INTERGOVERNMENTAL PANEL ON climate change

**SIXTY-SECOND SESSION OF THE IPCC**
**Hangzhou, China, 24 to 28 February 2025**

IPCC-LXII/INF. 4
(24.I.2025)
Agenda Item: 10.6
ENGLISH ONLY

## PROGRESS REPORTS

## Report by the Task Force on National Greenhouse Gas Inventories

(Prepared by the Co-Chairs of the Task Force on National Greenhouse Gas Inventories)

(Submitted by the Secretary of the IPCC)

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UN environment programme

## PROGRESS REPORTS

### Report by the Task Force on National Greenhouse Gas Inventories

This report describes the activities undertaken by the Task Force on National Greenhouse Gas Inventories (TFI) since the last update presented during the Sixty-first Session of the IPCC in July 2024.

A. Activities to develop methods for the estimation of emissions of greenhouse gases (GHGs) by sources and removals by sinks:

   i. preparation for the Methodology Report on Short-lived Climate Forcers (SLCFs);
   ii. IPCC Expert Meeting on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage;
   iii. IPCC Scoping Meeting on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage; and
   iv. IPCC Expert Meeting on Reconciling Anthropogenic Land Use Emissions.

B. Activities to promote the dissemination of information related to inventory methods and practices:

   i. management of the IPCC Inventory Software;
   ii. development of a TFI Communications Strategy;
   iii. IPCC Workshop on the IPCC Inventory Software; and
   iv. review of the procedures governing the IPCC Emission Factor Database.

C. The set up of the TFI Technical Support Unit (TSU).

**A. Activities to develop methods for the estimation of emissions of greenhouse gases (GHGs) by sources and removals by sinks**

**(i) Preparation for the Methodology Report on Short-lived Climate Forcers**

The Panel at its $61^{st}$ session (IPCC-61) agreed the outline for a Report to be entitled "2027 IPCC Methodology Report on Inventories for Short-lived Climate Forcers'.

The IPCC Secretary invited nominations from IPCC Focal Points for author positions and 394 nominations were received. After consultation with WG chairs, the Task Force Bureau (TFB) has selected an author list which includes 53 authors from developing and economies-in-transition countries based on the budget agreed at IPCC-60. Statistics are reported in Attachment A.

The First Lead Author Meeting will be held 24-26 March 2025 in Bilbao, Spain while the Report will be completed by 2027.

Given the expansive nature of the task, which is to provide methodologies for all sources of SLCFs, additional authors may be sought to complete the writing process starting from LAM2.

**(ii) IPCC Expert Meeting on Carbon Dioxide Removal Technologies, Carbon Capture and Storage**

The Expert Meeting on Carbon Dioxide Removal Technologies, Carbon Capture and Storage was held in Vienna, Austria, on 1-3 July 2024 and attended by 76 experts. Participation statistics are reported in Attachment A.

A Report of the Meeting is in Attachment B and available on line at *Publications - IPCC-TFI* together with presentations by experts and the TSU background paper.

**(iii) The IPCC Scoping Meeting on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage**

The Scoping Meeting for the Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage was held in Copenhagen, Denmark on 14-16 October 2024 and attended by 78 nominated experts, of which 18 were on-line. The participation statistics are in Attachment A.

A Report of the Meeting is in Attachment C and available on the TFI website here.

The draft decisions recommended by the Meeting participants for the title, outline, terms of reference and instruction to authors will be considered at IPCC-62. The title of the Report is recommended to be *2027 IPCC Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage (Supplement to the 2006 IPCC Guidelines).*

The First Lead Author Meeting for the drafting of the Methodology Report is planned to take place 16-19 July 2025.

**(iv) The IPCC Expert Meeting on the Reconciling Anthropogenic Land Use Emissions**

The Expert Meeting on Reconciling Anthropogenic Land Use emissions was held in Ispra, Italy on 9-11 July 2024 and attended by 102 experts, of which 24 were on-line. The Meeting preparation was overseen by a Science Steering Committee, established by the TFI TFB, and comprised representatives from each IPCC region as well as from TFI and from each of the IPCC Working Groups I, II and III. The Science Steering Committee commenced work in March 2024 and met four times in total.

The objective of the Meeting was to enhance the policy relevance of IPCC products by reconciling the apparent discrepancies between modeling estimates of net emissions from the land and estimates reported using IPCC Methodologies.

The participation statistics are in Attachment A.

A Report of the Meeting is in Attachment D and available on the TFI website here.

## B. Activities to promote the dissemination of information related to inventory methods and practices

**(i) The management of the IPCC Inventory Software**

The IPCC Inventory Software Update was launched in June 2024 to support the use of the *2006 IPCC Guidelines* in reporting under the Paris Agreement and, in particular, by those national governments reporting for the first time and scheduled for the end of 2024.

The TFI TFB received a progress report from the Technical Support Unit (TSU) at the 37th session of the TFB Meeting held in Copenhagen, Denmark 17-18 October 2024.

The ongoing challenge for the TFI TFB will be to devise processes and funding to manage the maintenance of the software over time and, given that the software will be an important element in many countries' reporting processes, to devise a plan for the long-term management of the software.

The latest version of the IPCC Inventory Software can be downloaded from the TFI website here.

### (ii) Development of a TFI Communications Strategy

The TFI Communications Strategy was considered by the 37th session of the TFB. The Strategy aims to promote the dissemination of IPCC products and practices within the context of both the TFI objectives and the existing over-arching IPCC Communications Strategy.

Activities under the Strategy include the renewal of the TFI website (including closer links with the IPCC website); the dissemination of IPCC TFI products more consistently to targeted audiences; and the consolidation of existing Methodological Guidance. The TFB has agreed that a consolidation of existing guidance (*2006 IPCC Guidelines for National Greenhouse Gas Inventories,* the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands* and the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*) would be welcomed by GHG inventory compilers, even though it would not have the status of an IPCC Methodology Report. The TFB aims to publish this consolidated document by mid-2025.

### (iii) The IPCC Workshop on the IPCC Inventory Software

The IPCC Workshop on the IPCC Inventory Software was held in Baku, Azerbaijan on 4-6 September 2024. The Workshop was held at the invitation of the Parties to the Paris Agreement and was co-presented by the UNFCCC secretariat.

The main objectives of the Workshop were to support reporting by Parties under the UNFCCC and Paris Agreement by demonstrating the IPCC Inventory Software functionality (which encompasses the IPCC Methodologies) and the interoperability of the IPCC Inventory Software with the UNFCCC Enhanced Transparency Framework reporting tool.

Experts from a total of 84 countries were represented at the Workshop (participation statistics are in Attachment A) while an additional 49 participants were able to participate online. A pre-Workshop webinar for participants was held on 15 August 2024. Workshop presentations are available at Publications - IPCC-TFI.

Over 95 per cent of participants expressed satisfaction with the quality of the Workshop according to the results of the ex-poste survey (51 respondents out of 84 attendees).

Around two-thirds of the participants expressed their intention to use the IPCC Inventory software in some capacity to support their preparation for future submissions of emission estimates under the Paris Agreement.

### (iv) Review of the procedures governing the IPCC Emission Factor Database

A review of the Emission Factor Database (EFDB) is being undertaken by an EFDB Management Group comprising the Co-Chairs, the EFDB Chairs/users and 2 members of the TSU. This group will report on the governance and functioning of the EFDB for the TFI TFB's consideration in early 2025.

## C. Set up of the TFI Technical Support Unit (TSU)

The TSU has put in place an enlarged team to manage the increased volume of Meetings and the simultaneous production of two Methodology Reports for the seventh assessment cycle and now comprises a 'Head of Operations' officer; a 'Head of Science', a 'Deputy Head' and 6 Programme and administrative officers.

The Co-Chairs would like to thank the Governments of Australia, Austria, Azerbaijan, Denmark, Norway, the United States of America, and the European Commission for their generosity in supporting the work of the TFI in 2024 through voluntary and in-kind contributions.

**Attachment A**

# Process of participant selection and statistics of participants at IPCC TFI Expert Meetings and Workshops

## Expert Meeting on Carbon Dioxide Removal Technologies Carbon Capture, Utilization and Storage (1-3 July 2024)

### Objective

The objective of the selection process was to invite around 80 experts for the Meeting considering criteria stated in Appendix A of Principles Governing IPCC Work (40 travel supports were provided by the IPCC Trust Fund (Decision IPCC-LX-10)).

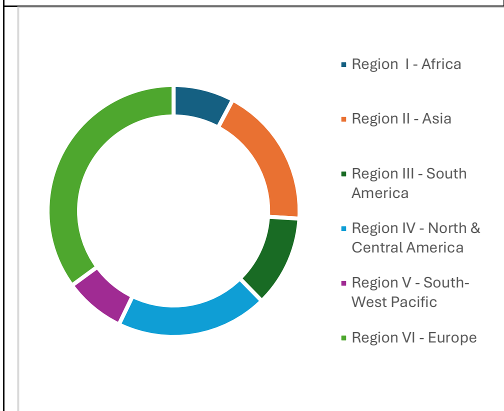
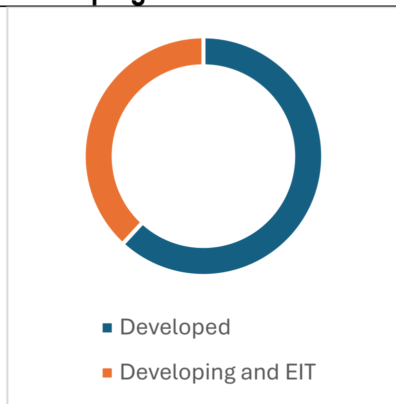
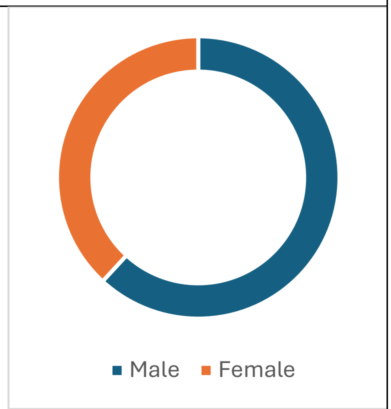
### Selection process

The decision to proceed with the Meeting was taken at the 60th session of the IPCC on 16-19 January 2024. The selection of invitees for this Expert Meeting was implemented by the TFI TFB, with assistance of the TFI TSU. Invitations were issued by the TFI Co-Chairs from 2 April 2024.

