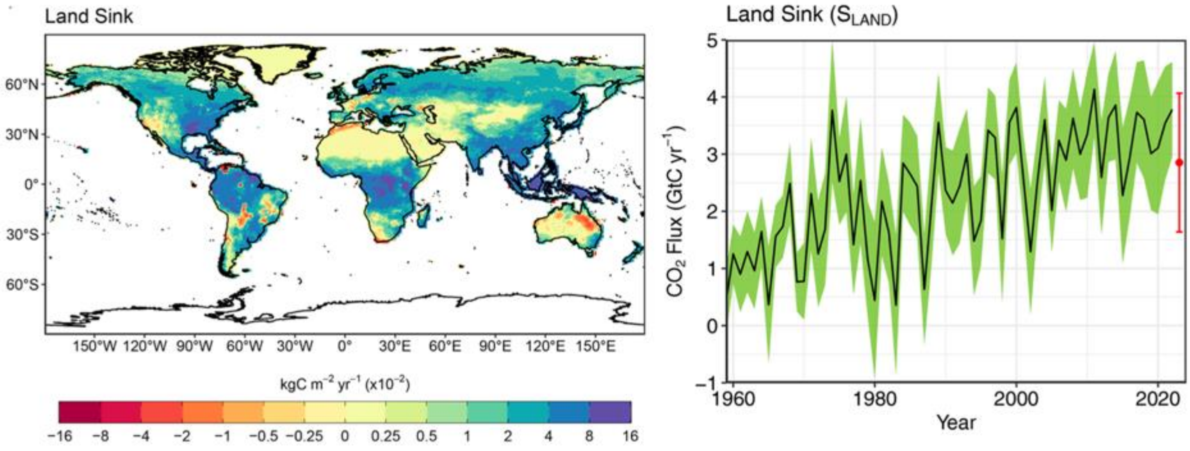


Figure 5.1.3: SLAND averaged over 20 DGVMs from the GCB2023. Left: decadal average 2013–2022, right: time series (mean with standard deviation across DGVMs). Positive values are fluxes from the atmosphere to land (i.e., a sink), negative values a source. SLAND amounts to 12.3±3.0 $GtCO_2$ (3.3±0.8 GtC) per year for 2013–2022 (figure from Friedlingstein et al., 2023).

5.1.1.4 Linking ELUC, SLAND and NGHGIs

Sections 5.1.1.1 to 5.1.1.3 presented the scientific ELUC definition as used by global carbon cycle models, which counts fluxes due to environmental changes on managed land towards SLAND. This is in contrast to the national greenhouse gas inventories (NGHGIs), most of which include fluxes due to environmental changes on managed land in their LULUCF flux estimates. Thus, NGHGIs often report significantly lower land-use emissions than bookkeeping models (Grassi et al., 2018; Petrescu et al., 2020). A translation between the bookkeeping and NGHGI estimates can be achieved based on the methodology of Grassi et al. (2018, 2023), using natural fluxes (SLAND) on managed land estimated by DGVMs and maps of managed forest. Harmonized (or conceptually 'reconciled') estimates of the bookkeeping modelling and NGHGI approaches are now routinely provided (Friedlingstein et al., 2023; Grassi et al., 2023), including at the country level (Schwingshackl et al., 2023).

5.1.2 Integrated Assessment Models and representation of land use

5.1.2.1 General description and types of IAMs

Integrated assessment models (IAMs) aim to represent the interaction between the economy, society, and the environment to support environmental policymaking. They typically include a description of human activity (such as energy and agriculture), direct drivers of environmental change (e.g., emissions, land use, and resource use), environmental change processes (like the carbon cycle, climate change, and pollution), resulting impacts (e.g., consequences for crop yields), and response options (e.g., diet change or investments in yields). The most common use of IAMs is in the field of climate mitigation, through the generation of scenarios representing climate action (from no action to the 1.5°C goal) under a broad range of assumptions about future socio-economic, institutional, and technological developments.

A broad range of IAMs exists, differing in their core topic, level of detail, type of representation, relationships with various disciplines (leaning towards economics or engineering), solution concept (optimization versus simulation), and temporal and spatial system boundaries (particularly global versus national scope). A set of IAMs, such as DICE, MIMOSA, and FUND, are primarily focused on optimizing the costs and benefits of climate policies, often with little detail in the representation of the processes involved. Another class comprises the so-called process IAMs, like REMIND-MagPIE, MESSAGE-GLOBIOM, IMAGE, AIM, GCAM, and COFFEE, which typically include a considerably more detailed representation of energy and land use processes.

IAMs are also used in other fields, such as exploring how to meet biodiversity goals, adapt to climate change, and ensure food or water security. Regarding land use, IAMs primarily focus on land-based mitigation, food production, and biodiversity protection. This means that several critical themes can be found in the literature, such as the relationships between agricultural policies, climate mitigation, and hunger, or between ambitious biodiversity goals and land use in climate policies (e.g., reforestation). An overview of many IAMs can be found here: https://www.iamcdocumentation.eu/IAMC_wiki. See also (Popp et al., 2017).

5.1.2.2 Land use and agriculture

Land cover and land use form important elements of most IAMs, given their roles in climate change (as a cause, solution, and impact sector) and biodiversity loss. Some IAMs, such as MESSAGE-GLOBIOM, REMIND-MAgPIE, and IMAGE, have detailed agriculture-food systems, while others have a simplified land representation as an integral part of the overall model. The land use component of IAMs describes how land is used to meet the demand for producing food, fibers, timber, and energy, as well as providing space for shelter and nature. The representation of these processes can be at either the regional or gridded scale.

Modelling usually starts with the demand for products, including food. Food demand is affected by population size, income levels (at higher income levels, both the volume and composition of the diet change), and additional shifts in demand preferences. Demand is often also influenced by price changes resulting from supply-side dynamics. Most models compute demand and supply using an equilibrium economic approach, either general or partial. The supply side, i.e., the ability to produce agricultural products, is described as a function of labor, capital, technology, and natural factors. Increases in demand are thus met by increasing production, either through yield improvements (intensification) or expansion of agricultural land (extensification). Regions can meet demand domestically or through trade. Land use is typically described in terms of cropland, pasture, urban land, and natural areas (including different forest types). Supply and demand are usually modelled at a national or regional scale. Some models additionally apply downscaling to specify land use on a geographic grid, either as a post-processing step or as an integral part of the calculations, which also allows feedback. Land use for climate change mitigation (e.g., biofuel crops, afforestation) is typically driven by a coupled energy system model, whereby the coupling exchanges land available for land-based mitigation, prices, and the resulting demand. Mitigation of non-CO_2 emissions also affects land use, as abatement or carbon prices increase commodity prices and thus influence land use (see Frank et al., 2019).

The land use categories specified by IAMs typically include cropland, pasture, built-up area, forests, and other land. Cropland and pasture follow the definitions of the FAO, describing the physical cropland area and the grazing area as reported in FAO statistics. It should be noted that these categories do not always align with remote sensing products that allow for mixed land cover of cropland and other vegetation (see Doelman & Stehfest, 2022). This discrepancy needs to be accounted for when coupling IAM land-use data to ESMs or DGVMs. Built-up area in most IAMs is described for the present day, but only a few models project future built-up areas (in the IPCC scenarios, this has been corrected using projections from one model). The description of all other land cover classes is based on biome distribution maps, either static or dynamic, distinguishing vegetation into at least forest and non-forest natural vegetation that can potentially be converted to agriculture, as well as other lands. Within forests, models distinguish between managed forests and natural forests. However, the area of managed forest in IAMs is generally lower than that reported under UNFCCC reporting (Grassi et al., 2021).

5.1.2.3 GHG emissions from agriculture, land use, and land use change

IAMs IAMs calculate both CO_2 emissions from land-use change and non-CO_2 emissions from agricultural activities. We will discuss this briefly below. The IAM methods to calculate mitigation for non-CO_2 and CO_2 emissions, including afforestation, are also described in Roe et al. (2021). Table 5.1.1 provides an overview of several detailed IAMs regarding land use and related emissions.

CO_2 emissions from land. IAMs use a wide range of approaches to estimate CO_2 emissions caused by land use and land cover change. The models typically include both anthropogenic and natural CO_2 flows related to land. Conceptually, they align with the approach used in bookkeeping models, defining anthropogenic emissions only in cases of land use changes and sometimes additional forest management. The overall approach involves estimating the difference in equilibrium carbon stocks caused by the land use and land cover change between two of the model's time steps. The exact approach depends on internal assumptions and whether the IAM includes or is informed by a land carbon-cycle model. Key differences across IAMs are:

- Which carbon pools are considered? For instance, some IAMs provide carbon fluxes based only on changes in living biomass carbon pools, thereby ignoring changes in the dead biomass, litter, and soil organic carbon pools, while others provide comprehensive estimates.
- How carbon emissions are distributed over time? Most IAMs assume the difference in carbon stocks is emitted following a response curve that depends on the land use activity that triggers the emission (e.g., forest biomass regrowth) or on the pool itself (e.g., soil carbon equilibration). However, a few models assume immediate release of the carbon to the atmosphere, especially if considering only biomass.
- Whether carbon densities are fixed or change because of environmental conditions (such as atmospheric CO_2 and climate)? Most IAMs rely on fixed carbon densities (similar to most bookkeeping models), in which case the difference in carbon stocks used to estimate emissions is caused only by land use and land cover change. However, a few IAMs include transiently changing carbon densities informed by a vegetation model. In these cases, additional steps are required to exclude the natural response and isolate the carbon flux that is consistent with the bookkeeping approach. This can be done, for instance, by using a cut-off period after the conversion has occurred.
- Forest management. The CO_2 stocks in forest cells can also be influenced by forest management. The level of detail with which IAMs represent forest management varies significantly. Many models allow for afforestation, often assuming some form of active management. However, some models include even more detailed management categories.

Non-CO_2 emissions. Non-CO_2 emissions are typically calculated by multiplying agricultural activities with emission factors (Harmsen et al., 2023). For methane, this includes activities such as paddy rice production (measured in area, volume, or monetary production), use and management of manure and fertilizers, animal husbandry, biomass burning, and conversion of land cover types. Emission factors are usually derived from existing databases such as EDGAR, CEDS, or GAINS. This approach allows for the calculation of emissions not only for methane (CH_4) and nitrous oxide (N_2O) but also for a range of air pollutants. Emission factors are assumed to change over time due to technological developments and can also be directly influenced by climate policy.

Table 5.1.1 - Overview of several well-known IAMs with detailed land representation.