### Participation of invitees

A total of 76 invitees participated in the Expert Meeting, of which 21 were online. The list of participants, together with the members of TFB and TFI TSU staff present at the meeting, is provided in Appendix 2 of the Meeting Report.

### Statistics of participants

| Distribution of participants by region | Distribution of participants by developed and developing/EIT countries | Distribution of participants by gender |
|---|---|---|
|   |   |   |

## Expert Meeting on Reconciling Anthropogenic Land Use Emissions (9-11 July 2024)

### Objective

The objective of the selection process was to invite around 80-100 experts considering criteria stated in Appendix A of Principles Governing IPCC Work (40 travel supports were provided by the IPCC Trust Fund (Decision IPCC-LX-10)).

### Selection process

The decision to proceed with the Meeting was taken at the 60th session of the IPCC on 16-19 January 2024. The selection of invitees was implemented by the Science Steering Committee established by the TFI TFB and comprising representatives from all WGs. Invitations were issued by the TFI Co-Chairs from 25 March 2024.

### Participation of invitees

A total of 102 invitees participated in the Expert Meeting, of which 24 were online, while around 100 experts participated in the pre-Meeting webinar, held on 25 June 2024. The list of participants, together with the members of TFB and TFI TSU staff present at the meeting, is provided in Attachment C.

### Statistics of participants

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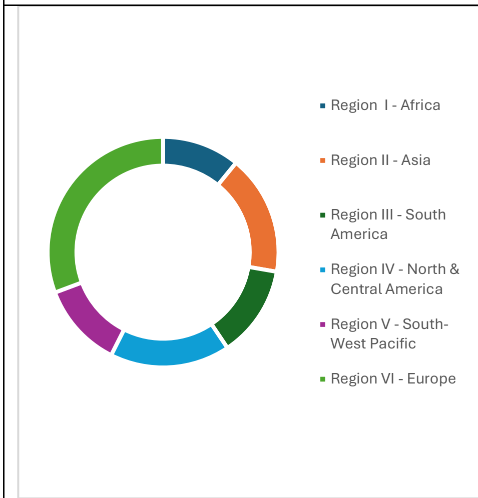
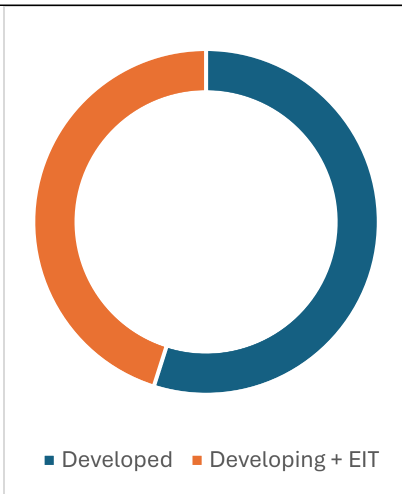
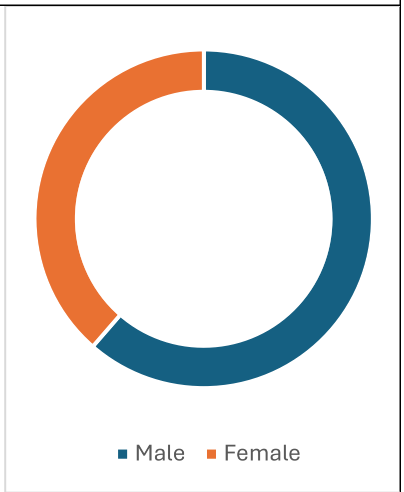
<tr><th>Distribution of participants by region</th><th>Distribution of participants by developed and developing/EIT countries</th><th>Distribution of participants by gender</th></tr>
<tr><td>
</td><td>
</td><td>
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## IPCC Workshop on IPCC Inventory Software (4-6 September 2024)

### Objective

The objective of the selection process was to invite one expert per country, consistent with the decision of Decision IPCC-LX-10 while 138 travel supports were available from the IPCC Trust Fund.

### Selection process

The decision to proceed with the Meeting was taken at the 60th session of the IPCC on 16-19 January 2024. Nominations were sought from IPCC Focal Points by the IPCC Secretary on 23 May 2024 using the IPCC nominations portal. The selection of invitees was implemented by the TFI TFB and invitations were issued by the TFI Co-Chairs from 16 July 2024.

### Participation of invitees

Representatives from a total of 84 countries participated in the Workshop, while an additional 49 participants were able to participate online. Around 100 experts participated in the pre-Meeting webinar, held on 15 August 2024.

### Statistics of participants

<table>
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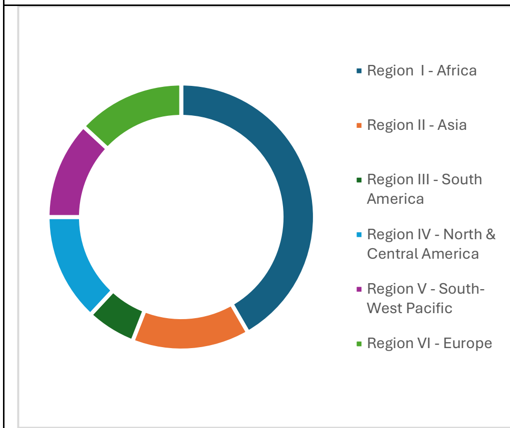
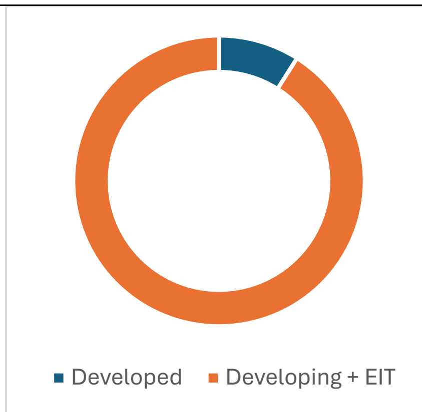
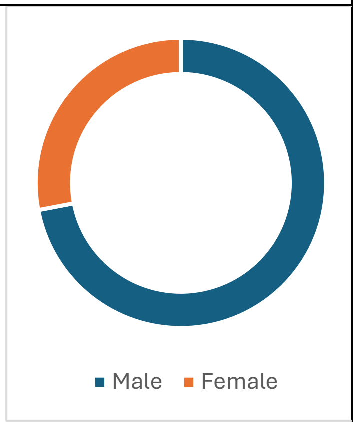
<tr><td>
</td><td>
</td><td>
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## IPCC Scoping Meeting on Carbon Dioxide Technologies, Carbon Capture, Utilization and Storage (14-16 October 2024)

### Objective

The objective of the selection process was to select around 80 experts (40 travel supports were provided by the IPCC Trust Fund (Decision IPCC-LX-10)).

### Selection process

The decision to proceed with the Meeting was taken at the 60th session of the IPCC on 16-19 January 2024. Nominations were sought from IPCC Focal Points by the IPCC Secretary on 14 June 2024 using the IPCC nominations portal. The selection of invitees was implemented by the TFI TFB and invitations were issued by the TFI Co-Chairs from 13 August 2024.

### Participation of invitees

There were 78 invited experts that participated in this Scoping Meeting, with 18 of these participating on-line.

### Statistics of participants

| Distribution of nominations by region | Distribution of nominations by developed and developing/EIT countries | Distribution of nominations by gender |
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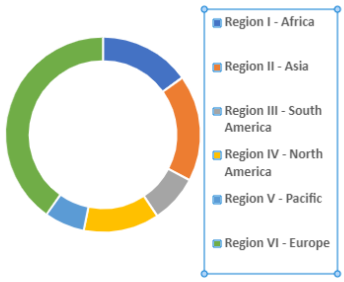
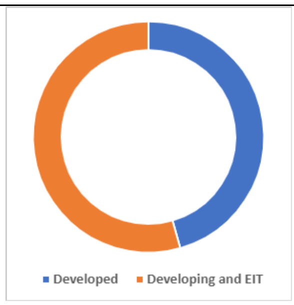
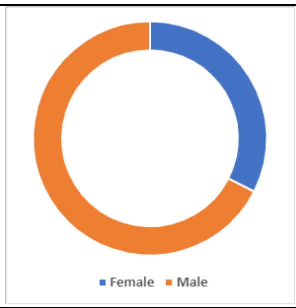
|  |  |  |
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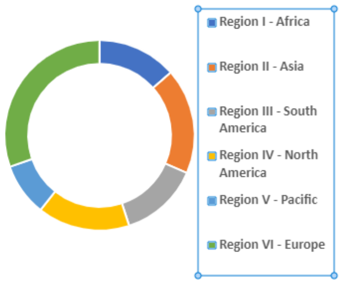
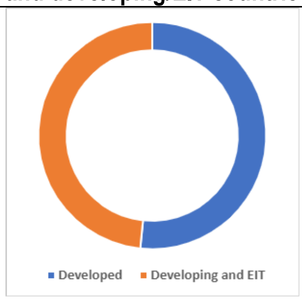
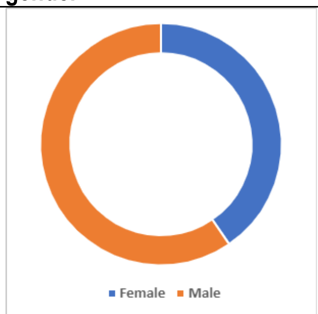
|  |  |  |
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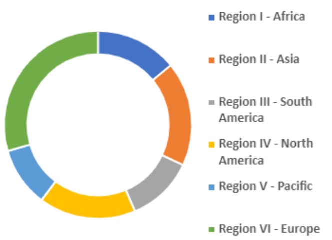
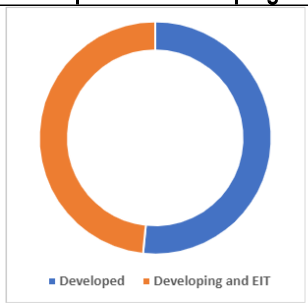
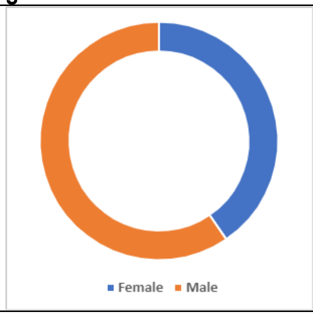
|  |  |  |

## IPCC Methodology Report on Short Lived Climate Forcers: First Author Lead Meeting (24-26 March 2025)

### Objective

The objective of the selection process was to invite around 110 experts (53 travel supports were provided by the IPCC Trust Fund (Decision IPCC-LX-10)).