	AIM	GCAM	GLOBIOM	IMAGE	MAgPIE
Calculation level	17 regions nd 30'x30' grid	32 energy regions; 384 land use regions	37 regions and 30'x30' grid	26 regions + 5'x5' grid	12-16 regions, up to 2000 spatial units, downscaling to 30'x30' grid
Demand detail	7 crop types and 3 animal products;	24 crops: 7 animal commodities; Forest products, biomass for energy	18 crops, 8 animal products, finished & semi-fini forest products, biomass for energy	16 crop types and 5 animal product types, 5 bioenergy commodities; 4 wood products	16 food/feed crop types, 2 bioenergy crop types, 5 animal product types, 2 wood product types
Land use classes	Crop, intensive pasture, range-land, unmanaged forest, managed forest, natural land, build-up area and others.	Crops, Cellulosic biomass, Forest (managed and unmanaged), Pasture ; Grass, Shrubs, Desert (fixed), Rock/Ice/Tundra (fixed), Urban (fixed)	Cropland, grassland, short rot. plantations, managed forests, unmanaged forests, other natural vegetation land, urban (fixed), Rock/other (fixed)	Crop, intensive pasture, extensive pasture, managed forest; unmanaged forest, natural vegetation (14 biomes), built-up area, rock/other (fixed)	Crops, 2nd generation bioenergy crops, pasture and rangeland, timber plantations, re/afforestation, primary forest, secondary forest, other natural land, urban land
Forest management types	managed or unmanaged.	Managed and unmanaged, tree crops (softwood, hardwood)	short rotation plantations, managed forests	Clearcut, selective cut, forest plantations	Timber plantations with clear-cut after a certain rotation length. Selective harvest from natural forests.
Land-use change related CO2	Delta stock with fixed densities based on DGCM (VISIT). Instantaneous except sequestration (regrowth curve based on DGVM).	Delta stock with fixed densities. Instantaneous for above ground sources of CO_2 except afforestation (regrowth curve), but below ground gets emitted with a decay rate.	Delta stock with fixed densities. Instantaneous except afforestation (regrowth curve).	LPJml calculates all stocks and flows, for natural vegetation dynamics, and land use transitions. After a transition, net flux assumed anthropogenic for a number of years, then natural.	Carbon stocks based on LPJml (input data) are used to calculate annual emissions. Emissions include both direct anthropogenic and indirect natural / environmental effects.
CO_2 stocks included	Vegetation, litter and soil carbon	Biomass and soil	above- and below ground biomass changes, dead organic matter, soil carbon	LPJmL's carbon pools: Vegetation, litter and soil carbon (divided in different stocks)	vegetation, litter and soil carbon
Non-CO_2	Activity and emission factors (CH_4, N_2O) in combination with MAC curves	Activity and emission factors (CH_4, N_2O) in combination with MAC curves	Activity and emission factors (CH_4, N_2O) for different mgmt. systems in combination with MAC curves (explicit mitigation technologies)	Activity levels and emission factors (CH_4, N_2O) in combination with MAC curves	Activity and emission factors (CH_4, N_2O) in combination with MAC curves

5.1.2.4 Linkage with other climate research communities

From IAMs to climate models. ESMs and DGVM require patterns of land use and land cover change to simulate carbon fluxes caused by these perturbations in an internally consistent manner. There is a harmonization process that connects historical land-use reconstructions with future projections from IAMs in a format suitable for ESMs (Hurtt et al., 2020). This harmonization produces land use patterns, identifies underlying land use transitions, provides key agricultural management information, and predicts resulting secondary lands. The historical reconstruction seamlessly extends into the future based on land-use changes projected in IAM scenarios. The latest iteration also includes detailed information on multiple crop and pasture types, along with associated management practices such as irrigation and fertilizer use. The harmonization process applies definitions used in the historic land use dataset HYDE. Challenges can arise from differences in definitions between human and natural land use/cover. For example, ESMs and DGVMs often use a land cover approach based on remote sensing, while IAMs provide information on land use. Additionally, Simple Climate Models (SCMs) are used in the IPCC, calibrated to outcomes from complex climate models to evaluate a broader range of scenarios. SCMs have a simplified carbon cycle representation and therefore rely on land use CO_2 emissions estimated by IAMs as input. As part of the process, IAM data is adjusted to be consistent with historical emissions used in complex models. By design, this ensures that the land use CO_2 emissions provided as input to SCMs align with bookkeeping emissions. The overall consistency of the land carbon cycle—between prescribed anthropogenic fluxes and their natural responses—depends on each SCM's specific configuration.

From IAMs to UNFCCC. As described above, IAMs define land-use-related CO_2 emissions directly based on land use/land cover change, excluding natural processes such as CO_2 fertilization from this category. This means that the IAM estimates are aligned with emission inventories, which typically use a bookkeeping approach. The UNFCCC, however, uses a different definition in which the net uptake of CO_2 in managed forests can be accounted for as an additional sink. The difference between these definitions is quite substantial. Recently, both Grassi et al (2021) and Gidden et al (2023) used methods (either using IMAGE/LPJml or a simple climate model) to calculate land use emission data that is consistent with the bookkeeping models and the national inventory conventions. In mitigation scenarios, the difference between the two estimates decreases over time as the CO_2 stored in forests starts to reach equilibrium with atmospheric CO_2. As a result, the conversion has a strong impact on annual emissions and carbon budgets, but only a small influence on, for instance, the net zero year.

Annex 5.2. Earth Observation tools

By Martin Herold (GFZ Potsdam), Philippe Ciais (LSCE Paris), Alessandro Cescatti (Joint Research Centre).

5.2.1. Earth Observations for the estimation of LULUCF GHG fluxes

5.2.1.1 Satellite and ground data

Space-based Earth observations (EO) have been crucial in the monitoring and quantification of changes in the Earth system – from the build-up of greenhouse gases (GHGs) in the atmosphere, the rising surface temperatures and melting sea ice, glaciers and ice sheets, to the impact of climate extremes. In addition to documenting a changing climate, EO is needed for effective policy formulation, implementation and monitoring, and ultimately to measure progress towards the overarching goals of the UNFCCC Paris Agreement (Hegglin et al., 2022).

Many EO satellite sensors and platforms are currently available and operating in different modes (primarily optical, radar, thermal and LiDAR (Light Detection and Ranging o Laser Imaging Detection and Ranging) for monitoring and assessing critical changes in land systems at high spatial and temporal detail. They provide systematic and global information on land use and carbon changes for scientific assessments, Earth system modelling and the IPCC LULUCF (Land Use Land-Use Change and Forestry) and AFOLU (Agriculture Forest Other Land Use) sector estimation and reporting (Herold et al., 2019). Because of the space-time detail provided by EO datasets, they are increasingly used for supporting climate policies and actions with 1) timely information to regularly assess performance and compliance, and adjust policies if needed, 2) spatial distribution of carbon stocks and fluxes related to LULUCF and 3) specific locally-relevant data and information on land use and GHG for the implementation of climate actions (i.e. improved land management) to enhance transparency and accountability.

Different space-based missions have been or are operating for such purposes and provide both long, consistent time series (30+ years) and timely information (weekly/monthly updates) on land cover/use, land management and changes (i.e. deforestation, agriculture crop types), land use type characteristics (extent/area, height and structure) and their related biomass and changes (Fig.5.2.1). The long-term, sustained and open-source availability of global satellite time-series by programs like USGS/NASA Landsat and European Copernicus provide the main foundation for climate -related land use monitoring historically and for the near future (Ochiai et al. 2023).

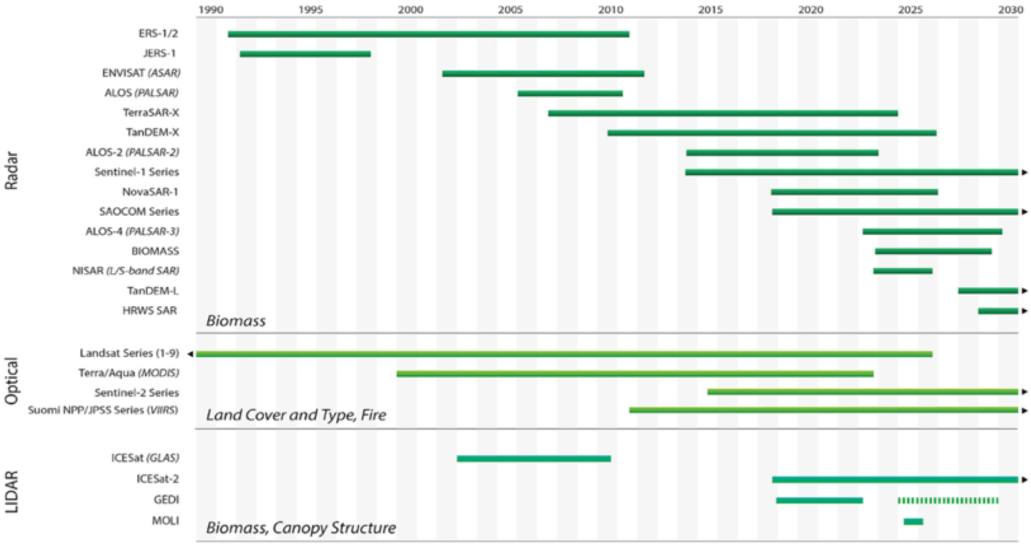


Figure 5.2.1. Different CEOS Earth observation satellite sensors/missions supporting land cover, use, fire and biomass information needs and their (estimated) lifespans (from Ochiai et al., 2023).

Box 5.2.1. Linking ground and remote sensing data

EO-based monitoring estimations need to be underpinned by ground and near-sensing measurements (i.e. from plot surveys, terrestrial or drone-based sensing and aerial surveys). The link between surface and satellite data occurs at different levels. Fiducial Reference Measurements are commonly done by space agencies for robust uncertainty assessment of space-based satellite measurements (Goryl et al. 2023). Networks of ground-reference data for land cover/use and for biomass and carbon monitoring are used for training and independent validation of EO-based products and estimates (Duncanson et al., 2019, Araza et al., 2022). There are also successful examples on how ground measurements and national inventories are integrated with EO approaches by combining the advantages of the different data streams (i.e. by putting more focus on ground measurements in areas of active changes and synergistically use timely EO-data input to provide annual estimates, while national inventories or censuses are taking several years to complete). In particular, in times of increasing use of machine learning and artificial intelligence in Earth Observations, the availability of quality reference data for training and validation is of fundamental importance to fully develop the potential of satellite remote sensing.

5.2.1.2 Land cover/use and change monitoring

Land Use, Land Cover (LULC) and change information are essential for national GHG inventories (LULUCF and AFOLU) and related activity data estimation, for advancing Earth system science and for informing global assessments of the terrestrial carbon budget. EO-based LULC data have a key role in enhancing the consistency and comparability of national GHG inventories and global GHG analyses. EO-based time series estimates commonly provide critical information on trends in deforestation and forest degradation at national and global levels, and on the impacts of climate extremes on forests.

As part of LULC characterisation, forest/tree cover data derived from EO are key for assessing forest loss, gain and disturbance/regrowth dynamics. EO data can also contribute to defining forest extent and types, which ultimately contribute to a more accurate assignment of growth rates, biomass and emissions factors. For this purpose, notable is the dataset of Hansen et al. (2013), which is available through UMD/GLAD and the Global Forest Watch (GFW). GFW provides annual maps of tree cover loss since 2000 at the global scale retrieved from Landsat sensor data with 30 m nominal spatial resolution. Tree cover height maps for 2000 and 2020 are also available and, in future, annual maps of tree cover height will allow annual extent, loss, and gain to be derived with higher accuracy. Contextual products, such as plantation datasets and primary forest /intact forest maps allow to move from tree cover to forest-related land use information. Other relevant forest cover datasets available include global forest age (Besnard et al. 2021), or forest types and plantations (i.e. Du et al., 2022).

LULC products with information for multiple land cover and use types (i.e. forests, croplands, grasslands, urban, wetlands) from EO data at the global scale are being developed as part of several ongoing projects and programs. Examples are the Copernicus Global Land Cover Monitoring Service or the European Space Agency's (ESA) WorldCover (Table 5.2.1). In addition, there are longer-term land cover and change products, such as HILDA+ (Winkler et al., 2021) that combine several EO-derived LULC datasets and national land use statistics from FAO to provide a consistent approach for global and national scale assessments of annual global LULC transitions between 1960 and 2020. An even longer time series of land use data (from 850 BC) is presented in LUH2 (Hurtt et al., 2020), which combines data on historical land use, crop functional type maps, Landsat-based forest loss and shifting cultivation estimates with future projections from Integrated Assessment Models (IAMs). This harmonized dataset is used as a common input dataset to run ensembles of Earth System Models (ESMs) for assessing the effects of land use on the global carbon-climate system. Despite the increasing availability of data and tools, there is significant variability among the LULC and LULC transitions inferred from the available products both in the magnitude of LULC classes and in the trend of LULC transitions in the past decades (e.g., Rosan et al., 2021; Vancutsem et al., 2021, Mousivand & Arsanjani 2019). Reconciling the different approaches and definitions and addressing issues of accuracy and consistency of time series is therefore a major focus in the forest and land use monitoring community.

Table 5.2.1. Examples of global land and forest cover/use and change datasets and their characteristics

Dataset name	Sensors / data source	Temporal coverage (frequency)	Spatial resolution	Reference
ESA WorldCover	Sentinel-1, Sentinel-2	2020, 2021 (one-time products)	10 m	Zanaga et al. 2021
Global tree cover loss	Landsat	Since 2000 (annual updates)	30m	Hansen et al. 2013
Copernicus Global Land Cover monitoring service (LCFM)	PROBA-Vegetation, now Sentinel 1/2	2015 – present (annual updates)	100 m, now moving to 10 m	Buchhorn et al. 2020
HILDA+	Various data, based on existing EO-derived datasets, models and statistical data.	1960-2019 (annual)	1 km	Hurtt et al. 2020
LUH2	Various data based on existing RS-derived datasets including Hansen et al. (2013). Also incorporates models and statistical data.	850–2100 (annual)	0.25◦degrees	University of Maryland 2021

Box 5.2.2. Activity data and emission factors

In the national IPCC inventory process, emissions and removals in the land use sector are computed from two major input variables: (1) The extent of observed or reported changes in land use within and between six categories (forestlands, croplands, grasslands, wetlands, settlements and other lands) defined in the IPCC guidelines (activity data), where Earth observation is already a key data source in several countries and (2) GHG emissions factors (i.e. amount of GHGs emitted or removed from the atmosphere per unit area of change of land use). Land use and land cover changes in area units (activity data) can be derived from one of three sources: (i) statistical data from the national agency, (ii) statistical aggregates from a sample of geolocated points, extrapolated to the national coverage or (iii) by comprehensive and inclusive land use maps, geospatially disaggregated, derived from local survey or from satellite time series data. EO-based wall-to-wall national land cover maps are used in several countries directly for providing activity data. The quality of land cover change maps may not be sufficient for direct estimation of activity data, in particular if global datasets are used in national circumstances (Melo et al., 2023). It is good practice to combine wall-to-wall satellite-derived maps (for stratification of potential changes) and targeted sampling and data interpretations with stratified area estimation to provide robust estimates of activity data with confidence intervals (GFOI, 2022). The integration of EO data into National GHG inventories has seen significant progress in recent years, particularly in forest area monitoring and most tropical countries (Nesha et al., 2021).

5.2.1.3 New methods and tools for estimating biomass and biomass change

Remote sensing approaches to monitor biomass

The scientific community has strived to develop methods based on remote sensing to monitor biomass and biomass change at regional, national and global scales. The advantage of remote sensing data is that they provide wall-to-wall coverage and repeated measurements allowing in theory to obtain annual estimates of biomass changes. The main limitation of remote sensing is that no instrument measures biomass carbon directly, and models (with various degrees of uncertainty) must then inevitably be used to transform physical quantities such as optical reflectances, radar backscatter or passive microwave emissivity signals, LiDAR height and canopy structure measurements, into biomass. In general, all remote sensing proxies tend to saturate at high biomass, which adds difficulty to estimating biomass in wet tropical forests (see Hunka et al. 2023). The most direct and accurate approach to map biomass is the use of airborne LiDAR data which provide accurate very high resolution estimates of the volume of trees. However, such campaigns are only available in a few regions of the world, and repeated campaigns to estimate biomass changes are limited to a handful of locations (see ESA PVP 2023).

All space-borne remote sensing based biomass products require, to various extent, ground-based biomass observations to calibrate models (see the relevant Box above). Some remote sensing models (Saatchi et al. 2011; Xu et al. 2021) are directly trained from local plot observations and use microwave and optical remote sensing data for upscaling to the globe. Other remote sensing models (Liu et al. 2015, Brandt et al. 2018, Fan et al. 2019, Wigneron et al. 2020; Hang et al. 2023) calibrate remote sensing data into biomass using a reference map of biomass, which itself uses plot data. A third category of remote sensing models (Santoro et al. 2020 ; Liu et al. 2022 ; Schwartz et al. 2023; Dubayah et al. 2017) use plot data in their algorithm to derive allometries between remotely sensed variables such as height or volume, and biomass. For below-ground biomass, no method can estimate it from satellite data, but rather empirical expansion factors are used to infer below-ground from above-ground biomass (Spawn et al. 2020; Huang et al. 2021).

Remote sensing approaches to monitor biomass changes

To map biomass changes, remote sensing approaches can be subdivided into two families, just like NGHGI inventories: 1) a stock change approach where maps of biomass are produced during consecutive years, and their difference is used to produce changes (Xu et al. 2021, Liu et al. 2015, Wigneron et al. 2020 ; CCI-ESA) or 2) a flux-based approach where remote sensing data from a high-resolution map of biomass are combined with disturbances, in a space for time approach, to derive regrowth rates and loss rates after disturbances, and then used in a flux-based accounting model to calculate gains and losses, and eventually total biomass changes. Examples of method 2) for remote sensing include the studies by Heinrich et al. 2021 for Brazil, and Heinrich et al. 2023 for tropical forests, based on regionally averaged regrowth curves, with a space for time hypothesis; Harris et al. 2021 based on a high-resolution biomass map in 2000 and assuming fixed growth rates for gains in different forest types (a Tier 1 approach) and remotely sensed activity data for disturbance and harvest losses; Xu et al. (in review) for boreal and tropical forests, using local regrowth curves based on long term disturbance maps since 1984, and Ritter et al. (2024, in review) using a similar approach but calibrating the national biomass changes from their remote sensing models to match NFI reports.

We are only aware of four recent global gridded biomass change global datasets: the BIOMASCAT data from 1992 to 2018 based on C-band radar data (Bernard et al. 2021), the LVOD data based on long-wavelength passive microwave emissivity in the L-band which shows less saturation than most sensors from 2010 to 2023 (Hang et al. 2023), the machine learning model of Xu et al. 2021 trained on plot data and using optical and short wavelength microwave data from 2000 to 2022, the CCI maps produced by ESA for 2010 and onwards annually since 2017, based on L-band and C-band radar data, and using height measurements from ICE-sat2 as well. These products show large differences and have different spatial resolution. Araza et al. 2022 compared CCI, Xu et al. and L-VOD maps and attempted to evaluate their change against repeated regional airborne LiDAR campaign data in a few locations, with moderate agreement. One interesting common feature of these global biomass change maps from remote sensing is that the global increase of biomass stock ranges from 0.2 to 0.5 GtC y-1 over the last two decades, which is much less than the global net land sink inferred from the global carbon budget: 2.1 ± 1.1 GtC y-1 over the last decade (Friedlingstein et al. 2023).

5.2.1.4 Future research directions

The use of EO to estimate land cover/use change and characteristics is rapidly evolving and we may envisage an increased contribution of these technologies for the estimation and reporting in the LULUCF sector. While long-term data records will be systematically expanded in the future (e.g. Landsat and Copernicus programs), new satellite missions (e.g. higher resolution, hyperspectral, LiDAR, etc.), new modelling methods (such as AI) together with the expansion and availability of ground reference networks will continuously improve monitoring efforts and programmes. From a technical perspective, active research and operational demonstrations are underway to improve EO-based land change estimation, with priority to the following points.

- Moving from the detection of generic forest area change to land use change and linking forest change to that of other IPCC land use categories, and thus to broader AFOLU estimation and reporting.
- Leveraging the high temporal frequency of EO data to improve the timeliness of information on forest change and provide near-real time information at national and global levels.
- Develop novel approaches to provide both high-quality statistical estimates of land use change (i.e. often from stratified area estimations) and land use change maps, which are important to support reporting obligations and national policy development and implementation.
- Linking forest area and land use change with estimates of emissions and removals, including a link to satellite-based biomass estimates and land modelling.
- Use of EO-based data to improve forest and land characterisation, including planted vs. natural, young vs. old, grazing dynamics, different species/ecosystem types, crop types, etc.
- Use EO data to better link national data (i.e. those from GHG Inventories) and the global level in the context of the Global Stocktake.

Given the great technical prospects, a balanced approach is needed to effectively reduce the gap between what can be achieved in research and what is needed to support policymaking and meet reporting requirements. There are no unique solutions, as there is no single dataset that serves all users in terms of definition and type of measurements, geographical area and uncertainty requirements, and whether the need is for the latest estimate of forest area or to assess the long-term trend. The research and user communities should embrace the potential strength of jointly evolving EO capabilities to meet these diverse needs and ensure continuity for long-term data provision.

5.2.2. Top-down assessments based on atmospheric Inversion modeling

5.2.2.1 Continental to global scale CO_2 fluxes from inversions

Researchers have tackled the problem of quantifying the global distribution and variability of natural carbon sinks over lands and oceans using top-down atmospheric inversions. In these inversions, fossil fuel CO_2 emissions associated with human activities have been assumed to be much better known than natural fluxes at global and continental scales. The inversion approach makes use of the fact that the surface fluxes of CO_2 introduce spatiotemporal gradients in CO_2 concentration in the atmosphere. Measurements of those concentrations can be used to quantify or at least constrain sources and sinks at the Earth's surface. This has to be done within the context of global numerical atmospheric transport models, which relate the surface fluxes to the atmospheric concentrations at the observation sites.

Inverse techniques combine three ingredients: (1) prior knowledge of CO_2 fluxes, (2) measurements of atmospheric CO_2 concentrations, and (3) atmospheric transport models to translate information on surface fluxes into atmospheric CO_2 concentration gradients. This information is expressed statistically by probability distributions (PDFs) in inversions. The underlying assumption is that the true fluxes (if they were known) coupled to the transport model, which relates fluxes to atmospheric observations, would be consistent with the measurements. The inversion methodology refines the prior knowledge producing a reduced uncertainty on CO_2 fluxes, and an evaluation of the consistency of the three sources of information.

In most existing inversion studies, the prior information on global atmospheric CO_2 fluxes includes two critical assumptions. The first is a perfect knowledge of fossil fuel and cement CO_2 emissions and of their space-time patterns from emission maps derived from inventories. The second is an assumed estimate of ocean and terrestrial CO_2 fluxes obtained from flux estimates derived with bottom-up carbon cycle models, or statistical information (e.g. assuming that certain fluxes are correlated within a given spatial and/or temporal domain). Prior information may be additionally specified based on ad hoc plausibility arguments (e.g. no CO_2 sources over ice sheets or deserts, or assuming CO_2 uptake following fire emissions in grid-cells affected by fires).

Currently, global inversions use atmospheric CO_2 concentration measurements from a global in-situ surface network of about 150 sites contributed by different institutions with most of the observations coming from the NOAA ESRL network (https://www.esrl.noaa.gov/gmd/ccgg/ggrn.php). These observations have different sampling frequencies and can be grouped into discrete air samples (flasks) collected about once a week and continuous measurement sites. The continuous measurement sites contain more information about sources and sinks than the weekly flask data. An even spatial sampling of the global atmosphere is desirable to constrain global inversions, but this is not the case today, with most of the surface in-situ stations being located at marine sites and in North America, East Asia and Western Europe. The most important regions where the largest natural fluxes are located, like the Southern Ocean, tropical South America, tropical Africa, Siberia and the Arctic have very few observation stations, which severely hinder the ability of global inversions to constrain CO_2 fluxes over these regions.