### Selection process

The decision to proceed with the Meeting was taken at the 61st session of the IPCC on 27 July – 2 August 2024. Nominations were sought from IPCC Focal Points by the IPCC Secretary on 9 August 2024 and again on 2 October 2024 using the IPCC nominations portal.

The selection of invitees was implemented by the TFI TFB, after consultation with the WG chairs.

### Nominations received

There were 394 nominations received.

### Participation of invitees

There were 112 invitations issued.

### Statistics

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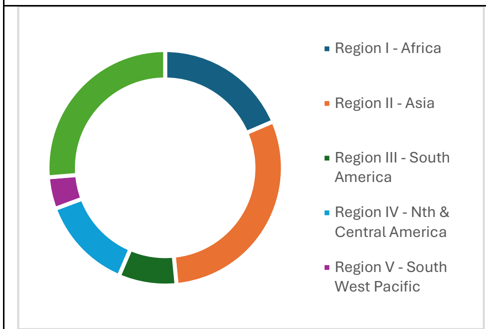
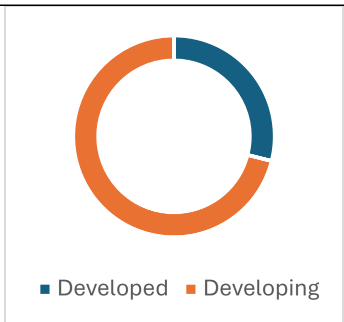
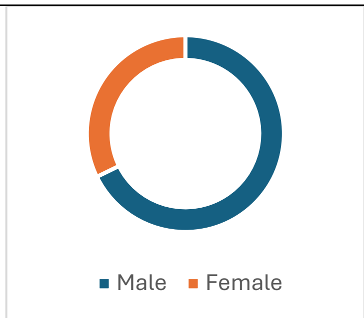
<tr><td>
</td><td>
</td><td>
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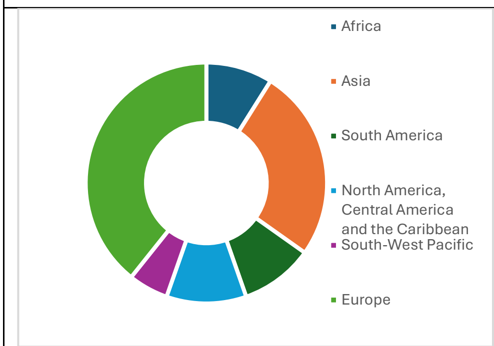
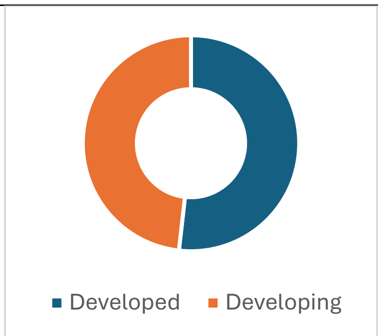
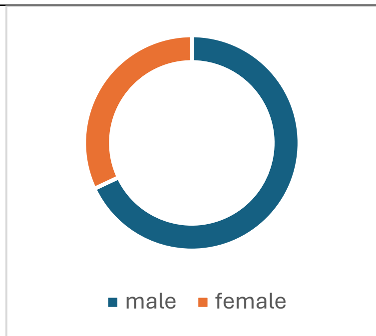
<tr><td>
</td><td>
</td><td>
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Attachment B

# IPCC Expert Meeting

# Carbon Dioxide Removal Technologies and Carbon Capture, Utilization and Storage

## Report of the IPCC Expert Meeting

1-3 July 2024, Vienna, Austria

Task Force on National Greenhouse Gas Inventories

The IPCC Expert Meeting on Carbon Dioxide Removal Technologies and Carbon Capture, Utilization and Storage was organized by the IPCC Task Force on National Greenhouse Gas Inventories (TFI) with support from the Government of Austria. It was held on 1-3 July 2024 in Vienna, Austria.

This meeting report was prepared by the Co-Chairs of the IPCC TFI (Takeshi Enoki and Mazhar Hayat) and the TFI Technical Support Unit (TSU) and subjected to review by the meeting participants.

Supporting material prepared for consideration by the Intergovernmental Panel on Climate Change (IPCC). This supporting material has not been subject to formal IPCC review processes.

Published by the Institute for Global Environmental Strategies (IGES), Hayama, Japan on behalf of the IPCC



Please cite as:

IPCC (2024). IPCC Expert Meeting on Carbon Dioxide Removal Technologies and Carbon Capture, Utilization and Storage Eds: Enoki, T., Hayat, M., Report of the IPCC Expert Meeting, Pub. IGES, Japan.

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## Preface

The IPCC Working Group III (WGIII) contribution to the Sixth Assessment Report (AR6) states that "The deployment of carbon dioxide removal (CDR) to counterbalance hard-to-abate residual emissions is unavoidable if net zero $CO_2$ or GHG emissions are to be achieved" and provides a summary of the role for CDR technologies in future mitigation pathways (IPCC 2022 Table TS.7).

The IPCC Guidelines already provide for inventory compilers to estimate and report on anthropogenic sinks from **any** process, activity or mechanism which removes a greenhouse gas from the atmosphere, in their national GHG inventories (NGHGI). This includes direct air capture technologies, for example, which currently do not have explicit methodologies specified.

Still, with the emergence of new carbon dioxide removal technologies and the generation of new empirical data on relevant sources and sinks, it may be valuable to consider new methods in the IPCC Guidelines. If adopted, these new methods will broaden the base of sinks and sources that inventory compilers should routinely monitor and facilitate their estimation and reporting in future national inventories.

With this context in mind, the IPCC tasked the Task Force on National Greenhouse Gas Inventories (TFI), in January 2024, to develop a Methodology Report on *Carbon Dioxide Removal Technologies, Carbon Capture Utilisation and Storage* activities (Decision IPCC-LX- 9).

An Expert Meeting on this topic was also mandated by the IPCC and held in Vienna on 1-3 July 2024. This was the first step along the journey to prepare the Methodology Report and this document is a Report of that Meeting.

Later in the year, a formal IPCC Scoping Meeting will be held to make recommendations on the Scope of the Methodology Report for consideration by the IPCC in early 2025. Following the decision of governments, a Methodology Report will be prepared through four Lead Author Meetings with the final report to be considered for acceptance by the IPCC Panel by the end of 2027.

This preparation process will be steered by the IPCC TFI Bureau.

This Expert Meeting was aimed at collecting evidence and information about gaps in the existing IPCC guidance (or where existing guidance might be updated and elaborated) and the capacity of the process to be able to rigorously specify IPCC methodologies for CDR technologies or where there was a need to update CCUS guidance. The meeting also aimed to identify knowledge gaps and any specific areas or issues to be prioritized in the development of methodologies.

This Report of the outcomes of the Expert Meeting is based on contributions by participants and includes materials prepared during Break Out Group discussions and considered by the Expert Meeting plenary. The Background document prepared by the TFI TSU and presentations made by invited experts have been published alongside this report.

We would like to thank the experts who gave their time to contribute to this Meeting and, in particular, we would like to express our sincere gratitude to the Government of Austria for its generous support as hosts.

The meeting was opened by the Federal Government of Austria Minister for Finance, Magnus Brunner, together with the IPCC Chair, Jim Skea, and closed by the Federal Government of Austria Minister for Climate Action, Environment, Energy, Mobility, Innovation and Technology, Leonore Gewessler.

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

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

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## 1. Introduction

The IPCC, at its 60th Session on 16-19 January 2024 in Istanbul, Türkiye, decided that the Task Force on National Greenhouse Gas Inventories (TFI) should hold an Expert Meeting and produce a Methodology Report on *Carbon Dioxide Removal Technologies and Carbon Capture, Utilization and* Storage (Decision IPCC-LX-9).

This IPCC TFI Expert Meeting was held on 1-3 July 2024 in Vienna, Austria.

The Meeting was supported with a Background Paper prepared by the IPCC TFI TSU.

The Meeting process comprised presentations by invited experts and discussions held in 3 Break Out Groups (see Appendix 1 for the Agenda). The invited presentations are listed in Table 1. See Appendix 2 for the list of participants.

**Table 1: List of Speakers and Presentations**

| | **Presenter/Title** |
|---|---|
| 1 | Simon Pang (Lawrence Livermore National Laboratory), *Engineered Solutions to Carbon Dioxide Removal* |
| 2 | Mai Bui, (Imperial College London), *Assessing the deployment potential of direct air capture and BECCS technologies* |
| 3 | Mark De Figueiredo (US DoE) *Monitoring, Reporting and Verification of CDR and CCUS: US Experiences and Lessons Learned for National GHG Inventories* |
| 4 | Paul Zakkour (Carbon counts) *Experiences with the 2006 IPCC Guidelines for $CO_2$ transport and storage: a rapid review of national reporting practices* |
| 5 | Dario Gomez (Atomic Energy Commission of Argentina) [On-line] *Existing guidance and need for updating on carbon dioxide capture in Volume 2 of the IPCC Guidelines* |
| 6 | Karen Scrivener (Ecole Polytechnique Federale de Lausanne), *$CO_2$ Uptake by Cement Based Materials: Principles, estimation, unknowns and future trends* |
| 7 | Anu Khan (carbon180) *Jurisdiction-Level Monitoring for Enhanced Weathering: Infrastructure, Data, and Maintenance Needs* |
| 8 | Andrew Lenton (CSIRO) *CDR in territorial waters: the challenges and opportunities* |
| 9 | Claudia Kammann, (Hochschule Geisenheim University), *State of Biochar-CDR: Growth of industries, C persistence, CDR co-benefits and current C-sink certification and trading schemes.* |
| 10 | Mihri Ozkan (University of California), [On-line] *Advancing Direct Air Capture: Empirical Foundations and Methodological Innovations for Emission Reduction* |
| 11 | Omkar Patange (IIASA) and Amit Garg (Indian Institute of Management) *The feasibility of developing new or updated IPCC default methods (and default emission factors) for various emerging technologies* |

| | |
|---|---|
| 12 | Steve Smith (University of Oxford) *Current CDR activity and gaps in existing IPCC Guidelines* |
| 13 | Freya Chay (Carbon Plan) *Open scientific questions across carbon removal approaches* |
| 14 | Dr. Katherine Romanak (Bureau of Economic Geology, The University of Texas at Austin) and Tim Dixon, (IEAGHG), *Improving the Protocols for CO2 Leakage Monitoring with Attribution* |
| 15 | Miguel Ángel Sanjuán, (Spanish Institute of Cement and its Applications), *State of the art on the quantification of natural carbonation of cement-based materials as a $CO_2$ capture mechanism* |

Days 2 and 3 of the Meeting were devoted to discussions among experts in Break Out Groups (BOGs):

1. BOG1 – Engineered capture, utilisation & geological storage;
2. BOG2 – Inorganic processes and storage; and
3. BOG3 – Biogenic processes and storage.

The Break Out Groups considered the following guiding questions for each of the identified CDR technologies:

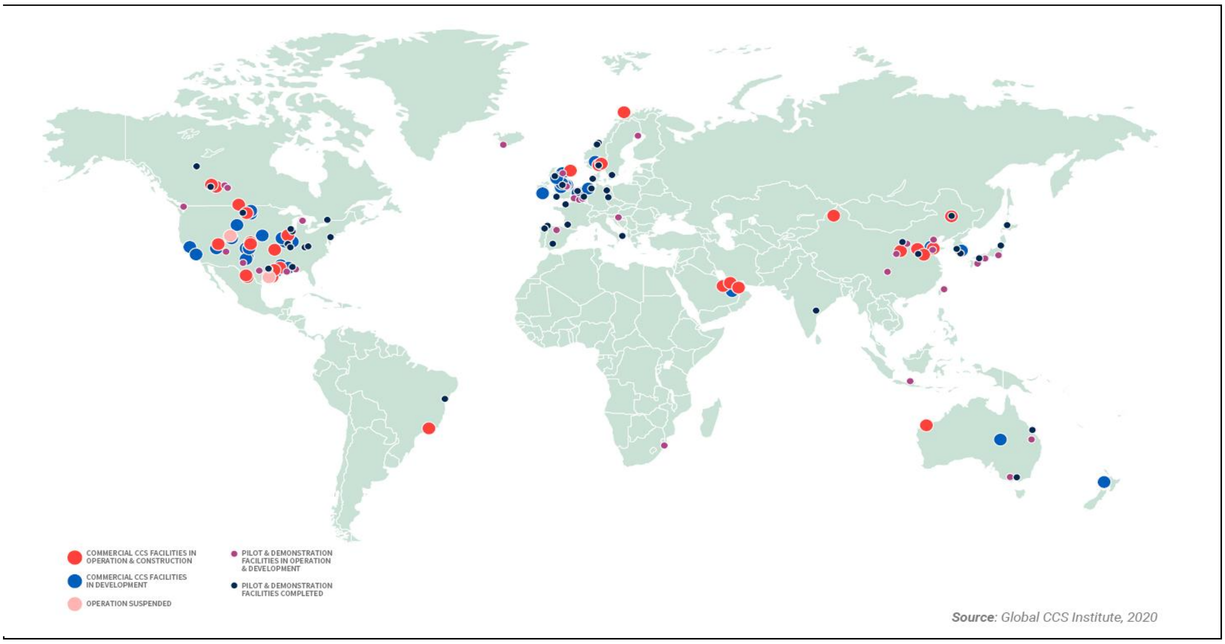
- Question 1 – Assessment Criteria
- Question 2 – Completeness
- Question 3 – Taxonomy of sources and sinks
- Question 4 – Preliminary assessment of existing IPCC Guidelines estimation methodologies
- Question 5 – Feasibility of Tier 1 methods
- Question 6 – Higher tier methods
- Question 7 – Verification Activities

The BOGs also considered additional questions which are reported in the next sections.

The Scoping Meeting presentations (invited presenters, BOGs and TSU) are available together with this report at the IPCC-TFI website: https://www.ipcc-nggip.iges.or.jp/ .

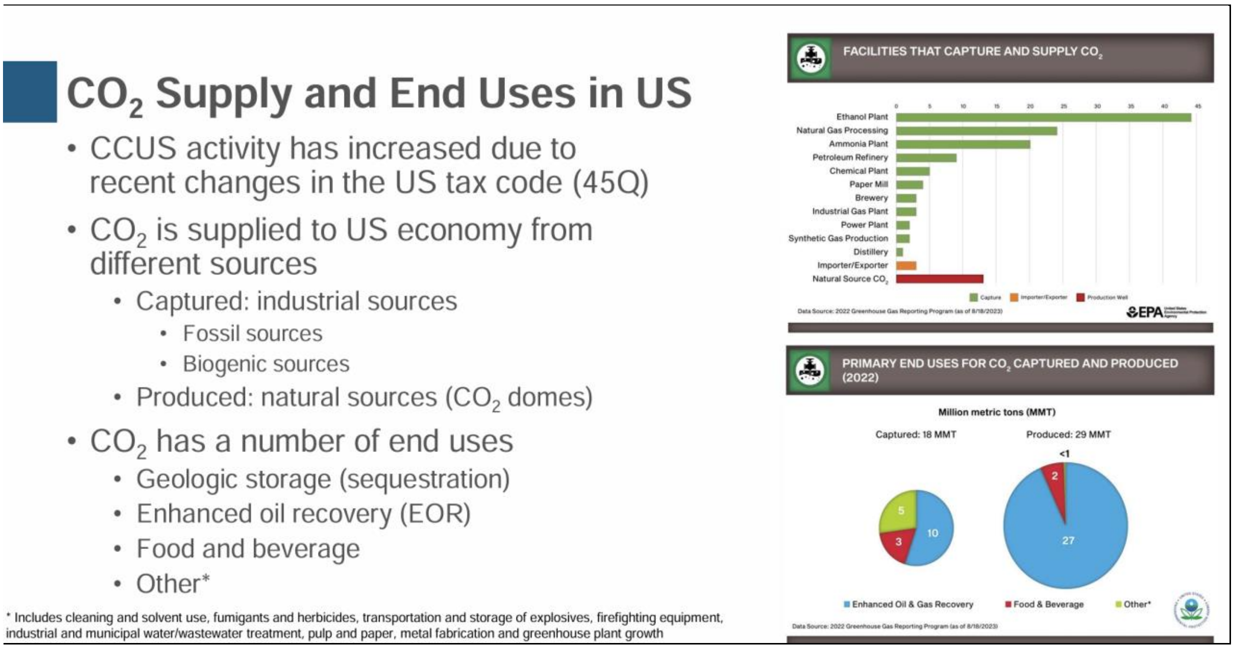
The presentations brought forward evidence and supporting material as to the prevalence of emerging CDR technologies and CCUS activities, some of which is captured in the following figures.