For atmospheric inversions, the surface network can be complemented by satellite retrievals of the column-averaged CO_2 dry air mole fraction, XCO_2. The spatial density of such measurements offers the prospect of a much stronger constraint on the CO_2 fluxes, despite significant uncertainty for individual sounding values. However, current inversion results based on polar-orbiting satellites vary a lot depending on the transport model, the inversion system or the retrieval algorithm used (Chevallier et al., 2017). They also show some inconsistency with other measurements (Houweling et al., 2015). Inversions based on GOSAT XCO_2 data produce a much larger CO_2 uptake over the European continent than other estimates, as discussed by (Reuter et al., 2016).

Global atmospheric transport models solve numerically the continuity equation for CO_2 given the three-dimensional, time-varying meteorological fields describing the state of the atmosphere. CO_2 is considered by global inversions to be an inert gas that is subject only to transport and surface emissions and sinks although there is chemical production of CO_2 in the atmosphere from the oxidation of CO, CH_4 and other hydrocarbons mainly by the OH radicals. The global fields used for transport models come either from analyses of numerical weather forecast models or atmospheric general circulation models running in climate mode. Currently employed global atmospheric transport models have horizontal resolutions of 2°-4° latitude and longitude and up to 50 layers in the vertical dimension. The temporal resolution is typically 3-6 hours as determined by the availability of the meteorological analyses.

Global atmospheric inversions constrained by in situ data have provided much of the information on the large-scale carbon cycle such as the existence of a northern terrestrial sink (Tans et al., 1990) or the role of the tropical land in modulating inter-annual variability (Bousquet et al., 2000). Their uncertainties are large at continental scales, typically on the order of 50 to 100% of the mean. Although on average the continent seems to be a net sink of carbon, the CO_2 uptake estimated from inversions is much larger than the net land carbon increase diagnosed from inventories and models. In tropical regions, global inversions only bring marginal uncertainty reduction on CO_2 fluxes due to the lack of atmospheric CO_2 stations. The scientific value of these inversions is that they provide long time series, therefore allowing the analysis of trends and variability of CO_2 fluxes over the past 30 years (Gurney and Eckels, 2011). For instance (Yue et al., 2017) used two global inversions to investigate the CO_2 flux anomaly during the 2015 El Nino event and found consistency between their results only when seasonal fluxes were analyzed at the scale of very large latitude bands. In their annual update of the global budget of anthropogenic CO_2 (Le Quéré et al., 2014) use the three inversions of Carbon-Tracker Europe (van der Laan-Luijkx et al., 2017), Jena Carboscope (Rodenbeck et al., 2003) and CAMS (Chevallier et al., 2010) which are regularly updated with results being used for the global separation between land and ocean fluxes and for three latitude bands. The variability of tropical CO_2 fluxes is consistent between the three inversions, but their mean value differs, with CAMS giving a larger northern sink and a smaller tropical flux than the two other inversions.

Despite the large experimental and modelling effort, the estimation of natural CO_2 fluxes from atmospheric measurements still constitutes a highly underdetermined mathematical inverse problem, because neither the present in situ observation network, nor any anticipated space-borne observation system is sufficient to sample the atmosphere with the required density and accuracy to resolve the complexity of CO_2 sources and sinks existing in the real world. Various improvements are expected in the future, for instance through higher-resolution global transport models or a more refined calibration and validation of the space-based data (Wunch et al., 2015), while new types of satellite missions will also make the inversion systems evolve.

5.2.2.2 National scale AFOLU CO_2 fluxes from inversions

Advances in modelling have been realised in some regions with denser networks of continuous stations, ultimately providing information on CO_2 fluxes at much smaller spatial scales. Firstly, Law et al. (2002) noted that high-frequency variations in concentration reflected smaller-scale features in emissions. Improvements in high-resolution modelling allowed the simulation of features with enough accuracy to constrain sources and sinks (Geels et al., 2007, Sarrat et al., 2009); (Pillai et al., 2010, Kountouris et al., 2016a). This allowed the recovery of sources first over sub-continental regions in Europe (Grégoire Broquet et al., 2011, Kountouris et al., 2016b) and North America (Gourdji et al., 2012) to evaluate bottom-up ecosystem models (Fang et al., 2014), and over smaller agricultural regions (Lauvaux et al., 2009, Schuh et al., 2013) or urban scales (Turnbull et al., 2015), (Bréon et al., 2015) – see below). A particular advance was realized with biweekly vertical profile measurements across the Amazon basin and regional inversions (Gatti et al., 2014, Alden et al., 2016); (van der Laan-Luijkx et al., 2015)) to reduce the uncertainty of the CO_2 budget of this important region for the global carbon cycle.

Other advances have been made with inversion simulation studies that use synthetic data, also called an Observation System Simulation Experiment (OSSE). One such study (Kadygrov et al., 2015) was based on networks of tall tower stations with a regional transport model that had a spatial resolution 0.5° by 0.5° over Western Europe, assuming unbiased measurement errors and a perfect transport model. This study concluded that uncertainty reductions of up to 60% in large EU countries with the best coverage of atmospheric continuous measurement stations could be achievable. This would make this approach competitive when compared to current uncertainties on the reported national-scale bottom-up inventories for natural CO_2 fluxes in the AFOLU sector (e.g. Stinson et al., 2011). In order to represent a particular region more closely, a nested, higher-resolution grid or a non-uniform zoom region may be employed. In addition to nesting, mesoscale inversion systems use lateral boundary conditions from a global inversion system. Ultimately, the resolution of atmospheric transport models is limited by the resolution of the parent model providing the meteorological fields.

Deng et al. 2022 have compared global inversions results from the Global Carbon Budget (Friedlingstein et al. 2023) with NGHGIs for the AFOLU fluxes. They found that northern countries like Canada and Russia had a greater total AFOLU sink than reported by NGHGIs, and that some tropical countries had a smaller AFOLU net emission than NGHGI.

Inversions do not separate different components of AFOLU reported by NGHGIs, but provide a constraint on the overall budget. For instance, inversion fluxes transformed into carbon storage changes do not separate biomass, deadwood and soil carbon stock changes, but independent estimates of soil and deadwood changes can be obtained by combining inversions with the above-mentioned maps of biomass carbon stock changes (Zhang et al., 2022, Huan et al. 2024). For countries that have NGHGIs that do not cover the entire national territory but only managed lands, gridded inversion CO_2 fluxes have to sample grid cells using a map of managed land. Further inversions estimate CO_2 fluxes that are caused by the lateral displacement of carbon and do not contribute to a stock change. These fluxes related to the river / inland water loop of the carbon cycle and to the harvest and trade of crop and wood products have to be calculated from separate data and subtracted from inversions.

Using an ensemble of inversions constrained by OCO2-satellite measurements since 2015, Byrne et al. also compared with a similar approach inversion AFOLU CO_2 fluxes with NGHGIs for selected large countries. Notably, the RECCAP-2 initiative has combined inversions with different bottom-up approaches to quantify the AFOLU CO_2 fluxes for 10 regions (groups of countries) covering the entire globe, for the last two decades. In the RECCAP2 studies, either global CO_2 inversions or regional higher-resolution inversions have been used, demonstrating the potential of these methodologies at a sub-continental scale.

Annex 5.3. Anthropogenic emissions and removals from land in national GHG inventories

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5.3.1 Introduction

The UNFCCC requires that Parties "develop, periodically update, publish and make available … national inventories of anthropogenic emissions and removals of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies to be agreed upon by the Conference of the Parties" (UNFCCC 1992, art 4.1.a). To this aim, The IPCC Task Force on National GHG Inventories (TFI) was tasked with the development of internationally-agreed methodologies used for the estimation of national anthropogenic GHG emissions and removals.

Reporting of the Parties in their national GHG inventories (NGHGIs) should be distinguished from accounting of anthropogenic GHG emissions and removals for the fulfilment of national obligations, particularly NDCs, which may have different approaches from those used in the reporting. The accounting scheme is often closely linked and based on reporting, but may include only a part of the GHG fluxes, in accordance with the national legislation. The Paris Agreement leaves ample freedom for the accounting scheme to Parties[21].

The 2006 IPCC Guidelines (IPCC 2006), which integrates and updates previous IPCC Guidelines and Guidance (IPCC 1996, IPCC 2000 and IPCC 2003), are currently considered by the UNFCCC as the mandatory methodologies for all Parties to report their NGHGIs under the UNFCCC and its Paris Agreement (Article 13, Enhanced Transparency Framework, UNFCCC 2019). A Refinement of the 2006 IPCC Guidelines was produced in 2019, to update, supplement and/or elaborate the 2006 IPCC Guidelines where gaps or out-of-date science have been identified (IPCC 2019). The 2019 Refinement might be used by Parties on a voluntary basis; it is part of the 2006 IPCC Guidelines and the new methodological information is provided as good practice for inventory compilers to produce GHG estimates consistent with the TACCC reporting principles under the UNFCCC (Transparency, Accuracy, Comparability, Consistency, Completeness).

IPCC methodologies aim to guide the development of GHG estimations based on a common understanding and to ensure that inventories are comparable among countries, do not contain double counting or omissions, and that the time series reflect actual changes in emissions. In that regard, methods and approaches proposed need to be of universal application and affordable by inventory compilers in terms of data access and capacity to implement while looking to include all sources of GHGs (see Box 5.3.1).

Generally, the definition of anthropogenic emissions is clear for most sectors. However, anthropogenic emissions and removals associated with land use are far more complex, since they are often difficult to distinguish from those of natural origin. This is particularly difficult for land categories such as forests and grasslands, where the growth of plants and the extent of fires depend on both natural causes and the management and protection measures applied.

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[21] Note that, following UNFCCC Decision 18/CMA.1, each Party shall clearly indicate and report its accounting approach to address: disaggregation of emissions and subsequent removals from natural disturbances on managed lands; emissions and removals from harvested wood products; the effects of age-class structure in forests. In practice, most countries use the net land CO_2 flux *reported* in national GHG inventories for accounting purposes, i.e. to assess compliance with their NDCs and track progress towards their long-term (i.e. 2050) emission reduction strategies under the Paris Agreement (Grassi et al., 2023).

Box 5.3.1. IPCC Methodological guidance basics[1]

IPCC Methodological Guidelines provide, in general, the minimum scope of national GHG inventories, i.e. time series of annual estimates of anthropogenic emissions and removals occurring within a country's nationally recognized borders with the aim of estimating and reporting emissions and removals when and where they occur (there are some exceptions including emissions from biomass combustion, and two methods used for HWP).

IPCC Methodological Guidelines are aimed at allowing the preparation of a consistent time series of complete and accurate estimates of GHG emissions and/or carbon dioxide removals associated with a human activity, under any national circumstances.

To be applicable under any circumstances, guidance to inventory compilers is designed as a *good practice* rather than setting standards. A *good practice* is a set of procedures intended to ensure that greenhouse gas inventories are accurate in the sense that they are systematically neither over-nor underestimates so far as can be judged, and that they are precise so far as practicable.

Tier approach to complexity

Good practice is provided for three tier levels of increasing methodological complexity and presumed increasing accuracy of estimates produced:

Tier 1 is the basic, default method designed to allow national inventory compilers to make estimates of emissions or removals for sub-categories in the IPCC classification system, even with limited national information. It must be applicable globally, under any national circumstances.

The tier 1 method requires the identification of the data of activity (AD), or a well-correlated proxy, and the assignment of a rate of emission/removal per unit of activity:

Emissions = AD*EF

To support the implementation by inventory compilers with limited information, the IPCC Guidelines include default values for each EF and parameter that the method requires.

Tier 2 is of intermediate complexity in terms of method and data requirement. It is *good practice* to apply Tier 2 methodological level to key source/sink categories -i.e. categories with a significant contribution in terms of emissions and removals to the national total. A tier 2 method can be the default method with country specific data, which means with a higher spatial and temporal resolution of data; or can have a different formulation and accordingly different variables, so providing for a deeper stratification of the estimated population, and thus for higher accuracy and precision of estimates.