**Figure 1: Carbon capture and storage sites**



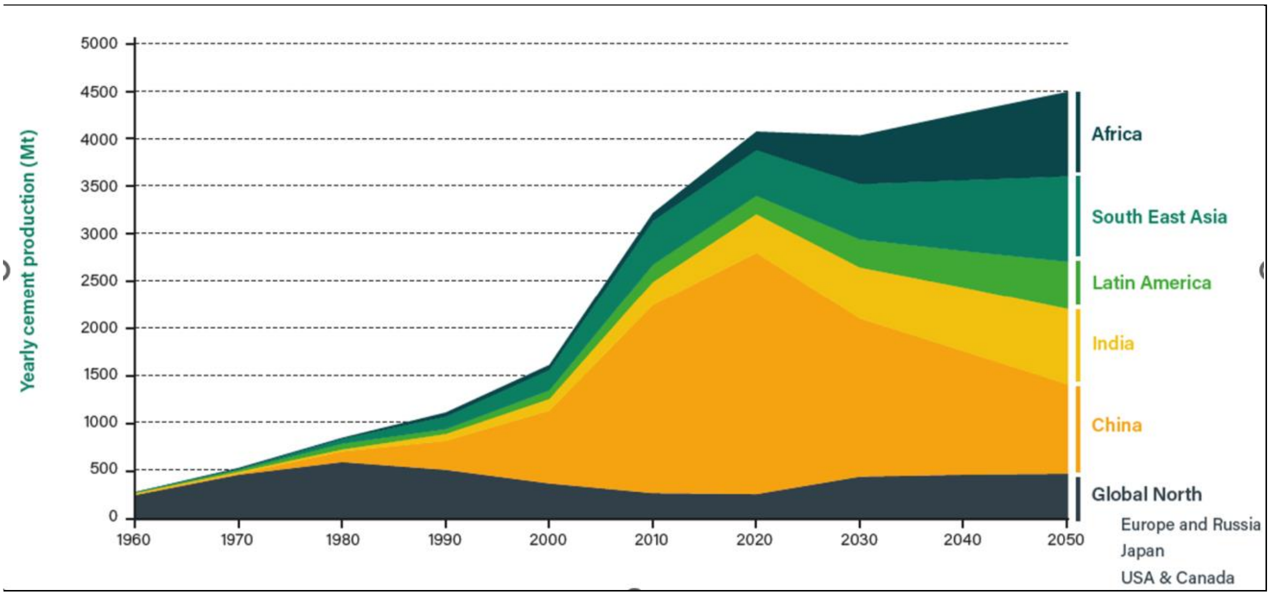

Presented by Paul Zakkour

**Figure 2: Example of carbon dioxide supply and utilisation: United States**



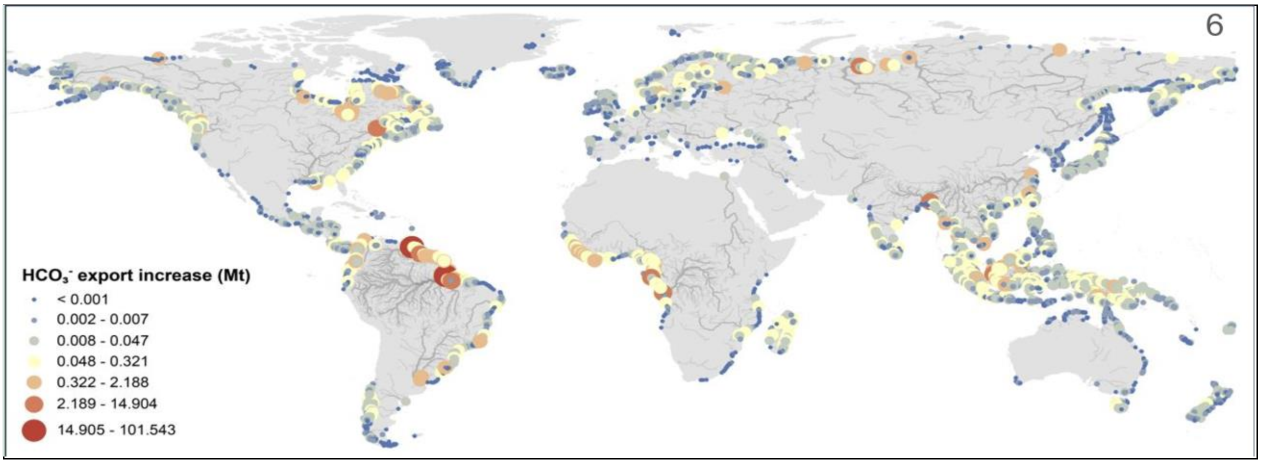

Presented by Mark de Figueiredo

**Figure 3: Projections for future cement supply**




Presented by Karen Scrivener

**Figure 4: Expected significance of river weathering**




Presented by Anu Khan

**Figure 5: Map of field trials for ocean activities**


Presented by Andrew Lenton

These descriptions of the extent of activities vary in significance from technology to technology. In Figure 1 the sites for existing carbon capture and storage activities are provided whereas in Figure 5 the map represents locations of the more limited concept of field trials for different types of ocean activities.

For more information, please refer to the published presentations on the IPCC TFI website.

## 2. Meeting Discussions

The reports prepared by each BOG are reported in full in the following sections. In this section, the results of discussions across the BOGs for certain elements are aggregated together for ease of reference.

### 2.1 Criteria for assessing scope of the future Methodology Report

This Meeting recommended criteria to assess sinks and sources for inclusion in the draft scope of the future Methodology Report to be used by participants to the Scoping Meeting. These criteria were supported by all BOGs and include:

1. the **identification of gaps** in the existing IPCC Guidelines for specific anthropogenic sinks or sources; or the identification of relevant existing sources and sinks where an elaboration of the Guidelines is considered desirable;

2. the **delineation** of the anthropogenic sink or source to be estimated;

3. the current and **expected significance** of the anthropogenic activity;

4. the knowledge available to generalize an IPCC Tier 1 methodology applicable under any national circumstances:

    a. availability of necessary **activity data** to implement the methods (readily available national or international statistics); and

    b. the ability to specify **tier 1 default values**:

    i. sufficient availability of data[1] to calculate a global (at least) value from a sample large enough to have it as a central value; and

    ii. which should be expected to produce unbiased estimates, so far as can be judged.

[1] Including expert judgments provided according to the IPCC elicitation protocol.

5. the feasibility of being able to specify higher tier methods for use by inventory compilers; and

6. guidance for inventory compilers as to how they may be able to devise appropriate verification activities.

One issue further discussed by participants related to the concept of significance: – this has not been defined and could mean a range of things to participants including, as noted by BOG1, the Long-term Low-Emission Development Strategies of countries.

## 2.2 Processes/technologies considered

The meeting initially considered the list of CDR technologies provided in the IPCC WGIII sixth assessment cycle report (Table TS.7). During the Meeting, the list of technologies considered was expanded beyond the list initially identified (Table 2).

The concept of 'technologies' received some discussion since it is not defined and does not fit within the IPCC classification system, which is based on delineating sources and sink processes with common estimation methods. Discussions among experts at this Meeting tended to adopt a broad understanding of the meaning of 'technology'.

**Table 2 List of CDR technologies considered**

| Type of process | IPCC WGIII | Final list identified by BOGs |
|---|---|---|
| Engineered carbon capture with geological storage in the lithosphere | Direct air carbon capture and storage | Direct air carbon capture and storage |
| | Bioenergy with carbon capture and storage | Bioenergy with carbon capture and storage |
| Carbon capture in products | | Concrete carbonation (incl. enhanced concrete carbonation) |
| | | Carbonatable by-product materials (where not included elsewhere in national GHG inventory, e.g. slags, precipitated) |

| Type of process | IPCC WGIII | Final list identified by BOGs |
|---|---|---|
| Anthropogenic mineral processes with storage of inorganic carbon in minerals or as bicarbonate ions | Enhanced weathering | Enhanced weathering on managed land |
| | | Enhanced weathering in rivers |
| | | Ex-situ mineralization (open and closed systems) including enhanced weathering using biogenic $CO_2$ (wastewater alkalinity dosing) |
| | | In-situ mineralization (sub-surface injection and rapid mineralization) |
| | Ocean alkalinity enhancement | Ocean alkalinity enhancement (mineral based and electrochemical) |
| | | Direct ocean $CO_2$ removal (stripping $CO_2$ from seawater) |
| Anthropogenic biological processes (photosynthesis) – biomass | Afforestation/Reforestation | Afforestation/Reforestation |
| | Agroforestry | Agroforestry |
| | Improved Forest Management | Improved Forest Management |
| | Blue carbon management” in coastal wetlands (seagrass meadow, macro algae) | Blue carbon management” in coastal wetlands (seagrass meadow, macro algae) |
| Anthropogenic biological processes (photosynthesis) – soils and waterways | Soil carbon sequestration in croplands and grasslands | Soil carbon sequestration in croplands and grasslands |
| | Peatlands and coastal wetlands restoration | Peatlands and coastal wetlands restoration |
| | Biochar | Biochar |
| | Ocean fertilization | Ocean fertilization |
| | | Biomass burial, Slurry and Oil |

Source: Derived from BOG reports (see sections 3-5).

## 2.3 Processes/technologies preliminary assessments

Each of the 3 BOGs considered the CDR technologies and CCUS activities in detail. The comments and BOG assessments reported for each of the CDR technologies and CCUS activities is included in the following sections 3-5. An overview of key findings is included in Table 3.

**Table 3 Preliminary assessment of CDR technologies Carbon Capture, Utilisation and Storage**

| | For further consideration? | What would be required? | | |
|---|---|---|---|---|
| **Activity** | | **Update to IPCC classification** | **New Guidance** | **Review of existing guidance** |
| Direct air carbon capture and storage | Yes | Yes | Yes | - |
| Carbon capture, utilisation and storage | Yes | Maybe | No | Yes |
| Bioenergy with carbon capture and storage | Yes | No | No | Yes |
| Concrete carbonation (incl. enhanced concrete carbonation) | Yes | Yes | Yes | - |
| Carbonatable by-product materials (where not included elsewhere in national GHG inventory, e.g. slags, precipitates | Yes | Yes | Yes | - |
| Enhanced weathering on managed land | Yes | Yes | Yes | - |
| Enhanced weathering in rivers | Yes | Yes | Yes | |
| Ex-situ mineralization (open and closed systems) including enhanced weathering using biogenic $CO_2$ (wastewater alkalinity dosing) | Yes | Yes | Yes | - |
| In-situ mineralization (sub-surface injection and rapid mineralization) | Yes | Yes | Yes | - |
| Ocean alkalinity enhancement (mineral based and electrochemical) | Yes | Yes | Yes | - |
| Direct ocean $CO_2$ removal (stripping $CO_2$ from seawater) | Yes | Yes | Yes | - |
| Afforestation/Reforestation | No | - | - | - |
| Agroforestry | Maybe | No | No | Yes |
| Improved Forest Management | No | - | - | - |
| Blue carbon management" in coastal wetlands (seagrass meadow, macro algae) | Yes | Yes | - | Yes |
| Soil carbon sequestration in croplands and grasslands | Maybe | No | - | Yes |
| Organic Soils and Peatland and coastal wetlands restoration | Maybe | No | - | Yes |
| Biochar | Yes | No | - | Yes |
| Ocean fertilization | No | - | - | - |
| Biomass burial, Slurry and Oil | No | - | - | - |

Source: Derived from BOG reports (see sections 3-5).

## 3. BOG 1: Engineered capture, utilisation & geological storage

Co-facilitators: Bill Irving and Songli Zhu

Rapporteur: Jongikhaya Witi

### 3.1 Engineered capture, utilisation & geological storage technologies

**Q1: Assessment Criteria**:

- General acceptance of the assessment criteria as presented in the background paper
- New guidance should also include an equivalent of Volume 1 of the 2006 IPCC guidelines to deal with cross-cutting issues and general principles
- Clear guidance on the treatment of import and export of captured $CO_2$ (and derived products) as well as cross-boundary transport and storage
- Significance - The Party's Long-term Low-Emission Development Strategies (LT-LEDS) provide some insights into the future uptake of CDR technologies
- Important to pay attention to durability as we cannot assume permanent storage
- Criteria for significance should also be considered.