Tier 3 is generally the most demanding in terms of complexity and data requirements. It has the highest spatial and temporal resolution and can be characterised as being based largely on:

a) measurements - e.g. monitoring emissions at stack or carrying forward continuous forest inventories - or

b) a set of variables for which annual values are either modelled on the basis of partial information, including on proxies from which variables are derived, not necessarily collected in a continuous fashion. In the latter, the verification of modelled results is a *good practice* given that continuous modelling can, across time, significantly diverge from the actual status of variables.

[1] From the IPCC Background paper on " Carbon Dioxide Removal Technologies and Carbon Capture, Utilization and Storage"

5.3.2 Definition of the "Managed Land Proxy" (MLP)

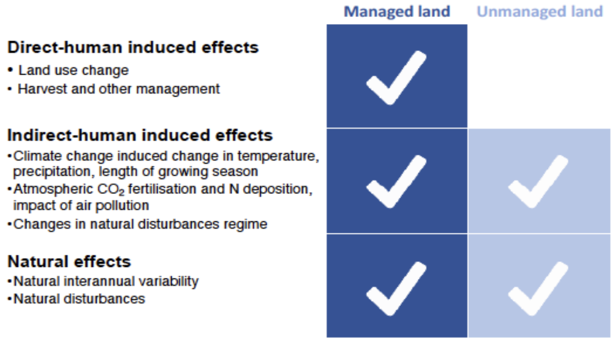
In the early 2000s, in response to a request of the UNFCCC, the IPCC held several meetings on the issue of anthropogenic GHG emissions and removals from land use. The IPCC's first meeting (in 2002) developed a work plan for a possible IPCC report to provide a framework for factoring out direct human impacts from all others, but questioned the feasibility of providing a definite methodology. The second meeting (in 2003) concluded that "The scientific community cannot currently provide a practicable methodology to factor out direct human-induced effects from indirect human-induced and natural effects for any broad range of LULUCF activities and circumstances" (IPCC 2003).

Given these difficulties, the 2006 IPCC Guidelines (IPCC 2006, Vol 4, Ch. 1) chose to use estimates of GHG emissions and removals on "managed land" as a proxy (MLP) for the anthropogenic GHG emissions and removals (see box 5.3.2).

Box 5.3.2. The Managed Land Proxy (MLP) and the anthropogenic and natural effects

Managed land is land where human interventions and practices have been applied to perform production, ecological or social functions (IPCC 2006). All land definitions and classifications should be specified at the national level, described in a transparent manner, and be applied consistently over time. Emissions and removals of GHGs do not need to be reported for unmanaged land. However, it is good practice for countries to quantify, and track over time, the area of unmanaged land so that consistency in area accounting is maintained as land-use change occurs. Furthermore, if there is a direct human induced activity in a land that previously was unmanaged (e.g., deforestation of primary forest), that land immediately becomes managed land.

The key rationale for using GHG emissions and removals from managed land as a proxy for anthropogenic GHG emissions and removals is that the preponderance of anthropogenic effects occurs on managed lands. By definition, all "direct human-induced" effects (see figure below) on GHG emissions and removals occur on managed lands only. While it is recognized that no area of the Earth's surface is entirely free of human influence (e.g., CO_2 fertilization), many "indirect human" influences on GHGs (e.g., increased N deposition) predominately occur on managed lands, where human activities are concentrated. Finally, while local and short-term variability in emissions and removals due to natural causes can be substantial (e.g., emissions from fire), the natural background of GHG emissions and removals by sinks tends to average out over time and space. This leaves the GHG emissions and removals from managed lands as the dominant result of human activity. Nonetheless, the natural interannual variability can have an important impact on annual NGHGIs (see Ch 5.3.3).



	Managed land	Unmanaged land
Direct-human induced effects • Land use change • Harvest and other management	✓	
Indirect-human induced effects •Climate change induced change in temperature, precipitation, length of growing season •Atmospheric CO_2 fertilisation and N deposition, impact of air pollution •Changes in natural disturbances regime	✓	✓
Natural effects •Natural interannual variability •Natural disturbances	✓	✓

Source: IPCC 2019 (Fig 2.6a), based on Grassi et a. (2018)

In 2009, an IPCC Expert Meeting on "Revisiting the Use of Managed Land as a Proxy for Estimating National Anthropogenic Emissions and Removals" was held in Brazil to assess the appropriateness of the use of managed land as a proxy for anthropogenic effects in different contexts, and re-consider methods to apportion emissions and removals to specific drivers (IPCC 2009). Specifically, the Expert Meeting examined the key assumptions underlying the managed land proxy, i.e. that: (i) all direct human-induced effects on GHG emissions and removals occur on managed lands only, (ii) many indirect human influences on GHG will be manifested predominately on managed lands, where human activities are concentrated; and (iii) while local and short-term variability in emissions and removals due to natural causes can be substantial, the natural 'background' of GHG emissions and removals tends to average out over time and space. After consideration of these assumptions, and the review of a number of proposed alternatives to the MLP, the Expert Meeting summarized that “While several concerns and deficiencies of the managed land proxy were identified, none of the alternatives considered at the meeting proved to be sufficiently well developed (for all Tier levels required) to justify an IPCC recommendation for change in the default estimation approach”. Thus, the meeting concluded that “the managed land proxy is currently the only widely applicable method to estimate the separation between anthropogenic and natural fluxes”. At the same time, the Expert Meeting noted that “work needs to continue to identify and test approaches to separating (factoring-out) anthropogenic impacts from others”.

In 2019, the IPCC Refinement to the 2006 Guidelines (IPCC 2019) further elaborated this topic (Vol. 4, chapter 2.6), specifically on:

(i) The relationship between different methodological approaches and the individual drivers/effects, i.e. direct and indirect human-induced as well as natural (see box 5.3.3).

(ii) The causes of interannual variability in emissions and removals, including an optional approach to disaggregate – under certain conditions - the emissions and subsequent removals associated to natural disturbances (see following section 5.3.3).

Box 5.3.3: Relationship between various estimation methods and individual drivers/effects

The choice of estimation method and data affects the extent to which the impact and interannual variability of different drivers/effects is reflected in the NGHGIs (IPCC 2019). Countries can apply different methods, with different temporal resolution and disaggregation of variables (annual to periodic, averaged or disaggregated by drivers). Two substantially different approaches are described by the IPCC for preparing national GHG estimates: the “stock-difference” and the “gain-loss”.

The Stock Difference method calculates net emissions and removals as the difference in estimated C stocks for relevant pools measured at two points in time. Average annual net emissions and removals can be calculated by dividing the C stock difference of a period by the number of years between the two observations. Periodic stock assessments without auxiliary data therefore do not allow the quantification of the interannual variability of emissions and removals and its relation to the various drivers. All direct, indirect and natural drivers and effects are in principle fully captured and cannot be disaggregated.

The Gain-Loss method estimates separately the components of the carbon balance of a land. It requires annual data on growth, management, land-use change and natural disturbances and when these are available it can provide estimates of the interannual variability of net emissions. A Gain-Loss approach utilising periodically updated yield tables or emission factors in principle captures all direct, indirect and natural effects. By contrast, constant yield tables or emission factors will be insensitive to natural climate variability and will implicitly capture indirect effects prevalent at the time of data collections, but not their transient effects over time. Gain-Loss methods that utilise climate-sensitive growth and mortality models can separate part of the indirect human and natural climate variability impacts on the interannual variability of emissions and removals (IPCC 2019).

It is important to note that the direct observations typically used in NGHGIs, such as the national forest inventories, cannot fully separate the direct human-induced effects from the indirect as well as natural effects. However, a transparent description of the methods and data used may help the scientific and policy communities to understand better the extent to which the various anthropogenic (direct and indirect) and natural drivers/effects are reflected in the NGHGIs (IPCC 2019, section 2.6.2). Useful information in the NGHGI include definition and spatial maps of managed land, information on areas of forest being harvested and those subject to other management, information on the main determinants of the GHG fluxes (e.g., forest age structure, harvested volumes, harvest cycle), measurement approach used in NGHGIs (stock-difference or the gain-loss), the extent to which indirect effects are captured in the NGHGIs (e.g., Tier 1 methods are not likely to fully include indirect effects), whether forests outside of forest transitions and areas with known anthropogenic disturbance history are considered to be in carbon equilibrium.

An overview of the implications of the methods used by selected countries on the inclusion of indirect effects in their NGHGIs is included in Annex 5.3.8. See also Suppl. Info, section 3, in Grassi et al. (2018).

5.3.3 Dealing with natural disturbances and interannual variability

Some of the emissions from managed land are characterised by high interannual variability (IAV) in the annual emissions estimates between years within a time series.

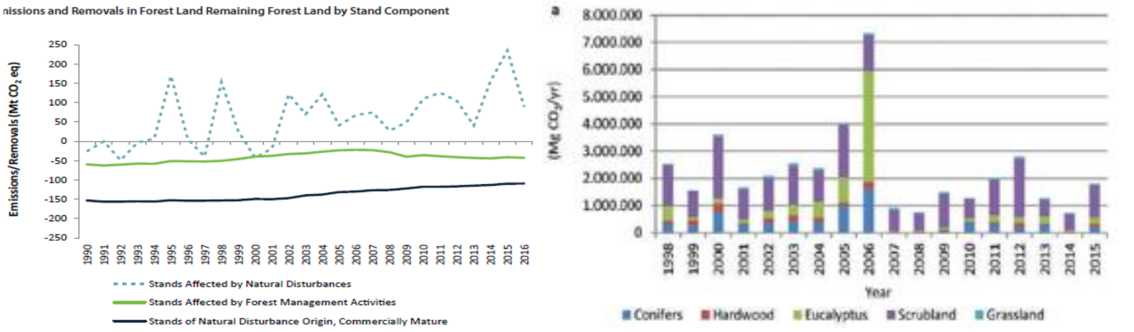
In the LULUCF sector, the application of the MLP means that IAV can be caused by both anthropogenic and natural causes. The three main causes of IAV in GHG emissions and removals in the LULUCF sector are (1) natural disturbances (such as wildfires, insects or pests, windthrow, and ice storms), which can cause large immediate and delayed emissions due to mortality; (2) climate variability (e.g. temperature, precipitation, and drought), which affects photosynthesis and respiration and therefor net primary production; and (3) variation in the rate of human activities, including land use (such as forest harvesting), and land-use change.

When the MLP is used and the IAV in emissions and removals due to natural disturbance is large (e.g., see box 5.3.4.), it might be difficult to gain a quantitative understanding of the role of human activities compared to the impacts of natural effects. In such situations, disaggregating MLP emissions and removals into anthropogenically induced and natural effects may provide increased understanding and refined estimates of the emissions and removals that are the result of human interventions, such as land management practices (including harvesting) and land-use change. In this way, it is recognized that disaggregation can contribute to improved quantification of the trends in emissions and removals due to human activities and mitigation actions that are taken to reduce anthropogenic emissions and preserve and enhance carbon stocks.

Recognizing that some but not all countries may address emissions and removals from natural disturbances on managed land, the IPCC 2019 Refinement of the 2006 GLs (IPCC, 2019) provided, as an option, guidance to disaggregate their reported MLP emissions and removals into those that are considered to result from human activities and those that are considered to result from natural disturbances. These supplementary approaches may be of interest to countries with LULUCF sector emissions where IAV due to natural effects is large and can be transparently excluded based on agreed criteria.