**Q2: Completeness**

- Production and use of synthetic fuels from captured $CO_2$ sources from the atmosphere and biosphere
- BECCS – current guidance in Chapters 2 and 5 of Volume 2 addresses BECCS. Further enhancement of the guidance would allow the chapter to also deal with DAC
- Storage of other forms of biogenic carbon in the lithosphere (e.g., bio-oil injection/biomass burial)
- Consider guidance on in-situ and ex-situ mineralisation. enhanced weathering (check with BOG 2 )
- Guidance Structure: guidance to be developed could focus on CDR/CCUS/CCS process steps rather than focusing on the various CDR technologies
- Sea water capture and its interaction with the atmosphere and ocean requires modeling to isolate the atmospheric $CO_2$ signal.

- Consider different types of mineralisation, especially mineral products (e.g. biogenic $CO_2$ going to mineral products, and in the future, we might have DAC going to mineral products)
- Consideration of fugitive $CO_2$ emissions from Shipping in international waters.
- Burial of carbon in an underground chamber (not geological storage) [cross-BOG issue] might require its own category.-

**Q3: Taxonomy of sources and sinks**

- Categorisation of DAC
  - Option 1: Air capture is distinctively different from other IPCC categories and could be treated in a separate category (e.g. Volume 6) and clarify different end-use cases (within or beyond IPCC categories) for any captured $CO_2$.
  - Option 2: Also consider DAC as an industrial activity that processes $CO_2$ and therefore placed under the IPPU sector
- Need to track $CO_2$ imports and exports (evaluate the adequacy of existing guidance – e.g. for shipping)
- Can consider the following options
  - Geological storage can remain in Chapter 5 of Volume 2
  - In accordance with the current IPCC guidance, $CO_2$ captured should be reported where it occurred
- Clear guidance on the treatment of cases with multiple capture sources that lead to single or multiple storage sites (attribution problem).
- Important to trace the origin and fate of $CO_2$ to allow for differentiation

**Q4: IPCC Guidelines methodologies**

- Chapter 5, Volume 2 already addresses EOR (including a T3 method) but authors could consider reviewing existing guidance in accordance with new developments.
- If a country is conducting these activities, it should use the data that is available from CDR and CCS projects (it is a mitigation project Afterall)
- Should we consider T1 and T2 methods for small-scale projects as using T3 might not be economically feasible (e.g. biogas to biomethane upgrading )?

- Tracking the connection between $CO_2$ capture by specific industries and use/stored (fate problem)

**Q5. Feasibility of Tier 1 methods**

- Some parts of the CDR and CCS technology value chain are pliable to tier 1 methods (e.g., pipeline transport), and others are not (e.g., storage).
- Authors can consider the principles followed in the treatment of non-energy use of fuels to deal with captured carbon in cases of $CO_2$ capture for utilisation (in particular, the conversion to mineralised products) instead of storage – might consider an approach equivalent to how the IPCC guidelines deal with non-energy use of fuels under IPPU
- Consider fugitive $CH_4$ EFs for displacement by $CO_2$ at geological storage sites (EOR).
- 2006 IPCC do not deal with fugitive $CO_2$ EF for transportation by Ship (T3 method only), rail, road any other form of transport.

**Q6. Higher tier methods**

- The general view is that there is less of a challenge in developing a T3 methodological guideline. However, therefore could be a practical challenge to implement a tier 3 method (e.g. in cases of long $CO_2$ pipelines (> 1000 km of pipeline)
- Even for T3 methods, more guidance is needed (e.g. clarifying minimum requirements such as monitoring points)
- New guidance needs to address the issue of baselines with respect to storage (e.g. to isolate natural $CO_2$)
- Need to reexamine the relevance of guidance in Annexure 5.1 on the summary description of potential monitoring technologies for geo $CO_2$ storage sites.

**Q7. Verification Activities**

- Assessment of the role of remote sensing, i.e., whether top-down measurements could be used to verify CDR activities, should be investigated.
- Current research is underway to look at top-down verification methods for $CO_2$ capture from point sources.

- Verification should not be prescriptive. Every project is different; therefore, the monitoring regime differs from project to project.
- Reach out to the community conducting top-down emission quantification approaches to enhance guidance on top-down methods for verification of CDR and CCS activities (e.g. tracking CO2 release episodes)
- Explore the use of data and information from market-based instruments that are linked to CDR and CCS technologies (e.g. ETS trading scheme.)
- Authors to emphasise the role of stakeholders involvement in the QA/QC processes for CDR and CCS processes.
- Consider qualitative indicators for verification
- Conducting material balance as a form of verification for the whole CDR/CCS/CCUS value chain.

**Raised Issues to be consider in later stages/ Relevant issues to consider**

- For cross-boundary transfers of captured carbon, the cradle-to-grave principle should apply (i.e. no negative accounting from the source if there is no evidence of storage);
- Addressing durability and permanence is important;
- Consider guidance with respect to CCS onboard a ship;
- Consider the circularity of $CO_2$;
- Injection of carbon-containing materials (e.g. bio-liquids);
- Geological $CO_2$ storage: Observation is that there is more storage capacity in shallow waters than in deep sea waters. Therefore, storage is unlikely in deep water, and more potential in shallow waters.
- Several elements of the system are not being reported (e.g. activity data for utilisation in most cases is not readily available) – Authors can consider some of the issues related to CDR and propose guidance on how to navigate some of the issues (e.g. treatment of confidential data)
- Address potential double-counting from the use of synthetic fuels (e.g. efuels)
- Assess the glossary of terms for any changes that may be needed.
- Revaluation of the principles concerning $CO_2$ purity in the existing IPCC guidance.

## 4. BOG 2: Inorganic processes and storage: rock weathering, ocean alkalinisation, concrete carbonation

Co-facilitators: Eduardo Calva and Laura Dawidowski

Rapporteur: Lisa Hanle

**Overview**

Inorganic processes and storage: concrete carbonation, rock weathering, ocean alkalinization

In some cases capture and storage activity are the same (e.g. weathering on croplands) and in some cases capture occurs, then storage (e.g. $CO_2$ removal from oceans)

Level of maturity of processes varies widely:

Experience on carbonation > rock weathering and oceans

**General Considerations: All**

Recognized activities that collectively offer significant removals/reductions in mitigation scenarios

They would benefit from international guidelines for MRV

Methods for CDR should be comparable and as rigorous as methods for capture

Q1. Assessment Criteria: Suggested evaluation criteria are valid; also considered what is scope of report/technology, “anthropogenic” versus “natural”, and whether annual removals/reductions could be assessed

Q2. Completeness: We started with three primary activities for consideration:

Concrete carbonation

Enhanced weathering

Ocean alkalinity enhancement

→ Discussions resulted in 9 activities to be considered in a future methodological report (Table 1).

## 4.1 CDR pathways inorganic processes and storage

**Table 4 Activities identified for inorganic processes**

| Group | Activities discussed |
|---|---|
| Carbon capture in products | • Concrete carbonation (incl. enhanced concrete carbonation)<br>• Carbonatable by-product materials (where not included elsewhere in national GHG inventory, e.g. slags, precipitates |
| Anthropogenic mineral processes<br><br>with storage of carbon in minerals or as bicarbonate ions | • Enhanced weathering on managed land<br>• Enhanced weathering in rivers<br>• Ex-situ mineralization (open and closed systems) including enhanced weathering using biogenic $CO_2$ (wastewater alkalinity dosing)<br>• In-situ mineralization (sub-surface injection and rapid mineralization)<br>• Ocean alkalinity enhancement<br>(mineral based and electrochemical)<br>• Direct ocean $CO_2$ removal<br>(stripping $CO_2$ from seawater) |

These were considered significantly different to warrant consideration

### *4.1.1 Concrete carbonation*

Scope: Concrete carbonation could include enhanced carbonation

**Table 5 BOG2 Assessment of concrete carbonation**

| Question | BOG assessment |
|---|---|
| Is the activity worth considering further? | Y |
| Are there gaps in existing methods? | Y |
| Can you delineate anthropogenic and natural? | Y (all anthropogenic) |
| Can you generate annual estimates? | Y |
| Can you estimate within national borders? | Y |

Relevant history:

- Proposed for inclusion in 2019 Refinement, but too late in the process for full consideration.
- Papers submitted to EFDB, but further revision was required (e.g. reflect historical use of concrete and annual emissions).
- View of the group: Methodological issues could be addressed.

**Question 3 on Taxonomy**

- Elements of technology chain are known; consider if clinker production in one country (emissions), and cement production and use in another country (uptake).
- Ensure that any methods reflect annual uptake
- If reported, is it reported in 2.H (Other) (consistent with text in 2006 IPCC Guidelines) or in 2.A (consistent with footnote 5 on "other reductions" in IPCC reporting tables).
    - 2.A. Is called "Cement Production" – if carbon capture in products consided here, would name of category change?

**Question 4 – Preliminary assessment of existing IPCC Guidelines estimation methodologies**

- Method for uptake not in Guidelines
- Possible options:
    - Amendment to existing equation to add uptake (could have negative emissions if uptake in current year greater than emissions)
    - Add $CO_2$ uptake separately
    - Adjust $CO_2$ EF for clinker to reflect year 1 uptake (category name would have to change)

**Question 5 – Feasibility of Tier 1 methods**

- Literature robust and growing; sufficient available evidence.
- Documented methods have been suggested (Sweden, UK). Methods may assume stable cement use; need to look where growth is.

- Can estimate year-by-year absorption applying an average carbonation rate to a type of concrete (know fraction of structural versus non-structural).
    - National level activity data for cement exists in most countries.

**Question 6 – Higher tier methods**

-Available in literature; we know factors leading to uptake.