Box 5.3.4. Examples where Natural Disturbances and Inter-Annual Variability are large

Although in most countries the IAV is due to human activities, in some countries IAV in emissions from natural disturbances can be larger than the IAV of emissions caused by human activities such as forest management. For example, IAV in Canada's 1990 to 2016 time series of annual emission and removals due to natural disturbances is much larger than the IAV in the emissions and removals on the remaining managed forest land (Figure below left)



Emissions from natural disturbances in (left, Canada's NIR, 2018) and annual CO_2 emission due to forest fires 1998–2015 in Spain (right, Enríquez de Salamanca, 2019).

The NGHGIs for Portugal's 2018 NIR and Australia's 2018 NIR are two other examples of time series with high IAV. In some countries, the emissions by wildfires can vary by two orders of magnitude between years (Genet et al. 2018; Enríquez de Salamanza, 2019).

5.3.4 Operationalization of the MLP in the IPCC Guidelines

The MLP is built on the ecological principle of long-term equilibrium of carbon stocks in carbon pools within a physically limited environment[22]: in natural conditions, net carbon stock changes across time are zero. In practice, this implies that any net change in C stock in managed land across a time series is anthropogenic only, both direct and indirect effects. However, the inter-annual variability of emissions, and subsequent removals, caused by non-anthropogenic events and circumstances beyond the control of the country (i.e., not within management practices) and not materially influenced by a country (i.e., not directly human induced) may mask the actual level and trend of anthropogenic emissions and removals, and can therefore be disaggregated in NGHGIs (see section 5.3.3).

By contrast, those natural fluxes that are not counted as carbon stock changes do not balance out across time, such as the natural emissions of N_2O from soils (due to mineralization of organic matter). These fluxes are not included in the NGHGI despite occurring on managed land. Nevertheless, the perturbation of those fluxes directly caused by human activities (e.g., due to anthropogenic N inputs to soils) is included in the NGHGI, not as a gross flux but rather as the difference between the flux in managed land subject to the activity and the flux in an equivalent managed land that is not subject to the activity. When a perturbation of those natural fluxes occurs because of indirect human-induced effects only - e.g., the increase in CO_2 emissions from soil respiration due to permafrost thaw associated to global warming - those fluxes are not included in the NGHGI as no IPCC methods are provided to simply deal with indirect effects. However, where a direct perturbation of those fluxes occurs in addition to the indirect impact, e.g., drainage or rewetting of organic soils, this requires estimating the entire flux and its reporting in the NGHGIs where a separation between direct and indirect effects is not possible.

Such approach materializes in the NGHGI for reporting of all C stock changes in managed land as well as some of other GHG fluxes as directly impacted by human activities.

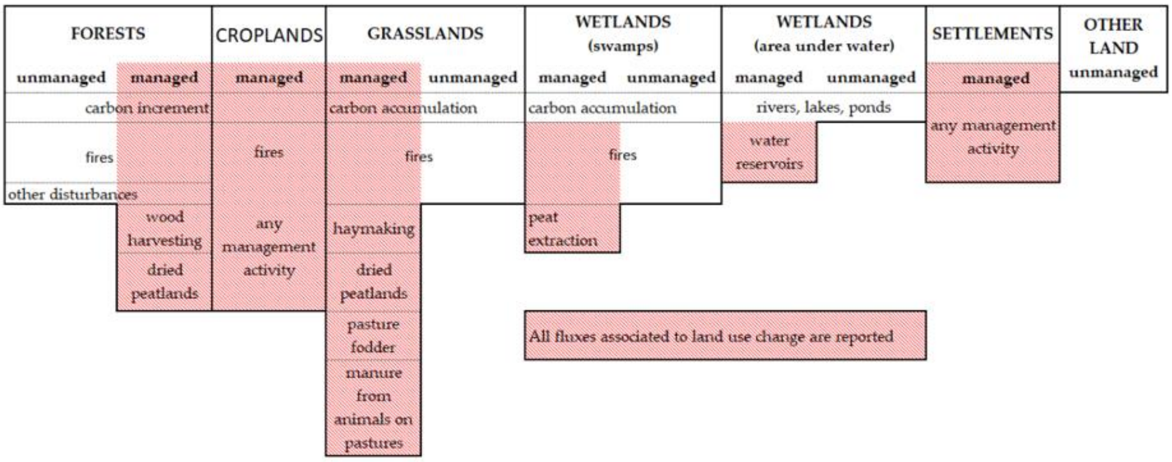


Figure 5.3.1. Illustrative example of emissions and removals on lands to be reported in GHG Inventories (shaded in red). Source: based on Romanovskaya and Korotkov (2024).

5.3.5 Application of the MLP in NGHGIs in practice

The Box 5.3.5 below illustrates how the MLP is applied in the case of forests across countries, based on the available information.

Most Annex I countries consider all lands as managed. Among those that do not report all land as managed, the United States considers around 8% of its total land area as “unmanaged”, or inaccessible to society due to the remoteness of the locations. Similarly, Canada has designated around 34% of its forests as “unmanaged”. For

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[22] The capacity of C pools of: Biomass, Dead Organic Matter (DOM), Soil Organic Matter (SOM) in mineral soils and Harvested Wood Products (HWP) to store C stocks is limited as constrained by environmental variables and management activities.

Russia, the area of unmanaged land is 47% of total territory (23% of "unmanaged" forests of total forests). In the European Union, less than 5% of land is unmanaged, mostly wetlands in Nordic countries.

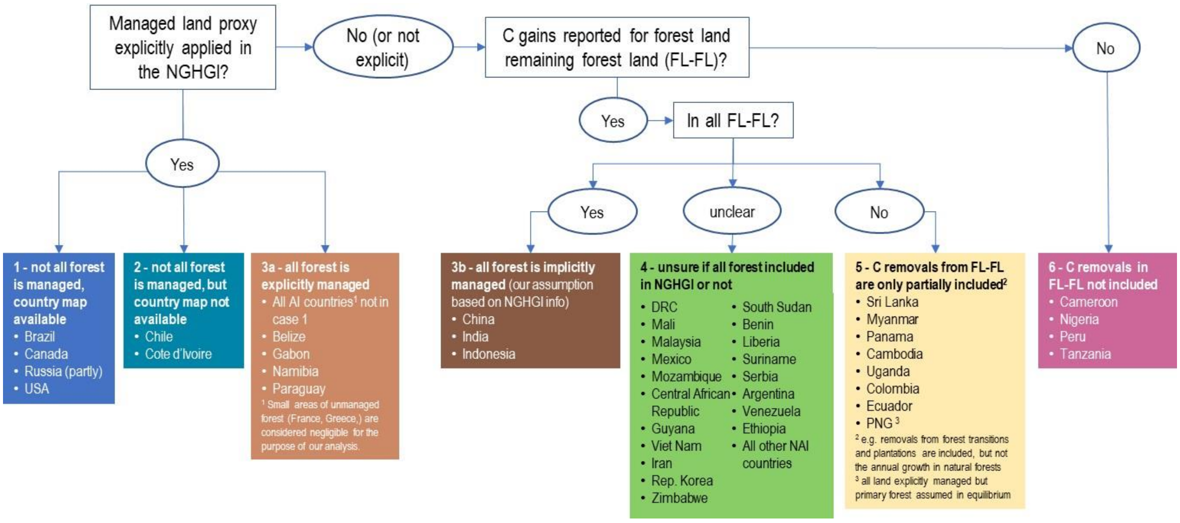
Many non-Annex I countries, however, do not make use of the managed land proxy or not explicitly, despite the fact that some have primary, intact forests that may not be subject to human interventions or practices.

Annex A provides detailed examples on how the MLP, the natural disturbance and interannual variability are being addressed by four developed countries in their latest NGHGIs submissions.

Finally, Annex B provides an analysis of concrete methods used to estimate forest CO_2 fluxes in NGHGIs of selected countries, and the implications for the inclusion of indirect effects.

Box 5.3.5. Use of the MLP: the case of forest land across countries

Forest lands are those where the separation of anthropogenic and non-anthropogenic emissions and removals of GHGs is most challenging. In the figure below a decision tree illustrates how countries are applying the MLP for forests in their reporting to the UNFCCC, reflecting a variety of countries' perspectives.



Use of MLP in UNFCCC Parties as per their GHG inventories and REDD+ submissions (source: Melo and Grassi, in preparation)

All Annex I and few Non-Annex I are applying the MLP approach explicitly in their NGHGIs, where few indicate that not all forests are managed identifying them spatially or not. The rest of the Non-Annex I countries are not explicit on how they use the MLP. In some cases, it can be interpreted that all forests are considered to be managed; in others, it is difficult to judge if all forests are included or are only partially included; and finally, some country explicitly only include part of their forest without a reference of it being managed or not. Many Non-Annex I countries have less experience in the development and regular reporting of NGHGIs to the UNFCCC and have not yet been exposed to the Inventory Review process. This might explain, in part, the lack of transparency regarding the approach used to report anthropogenic emissions and removals. However, it needs to be acknowledged that the REDD+ reporting and assessment processes have helped to improve the capacities of many developing countries to better understand the dynamics of their forest, and thus to include forests and the land sector in their NGHGIs.

5.3.6 Challenges and benefits of the MLP approach

According to IPCC guidance, managed land is land where human interventions and practices have been applied to perform production, ecological or social functions. The MLP is therefore a simple and pragmatic approach that - by considering the management at the core of the separation between anthropogenic from non-anthropogenic emissions and removals - allows to better connect the GHG estimates to the systems of practices of and to the implementation of the climate actions on the ground up to the extent the practices can be related to the a specific EF.

Furthermore, the use of the MLP allows for consistency, verifiability and transparency in estimations across countries with very different capacities. It is therefore currently recognised by the IPCC as the only universally applicable approach to estimating anthropogenic emissions and removals in the AFOLU sector (IPCC 2006, IPCC 2010). In addition, the new obligations of reporting for developing countries, with less and very variable capacities for reporting, require a practicable and simple approach such as MLP to estimate anthropogenic emissions and removals that inventory compilers can apply when starting to develop regular inventories, since they need to strategically allocate resources. Yet, the countries most advanced in terms of estimation and reporting capacity can apply the MLP additional guidance to deal with interannual variability caused by natural disturbances and maintaining the transparency of reporting (IPCC 2019, vol 4).

It is also important to consider the implications of too narrow a definition of managed forest, that potentially can lead to severe underestimation of stock losses, or an overly broad national definition of managed land, that may allow natural removals to be included in GHG inventory reporting, resulting in a loss of incentives to reduce fossil fuel emissions. This is why national approaches to identifying managed land are particularly carefully evaluated during inventory expert reviews.