-Analogues: waste model, HWP, F-gases, abandoned coal mines

**Question 7 – Verification Activities**

- If there are multiple tiers, can use alternative tiers.
- As we know factors that influence emissions, verification is possible

### *4.1.2 Other Carbonatable Materials*

- Carbonatable materials can be used as inputs to products, storage medium, or feedstock to processes discussed (e.g. Fly ash, slags, PCC)
- Overlap with storage of carbon in minerals, particularly ex situ mineralization
- Not further discussed

### *4.1.3 Enhanced Weathering*

- Approaches to quantifying anthropogenic removals from enhanced weathering are relatively immature
- Efficiency of carbon removal dependent on process specific information (e.g. mineralogy)
- Terminology needs to be refined

Scope suggested for further consideration:

Anthropogenic mineral processes with storage of inorganic carbon in minerals or as bicarbonate ions.

    - Enhanced weathering on managed land *(more advanced)*
    - Ex-situ mineralization (open and closed systems) including enhanced weathering using biogenic $CO_2$ (wastewater alkalinity dosing) *(closed systems including wastewater more advanced)*
    - Enhanced weathering in rivers
    - In-situ mineralization (sub-surface injection and rapid mineralization) *(important, but is this the correct place)*
- Valid to consider all activities; focused mostly on EW on managed land

**Table 6 BOG2 Assessment of enhanced weathering**

| Question | BOG assessment |
|---|---|
| Is the activity worth considering further? | Y |
| Are there gaps in existing methods? | Y |
| Can you delineate anthropogenic and natural? | Process: Y<br><br>CO2 uptake: ? (questions of baseline) |
| Can you generate annual estimates? | Probably |
| Can you estimate within national borders? | Where does uptake and reversal occur?<br>Land-based- Probably<br><br>Other - Y |

**Question 3 on Taxonomy:**

- Enhanced weathering on Managed Land:
    - Single category, if so where, OR updating EFs throughout GL to take account of EW practices (e.g. rice, croplands, wastewater treatment).
    - Boundary question: how do you separate EW and ocean alkalinity, as the ocean may ultimately be the fate.
    - Overlap with soil organic carbon ; emissions of other GHGs ($CH_4$ and $N_2O$)
- Other EW:
    - Single category, if so where, OR updating EFs throughout GL to take account of EW practices (e.g. energy (CCS), IPPU (chemical industry), wastewater)

**Question 4 – Preliminary assessment of existing IPCC Guidelines estimation methodologies**

- Method for EW not in Guidelines, but do have
  - $CO_2$ emissions from liming of soils;
  - Organic stocks from mineral soils
- Regarding dissolved inorganic carbon (DIC)- there are pools in soil, rivers and ocean. To understand the weathering you need to understand the impact on DIC. There is discussion on DIC in appendix to Wetlands Supplement.

**Question 5 -7 – Feasibility of methods**

- Limited data for all EW approaches, but growing rapidly.
- Tier 3 methods considered, insufficient information to develop Tier 1/ 2.

**Table 7 Factors to consider for higher tier methods: enhanced weathering**

| Activity | Factors that may need to be considered in a higher tier method (list not complete) |
|---|---|
| Enhanced weathering on managed land | Rocks react at different rates, impact water chemistry, soil storage.<br>Because it impacts soil storage and biomass, relationship with other AFOLU pools needs to be considered<br>Monitoring: How do we consider here organic carbon. Interaction with SOC, carbonate precipitation, rate of mineral weathering, secondary mineral formation (carbonate, clay formation), non-carbonic acid neutralization, methane and $N_2O$ emissions, mineral composition, mineral type, diameter and quantity. Soil type, soil moisture, crop type… |
| Enhanced weathering in rivers | Dissolution kinetics, secondary precipitation, interactions with ecosystems, interaction with DIC |
| Ex-situ mineralization (open versus closed systems) including enhanced weathering using biogenic $CO_2$ (wastewater alkalinity dosing) | Potential depends on the removal potential per ton of processed mineral and annual total production of mineral, $CO_2$ uptake rate |

| | |
|---|---|
| In-situ mineralization | Boundaries of in-situ and ex-situ mineralization |

**Verification**: Limited field data available to assess removal efficiency. Signal-to-noise problem common across open system pathways. Review paper from Cascade climate about EW on managed lands

### *4.1.4 Ocean-based Activities*

**Scope**

- Ocean alkalinity enhancement : Mineral-based and electrochemical acid removal
- Direct ocean $CO_2$ removal: Stripping $CO_2$ from seawater
- Would need to consider possible emissions/reversals related to the ocean-based activities
- How does IPCC definition of national boundary apply to Oceans? *National inventories include GHG emissions and removals taking place within national territory and* ***offshore areas over which the country has jurisdiction.***

**Table 8 BOG2 Assessment of ocean-based activities**

| **Question** | **BOG assessment** |
|---|---|
| Is the activity worth considering further? | Y (listed ones) |
| Are there gaps in existing methods? | Y |
| Can you delineate anthropogenic and natural? | Process: Y<br>$CO_2$ uptake: ? |
| Can you generate annual estimates? | Probably |
| Can you estimate within national borders? | Unknown |

**Question 3 on Taxonomy**

- Single category, if so where, OR include throughout GL (e.g. "Other", separate CDR category, IPPU (chemical industry or other))
- Technology chain of removals and emissions; all steps required for a net removal :
    - Adding alkalinity / remove $CO_2$
    - Sequester $CO_2$ / neutralize or sequester acid
    - Enhanced ocean uptake
- But consider –
    - How to handle oceans in national GHG Inventory (beyond Wetlands Supplement?)
    - Relationship with London Protocol, CBD, IMO

**Question 4 – Preliminary assessment of existing IPCC Guidelines estimation methodologies**

- No existing methods
- Who is responsible for monitoring and verification of reversals. Consider international law

**Question 5 – Feasibility of Tier 1 methods**

Not applicable

**Question 6 – Higher tier methods**

- Tier 3 method may be possible

**Question 7 – Verification Activities**

- Requires secure storage of the $CO_2$ (direct ocean removal), acid (electrochemical OAE), to avoid reversal

- Not possible to do measurement based verification; challenging to monitoring uptake in temporally and spatially and delineation of anthropogenic/natural) ; difficult to assess signal to noise

- Ocean alkalinity and $CO_2$ removal: both have air sea exchange. Facility level data required. But for mineral based, there may be additional elements that come in. This latter will require more experiments.

**Table 9 Factors to consider for higher tier methods: oceans**

| Activity | Factors that may need to be considered in a higher tier method (list not complete) |
|---|---|
| Ocean alkalinity enhancement : Mineral based and electrochemical | Measurement perturbation, how much $CO_2$ removed, how much alkalinity added (quantity, when and where), chemical distribution, biochemical behavior, mineralogy, biological impact, etc. |
| Direct ocean $CO_2$ removal: Stripping $CO_2$ from seawater | $CO_2$ removed (quantity, when and where), tracking $CO_2$ extraction, transport, storage. |

## 5. BOG 3: Biogenic processes and storage

Co-facilitator: Stephen Ogle

Rapporteur: Martial Bernoux

**Breakout Group main objectives**

1. Discuss and refine the **evaluation criteria**.
2. Learn about new **CDR** based on biological processes and develop methods for estimating $CO_2$ capture and long-term storage.
3. Identify and highlight potential important **issues for future meetings and authors** of the methodological guide.

**Guiding Questions:**

- Question 1 – Assessment Criteria
- Question 2 – Completeness
- Question 3 – Taxonomy of sources and sinks
- Question 4 – Preliminary assessment of existing IPCC Guidelines estimation methodologies
- Question 5 – Feasibility of Tier 1 methods
- Question 6 – Higher tier methods
- Question 7 – Verification Activities

**Appendix**

- Possible Criteria for assessing new methods
- CDR pathways by type of technology

**Framing issue**

- "Technology" issue:

- In the absence of clear definition we assume all what was considered is "technology";
- depending on the definition that will be adopted this can have impact/consequences on the "anthropogenic" approach for the AFOLU which is based on managed land proxy.
- We discuss both completely new methods as well as refining methods

- Geographical scope: our discussion went beyond land into territorial waters

## 5.1 CDR pathways for biogenic processes and storage

**Table 10: Activities considered for biogenic processes**

| **Group** | **The IPCC WGIII AR6 Report examples of CDR methods** |
|---|---|
| Anthropogenic biological (photosynthesis) – biomass | • Afforestation/Reforestation<br>• Agroforestry<br>• Improved Forest Management<br>• "Blue carbon management" in coastal wetlands |
| Anthropogenic biological (photosynthesis) – soils and waterways | • Soil carbon sequestration in croplands and grasslands<br>• Peatland and coastal wetland restoration<br>• Biochar |

Source: Derived from IPCC 2022 – IPCC WGIII Mitigation of Climate Change, Technical Summary.