5.3.7 - Examples of the application of the Managed Land Proxy

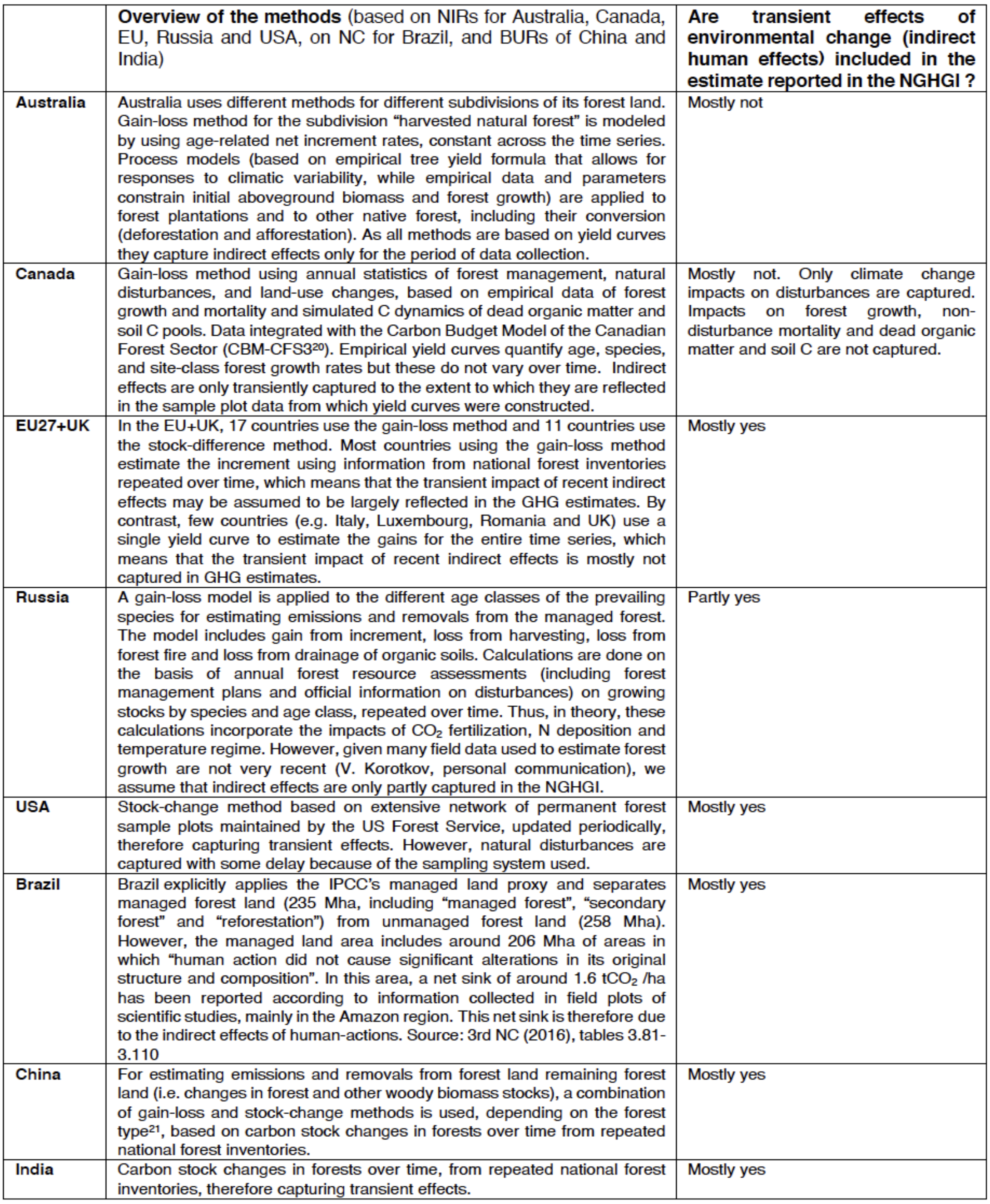
The table below provides examples on how the Managed Land Proxy (MLP), the natural disturbance and interannual variability are being addressed by four developed countries in their latest NGHGIs. Some of these countries are applying the additional guidance provided by the IPCC 2019 Refinement to address natural disturbances in managed land. A detailed analysis of managed land in the NGHGIs of Brazil, Canada and the United States can be found in Ogle et al. 2018.

Country	Description of how MLP is applied
US	2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories provide guidance for factoring out natural emissions and removals, the United States does not apply this guidance and estimates all emissions/removals on managed land regardless of whether the driver was natural. The total land area included in the United States Inventory is 936 million hectares across the 50 states. Approximately 886 million hectares of this land base is considered managed and 50 million hectares is unmanaged, a distribution that has remained stable over the time series of the Inventory. Wetlands are not differentiated between managed and unmanaged with the exception of remote areas in Alaska, and so are reported mostly as managed. In addition, C stock changes are not currently estimated for the entire managed land base, which leads to discrepancies between the managed land area data presented here and in the subsequent sections of the Inventory (e.g., Grassland Remaining Grassland within interior Alaska).11,12 Planned improvements are under development to estimate C stock changes and greenhouse gas emissions on all managed land and to ensure consistency between the total area of managed land in the land-representation description and the remainder of the Inventory. The United States definition of managed land is similar to the general definition of managed land provided by the IPCC (2006), but with some additional elaboration to reflect national circumstances. Based on the following definitions, most lands in the United States are classified as managed: • Managed Land: Land is considered managed if direct human intervention has influenced its condition. Direct intervention occurs mostly in areas accessible to human activity and includes altering or maintaining the condition of the land to produce commercial or non-commercial products or services; to serve as transportation corridors or locations for buildings, landfills, or other developed areas for commercial or non-commercial purposes; to extract resources or facilitate acquisition of resources; or to provide social functions for personal, community, or societal objectives where these areas are readily accessible to society.13 • Unmanaged Land: All other land is considered unmanaged. Unmanaged land is largely comprised of areas inaccessible to society due to the remoteness of the locations. Though these lands may be influenced indirectly by human actions such as atmospheric deposition of chemical species produced in industry or CO2 fertilization, they are not influenced by a direct human intervention (some areas, such as Forest Land and Grassland in Alaska that are classified as unmanaged land due to the remoteness of their location). In addition, land that is previously managed remains in the managed land base for 20 years before re-classifying the land as unmanaged in order to account for legacy effects of management on C stocks. There are examples of managed land transitioning to unmanaged land in the US: for example, in 2018, 100 hectares of managed grassland converted to unmanaged because data indicated that no further grazing occurred. Livestock data are collected annually by the Department of Agriculture, and no livestock had occurred in the area since the mid-1970s, and therefore there was no longer active management through livestock grazing, the area is also remote, at least 10 miles from roads and settlements. Unmanaged land is also re-classified as managed over time if anthropogenic activity is introduced into the area based on the definition of managed land. (NIR 1990-2021- US)
Canada	Not all Canadian forests are under the direct influence of human activities. For the purpose of the GHG inventory, managed forests are those managed for timber and non-timber resources (including parks) or subject to fire protection. Forest Land category includes all managed forest areas with anthropogenic impacts, as well as forest areas with natural disturbance impacts. Extensive areas of tundra in the Canadian North are considered unmanaged grassland.

	Annual estimates of managed and unmanaged forest areas are reported separately for the first time in the submission in 2023 and the remaining unmanaged land area reported includes both unmanaged and managed non-forest land for which there are no estimates of emissions and removals. Since the 2017 submission, Canada has implemented a Tier 3 approach to isolate the effects of anthropogenic activities on managed forests. This approach involves the separate monitoring and compilation of emissions and removals from forest stands impacted by anthropogenic and natural drivers (referred to as the anthropogenic and natural disturbance components respectively). The anthropogenic component includes emissions and removals associated with (i) stands that have been directly affected by past forest management activities (e.g. clear-cutting and partial harvesting, commercial and pre-commercial thinning, and salvage logging); (ii) mature stands affected by natural disturbances causing biomass mortality of 20% or less (i.e. insect defoliation) or having greater than 20% mortality and that have recovered to their pre-disturbance biomass; and (iii) mature stands affected by stand-replacing natural disturbances in the past that have reached a regionally-determined minimum operable age (i.e. that have reached commercial maturity and are actively monitored in forest management practice to serve the public interest). The natural disturbance component includes emissions associated with large, uncontrollable natural disturbances, such as wildfires or insect outbreaks causing more than 20% biomass mortality and the removals that occur as the stands regrow back to maturity or attain pre-disturbance biomass, respectively. To ensure transparency, all emissions and removals are presented here (Table 6–5; Figure 6–3 of CNIR, 2013), but reporting is based on the anthropogenic component in an effort to better capture the emissions and removals more closely linked to land management and to better inform stakeholders in the forest sector. A full accounting of natural disturbances and the C balance in managed forests can also be found in the State of Canada's Forests report (NRCan, 2022). Additional information on the estimation approach is provided in Annex 3.5.2.6 and in Kurz et al. (2018). (NIR, 2023 Canada)
Russian Federation	In Russia about 53% of lands are considered as managed. Unmanaged land (47% of the territory) include: 12% of forest land (23% of total forest land); 1% of grasslands (17% of total grassland); 13% of wetlands (99% of total wetlands); 21% of other land about 90% of which is tundra. Managed forests are defined as forests where systematic anthropogenic activities are carried out in order to fulfill the necessary social, economic and ecological tasks to ensure rational, continuous and sustainable forest management, reproduction, protection, conservation and monitoring of forests. Targeted activities on the use, conservation, protection and reproduction of forests, carried out and regulated by national legislation, form the basis of sustainable forest management. In the Russian Federation, forest management is defined as a system of anthropogenic (economic) activities for the rational management and use of forests in order to fulfill their respective ecological (including biological diversity), economic and social functions in a sustainable manner. Forest management includes the set of the following activities: regular accounting, quantitative assessment and analysis of the state, spatial, temporal and resource dynamics of the forest fund; reforestation and forest maintenance; protection and defense of forests from fires and other causes of forest plantation death; determination of the optimal size of forest harvesting (estimated cut); clear-cutting and thinning, harvesting of non-timber raw materials and other forest products. Forests where according to the national legislation there is no obligation to implement a full set of the above measures (including measures to protect and extinguish forest fires) are excluded from managed forests. All specially protected natural areas, including forests, are considered as "managed". In order to estimate GHG emissions and removals in forests Russia applies gain-loss IPCC method. Activity data are taken from the state forest registry and based on ground and satellite observations of stem wood stock volumes and fires. Therefore indirect anthropogenic effects such as CO2 fertilization and GHG emissions from increase in natural disturbances are included. However due to infrequent updating of forest registry these effects are included in the GHG inventory only partly. Russia is currently implementing a Major Innovation Project of National Importance for creating a national system of GHG monitoring, which involves the refinement of the national GHG inventory and the updating of the activity data on forests and other land categories. This may lead to full inclusion of indirect effects on managed lands.
Australia	In Australia, all lands are considered managed lands. All carbon stock changes on managed land from anthropogenic and natural 'background' emissions and removals are reported, consistent with the MLP, including from wildfires. Natural 'background' emissions and removals caused by natural disturbance fires are considered to be caused by non-anthropogenic events and circumstances beyond the control of, and not materially influenced by, Australian authorities and occur despite costly and on-going efforts across regional and national government agencies and emergency services organisations to prevent, manage and control natural disturbances to the extent practicable. These fires are considered to be part of the 'natural background' of non-anthropogenic emissions and removals, which under the MLP are understood to average out over time and space. This national definition of natural disturbances applies to wildfires on temperate forests, and does not apply to fires reported as controlled burning (e.g. in temperate forests or in wet-dry tropical forests and woodlands). All fires on land converted to forest land are treated as anthropogenic. The impacts of human activities (e.g. salvage logging, prescribed burning, deforestation) are excluded from the identification of natural disturbances through the application of an Approach 3 representation of lands which is used to track lands subject to natural disturbances and separately identify and exclude land subject to human activities. In order to disaggregate emissions and removals due to natural disturbances under the Tier 3 method applied in this inventory, natural disturbances are explicitly identified in the activity data. Both initial carbon losses and subsequent recoveries in carbon stocks are modelled as part of the disturbance event, and carbon stocks are spatially tracked until pre-disturbance levels are reached to ensure completeness and balance in reporting. A modelling approach is then applied to ensure that emissions and subsequent removals from non-anthropogenic natural disturbances average out over time, leaving greenhouse gas emissions and removals of anthropogenic fires as the dominant result in the national inventory (IPCC 2006 Volume 4 1.5), consistent with the MLP. The approach ensures that Australia's modelled implementation of the MLP is comparable with estimates generated using other methods, such as Tier 3 stock-difference approaches, that tend to average out interannual variability due to natural causes over space (scaling from plots to region) and time (averaging between periodic re-measurements). (NIR, 2023 Australia volume I) All estimated net emissions from managed land including from anthropogenic and natural sources are reported separately and transparently in the NIR.

5.3.8 - Examples of how different methods capture indirect effects

A recent study (e.g. Grassi et al. 2018) concluded that the impact of recent indirect effects on forest CO_2 fluxes is partly or mostly captured in the majority of Annex I countries' NGHGIs (corresponding to 87% of their total forest net GHG flux) and at least in largest Non-Annex I countries. While Box 4.3 illustrates the theoretical relationship between various estimation methods and individual drivers/effects, the table below provides an analysis of concrete methods used to estimate forest CO_2 fluxes in NGHGIs of selected countries, and the implications for the inclusion of recent indirect effects (see also Grassi et al. 2021, Supplementary Information)



	Overview of the methods (based on NIRs for Australia, Canada, EU, Russia and USA, on NC for Brazil, and BURs of China and India)	**Are transient effects of environmental change (indirect human effects) included in the estimate reported in the NGHGI ?**
Australia	Australia uses different methods for different subdivisions of its forest land. Gain-loss method for the subdivision "harvested natural forest" is modeled by using age-related net increment rates, constant across the time series. Process models (based on empirical tree yield formula that allows for responses to climatic variability, while empirical data and parameters constrain initial aboveground biomass and forest growth) are applied to forest plantations and to other native forest, including their conversion (deforestation and afforestation). As all methods are based on yield curves they capture indirect effects only for the period of data collection.	Mostly not
Canada	Gain-loss method using annual statistics of forest management, natural disturbances, and land-use changes, based on empirical data of forest growth and mortality and simulated C dynamics of dead organic matter and soil C pools. Data integrated with the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3[20]). Empirical yield curves quantify age, species, and site-class forest growth rates but these do not vary over time. Indirect effects are only transiently captured to the extent to which they are reflected in the sample plot data from which yield curves were constructed.	Mostly not. Only climate change impacts on disturbances are captured. Impacts on forest growth, non-disturbance mortality and dead organic matter and soil C are not captured.
EU27+UK	In the EU+UK, 17 countries use the gain-loss method and 11 countries use the stock-difference method. Most countries using the gain-loss method estimate the increment using information from national forest inventories repeated over time, which means that the transient impact of recent indirect effects may be assumed to be largely reflected in the GHG estimates. By contrast, few countries (e.g. Italy, Luxembourg, Romania and UK) use a single yield curve to estimate the gains for the entire time series, which means that the transient impact of recent indirect effects is mostly not captured in GHG estimates.	Mostly yes
Russia	A gain-loss model is applied to the different age classes of the prevailing species for estimating emissions and removals from the managed forest. The model includes gain from increment, loss from harvesting, loss from forest fire and loss from drainage of organic soils. Calculations are done on the basis of annual forest resource assessments (including forest management plans and official information on disturbances) on growing stocks by species and age class, repeated over time. Thus, in theory, these calculations incorporate the impacts of CO_2 fertilization, N deposition and temperature regime. However, given many field data used to estimate forest growth are not very recent (V. Korotkov, personal communication), we assume that indirect effects are only partly captured in the NGHGI.	Partly yes
USA	Stock-change method based on extensive network of permanent forest sample plots maintained by the US Forest Service, updated periodically, therefore capturing transient effects. However, natural disturbances are captured with some delay because of the sampling system used.	Mostly yes
Brazil	Brazil explicitly applies the IPCC's managed land proxy and separates managed forest land (235 Mha, including "managed forest", "secondary forest" and "reforestation") from unmanaged forest land (258 Mha). However, the managed land area includes around 206 Mha of areas in which "human action did not cause significant alterations in its original structure and composition". In this area, a net sink of around 1.6 tCO_2 /ha has been reported according to information collected in field plots of scientific studies, mainly in the Amazon region. This net sink is therefore due to the indirect effects of human-actions. Source: 3rd NC (2016), tables 3.81-3.110	Mostly yes
China	For estimating emissions and removals from forest land remaining forest land (i.e. changes in forest and other woody biomass stocks), a combination of gain-loss and stock-change methods is used, depending on the forest type[21], based on carbon stock changes in forests over time from repeated national forest inventories.	Mostly yes
India	Carbon stock changes in forests over time, from repeated national forest inventories, therefore capturing transient effects.	Mostly yes

Annex 5.4 Terminology used in the background paper

Agriculture, Forestry and Other Land Use (AFOLU) - In the context of national greenhouse gas (GHG) inventories under the United Nations Framework Convention on Climate Change (UNFCCC), AFOLU is the sum of the GHG inventory sectors Agriculture and Land Use, Land-Use Change and Forestry (LULUCF). [extract from IPCC AR6 WGIII Glossary]

Anthropogenic emissions and removals - means that GHG emissions and removals included in national inventories are a result of human activities (2019 Refinement to the 2006 IPCC Guidelines Vol 1.1.1 page 1.5). In the AFOLU sector, all emissions and removals on managed land are taken as a proxy for anthropogenic emissions and removals (Managed Land Proxy) (2019 Refinement to the 2006 IPCC Guidelines Vol 1.1.1 page 1.4).

Bookkeeping model - a semi-empirical approach that keeps track of the carbon stored in vegetation and soils before and after a land-use change event (transitions between various natural vegetation types, croplands, and pastures). In the current approach, carbon densities remain fixed over time to exclude the additional sink capacity that ecosystems provide in response to environmental changes. Used in the Global Carbon Budget to estimate emissions and removals from land-use change and land management (ELUC). [SSU note: extract from see section 5.1.1.2].

Dynamic global vegetation model (DGVM) – models that represent the processes of vegetation growth and mortality, as well as decomposition of dead organic matter associated with natural cycles. Many DGVMs also act as land surface schemes of Earth system models used for weather prediction and climate projections. A key purpose of DGVMs is to simulate the vegetation and soil carbon response, expressed as the net biome productivity, to trends and variability in environmental conditions. Used in the Global Carbon Budget to estimate the natural terrestrial sink (SLAND). [SSU note: extract from see section 5.1.1.3].

Emissions – means the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time (UNFCCC Article 1.4). [SSC note: Reported with a positive (+) sign in national GHG inventories].

Gain-Loss method – method that estimates separately all the components of the carbon balance of a land. Depending on the estimation methodology and the data sets used, it may disaggregate some of the drivers and effects on annual emissions and removals. [SSU note: extract from section 5.3].

Good Practice - "Good practice" is a key concept for inventory compilers to follow in preparing national greenhouse gas inventories. The key concept does not change in the 2019 Refinement. The term "good practice" has been defined, since 2000 when this concept was introduced, as "a set of procedures intended to ensure that greenhouse gas inventories are accurate in the sense that they are systematically neither over- nor underestimates so far as can be judged, and that uncertainties are reduced so far as practicable". This definition has gained general acceptance amongst countries as the basis for inventory development and its centrality has been retained for the 2019 Refinement. Certain terms in the definition have been updated based on feedback from the statistics community, such that this definition can be also understood as "a set of procedures intended to ensure that greenhouse gas inventories are accurate in the sense that they are systematically neither over- nor underestimates so far as can be judged, and that they are precise so far as practicable" in the context of refinement of Chapter 3 of Volume 1. Good Practice covers choice of estimation methods appropriate to national circumstances, quality assurance and quality control at the national level, quantification of uncertainties and data archiving and reporting to promote transparency. [from Glossary of the 2019 Refinement to the 2006 IPCC Guidelines]

Integrated assessment model (IAM) - Models that integrate knowledge from two or more domains into a single framework. They are one of the main tools for undertaking integrated assessments. One class of IAM used with respect to climate change mitigation may include representations of: multiple sectors of the economy, such as energy, land use and land-use change; interactions between sectors; the economy as a whole; associated GHG emissions and sinks; and reduced representations of the climate system. This class of model is used to assess linkages between economic, social and technological development and the evolution of the climate system. Another class of IAM additionally includes representations of the costs associated with climate change impacts, but includes less detailed representations of economic systems. These can be used to assess impacts and mitigation in a cost–benefit framework and have been used to estimate the social cost of carbon. [from IPCC AR6 WGIII Glossary]

Land use - A broad classification of land based on the activities and cover, and in this report refers specifically to six general types including Forest Land, Cropland, Grassland, Wetlands, Settlements and Other Land. Note that a specific parcel of land may have more than one land use, but it is generally the predominant land use that forms the basis for the classification. The land-uses may be considered as top-level categories for representing all land-use areas, with sub-divisions describing specific circumstances significant to emissions estimation. [from Glossary of the 2019 Refinement to the 2006 IPCC Guidelines]

Land use, land-use change and forestry (LULUCF) - In the context of national greenhouse gas (GHG) inventories under the United Nations Framework Convention on Climate Change (UNFCCC 2019), LULUCF is a GHG inventory sector that covers anthropogenic emissions and removals of GHG in managed lands, excluding non-CO_2 agricultural emissions. Following the 2006 IPCC Guidelines for National GHG Inventories and their 2019 Refinement, 'anthropogenic' land-related GHG fluxes are defined as all those occurring on 'managed land', that is, 'where human interventions and practices have been applied to perform production, ecological or social functions'. Since managed land may include carbon dioxide (CO_2) removals not considered as 'anthropogenic' in the scientific literature assessed in IPCC Assessment Reports (e.g., removals associated with CO_2 fertilization and N deposition), the land-related net GHG emission estimates from IPCC Assessment Reports are not necessarily comparable with LULUCF estimates in National GHG Inventories (IPCC 2006, 2019). [from IPCC AR6 WGIII Glossary]

Managed land - Land where human interventions and practices have been applied to perform production, ecological or social functions. All land definitions and classifications should be specified at the national level, described in a transparent manner, and be applied consistently over time. Therefore, what is not defined as 'managed land' by a country should be classified as unmanaged. [from Glossary of the 2019 Refinement to the 2006 IPCC Guidelines] [SSC Note: More details can be found in section 5.3]

National Greenhouse Gas Inventories (NGHGI) - a NGHGI includes a set of standard reporting tables covering all relevant gases, categories and years (2019 Refinement to the 2006 IPCC Guidelines, Vol 1.1.1 page 1.6). TSU Notes: (i) Coverage: sources and sinks - Inventories should be a complete account of anthropogenic sources and sinks consistent with the UNFCCC definitions and generally include, as a minimum, estimates of the anthropogenic sources and sinks identified by the IPCC Guidelines. (ii) Coverage: territorial - National inventories should include anthropogenic greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction (2019 Refinement to the 2006 IPCC Guidelines, Vol 1.1.1 page 1.6).

Removals - Removal of greenhouse gases and/or their precursors from the atmosphere by a sink. [SSC note: Reported with a negative (-) sign in national GHG inventories].

Sink - any process, activity or mechanism which removes a greenhouse gas (GHG), an aerosol or a precursor of a greenhouse gas from the atmosphere (UNFCCC Article 1.8).

Source - any process or activity which releases a greenhouse gas, an aerosol or a precursor of a greenhouse gas into the atmosphere (UNFCCC Article 1.9).

Stock Difference method - method that calculates net emissions/removals as the difference in estimated C stocks for relevant pools measured at two points in time. All drivers and effects (direct and indirect human induced effects and natural effects) are fully captured and cannot be disaggregated. [SSU note: extract from section 5.3].

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Additional online resources

IPCC side event at COP27 (2022)
Estimating GHG Emissions: Reconciling Different Approaches. https://apps.ipcc.ch/outreach/programme.php?q=81&e=5.

Carbon Brief

- Grassi et al. (2018). Credible tracking of land-use emissions under the Paris Agreement https://www.carbonbrief.org/guest-post-credible-tracking-of-land-use-emissions-under-the-paris-agreement/
- Grassi et al. (2021). A 'Rosetta Stone' for bringing land-mitigation pathways into line https://www.carbonbrief.org/guest-post-a-rosetta-stone-for-bringing-land-mitigation-pathways-into-line
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