*Additional – not included in the source data

**Table 11: BOG3 consideration of technologies**

| **Group** | **The IPCC WGIII AR6 Report examples of CDR methods** | **Q3-Taxonomy** | **Q4—Methodology** |
|---|---|---|---|
| Anthropogenic biological (photosynthesis) – **biomass** | Afforestation/Reforestation | No | No need for improvement at Tier 1; No need for improvement > Tiers. |
| | Agroforestry | No | May be (update EF1 – Cstock **or** EFDB update) |
| | Improved Forest Management | No | No need for improvement at Tier 1; No need for improvement > Tiers. |

| | | | |
|---|---|---|---|
| Blue carbon management" in coastal wetlands (seagrass meadow, macro algae) | | Yes | Develop Tier 1 EF (not covered in Wetlands Supplement - Chapter Coastal Wetlands) for seagrass, tidal marshes; develop Tier 1 EF for macro algae#. Develop Tier 2 (but see "Guidance for authors on taxonomy"); Lateral transfer of biomass |
| | Ocean fertilization | No* | No |
| Anthropogenic biological (photosynthesis) – **soils and waterways** | Soil carbon sequestration in croplands and grasslands | No | Tier 1 - May be: SOCref possible to develop for deeper depths; inputs/LU factors might be updated and extended to a deeper depth); Could consider develop an alternative Tier 1 approach taking into account changes before and after 20 years for LUC, or at least elaboration on the impact (box)<br><br>> Tiers: additional guidance to consider DEM at Tier 3 level) |
| | Organic Soils and Peatland and coastal wetlands restoration | Yes** | Tier 1: Not sure (no expert in the BOG). Default EF1 factors in the 2013 Wetland Supplement - Chapter 3: Rewetted Organic Soil, might be updated; Update the DOC EF; Develop lateral transfer (DIC, POC); Revisit EF Tier 1 for $CH_4$ and $N_2O$. Consider stratify EF based on water table depth<br><br>> Tiers: Lateral transfer (DIC, POC); Probably enough new science to consider the impact of the water table level at higher Tiers. |
| | Blue carbon management" in coastal wetlands (mud flats,seagrass bed, subtidal sediments) | No | Tier1: might expand (sea grass) or develop (mud flats and subtidals), considering DIC, DOC, POC;<br><br>> Tiers: Need to considered lateral transfer of sediment; |
| | Biochar | Yes | No Tier 1 for soil, (Basis for future methodological development of a |

| | | | |
|---|---|---|---|
| | | | Tier1 method in Appendix, but only for cropland/grassland); Need to consider the effect on the direct $N_2O$ emissions.<br><br>Developing/updated information on derivation of $FC_p$ and $Fperm_p$ values need to be considered (including evaluation of the feasibility of develop alternative methods based on pyrolysis temperature or ratios, e.g. H/OC).<br><br>Consider expands at Tier1 to other land use (settlement, wetlands, forest) and other sectors (e.g. construction material)<br><br>Develop production level (sub)category for Biochar and **consider the trade issue in the methodology** to avoid double counting, based on where the biochar is applied.<br><br>Production of syngas and oil in the Energy Sector and potential for storage in geological reservoir.<br><br>> Tiers: Some guidance already available. Impacts of different soil types / Impact of climate zones on EFs (for biochar with H/OC between 0.4 and 0.7) where it is applied; Considered eventual priming effect for verification. |
| Anthropogenic biological (photosynthesis) – **Soils?** **<u>Oceans? Or geological reservoirs</u>** | Biomass burial, Slurry and Oil*** | May be (new category [on top of] HWP or waste) | May be not enough information for EF Tiers; Need a taxonomy (type of burial, type of material: raw, dried, processed, etc); need to consider all GHGs (likely not enough science/information);<br><br>> Tiers: no further consideration |

*In view of international agreements allowing or prohibiting certain activities, e.g. according to the **London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter**); no clear evidence of C sequestration from experiments (satellite monitoring); issue of national boundaries (less nutrient limitation in territorial waters: probably more affected in open ocean – international waters - that in territorial waters)

# Most probably not enough information to develop Tier 1 EF

*** Risk of leakage on mid to long-term to be evaluated (risk of pollution from the "products" and/or "additives" and/or "packaging"); Loss of carbon and/or nutrients for the terrestrial or ocean agro-ecosystems; Changing oxygen levels in oceans; Impact on the waste sectors; National regulations/laws on waste/biomass deposition; Ensure the loss of biomass and the GHG associated with the production, is counted in the productive system(s); international trade and potential issues with double counting (similar to HWP); Verification: not feasible if ocean, should be possible in terrestrial.

VERIFICATION: Blue Carbon: might be challenging due to lateral transfer (floating biomass) in the tidal zone

VERIFICATION: Soil C (Possible and guidance available as needed); Blue Carbon: might be challenging for the sediments, due to lateral transfer in the tidal zone

VERIFICATION: Biochar consider using available registry on biochar/CDR at country level; Verification at production phase seems not an issue, might be more complex at application side

Further guidance for authors for "blue carbon"

- Consider developing a clear taxonomy for "Blue carbon management" in coastal wetlands
- Consider different species for each 'subcategory'
- Potential lateral transfer (potential double counting in sediments)

**Figure 6: Further guidance for authors of 'blue carbon'**

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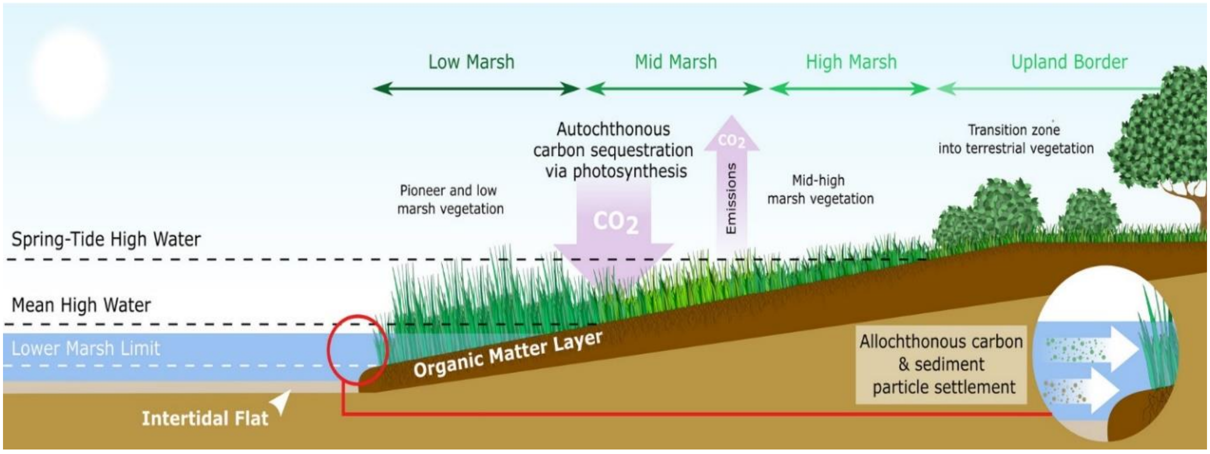
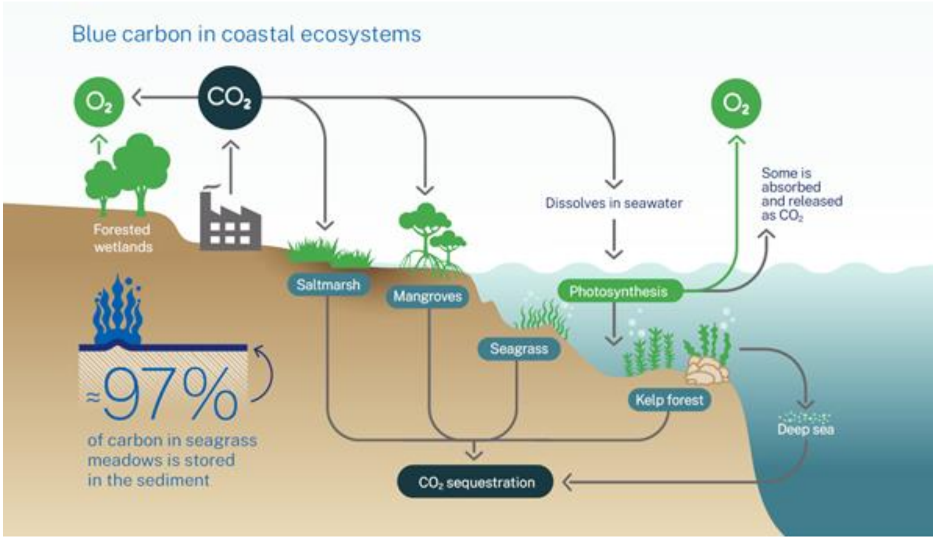
3.5.1. Shellfish beds .....................................................................................30
3.5.2. Macroalgae.........................................................................................32
3.5.3. Brittlestar beds....................................................................................35
3.5.4. Faunal turf...........................................................................................37
3.5.5. Sedimentary habitats (surficial sediment)..........................................38

Source: https://cdn.naturalresources.wales/media/692035/nrw-evidence-report-428_blue-carbon_v11-002.pdf

https://cdn.naturalresources.wales/media/692035/nrw-evidence-report-428_blue-carbon_v11-002.pdf




Source: https://onlinelibrary.wiley.com/doi/10.1111/gcb.16943




https://www.environment.nsw.gov.au/topics/water/coasts/blue-carbon-strategy

## Appendix 1. Agenda of the Expert Meeting

# IPCC Task Force on Inventories

# Expert Meeting on Carbon Dioxide Removal Technologies and Carbon Dioxide Capture, Use and Storage

**online and in Vienna, Austria**
**5 Johannesgasse Vienna**
**1-3 July 2024**

# Agenda

| | | |
|---|---|---|
| Day 1 | 8:30 - 9:15 | Registration |
| | 9:30 - 10:00 | **Welcome addresses**<br><br>Magnus Brunner, Federal Minister of Finance of the Republic of Austria<br><br>Jim Skea, IPCC Chair<br><br>Leonore Gewessler, Austrian Minister of Climate Action, Environment, Energy, Mobility, Innovation and Technology **[video]** |
| | 10:00 – 10:40 | **Plenary session 1 (Presentations and discussion)**<br><br>Takeshi Enoki and Mazhar Hayat, Co-Chairs of IPCC TFI<br><br>Rob Sturgiss, Background and objectives of the meeting (IPCC TFI TSU)<br>Q&A |
| | 10:40 -11:00 | *Morning tea* |
| | 11:00 – 13:00 | **DACS/BECSS/CCUS - Presentations (15 minutes each)**<br><br>Simon Pang (Lawrence Livermore National Laboratory), *Engineered Solutions to Carbon Dioxide Removal* |

| | | |
|---|---|---|
| | | Mai Bui, (Imperial College London), *Assessing the deployment potential of direct air capture and BECCS technologies*<br><br>Mark De Figueiredo (US DoE) *Monitoring, Reporting and Verification of CDR and CCUS: US Experiences and Lessons Learned for National GHG Inventories*<br><br>Paul Zakkour (Carbon counts) *Experiences with the 2006 IPCC Guidelines for $CO_2$ transport and storage: a rapid review of national reporting practices*<br><br>Dario Gomez (Atomic Energy Commission of Argentina) **[On-line]** *Existing guidance and need for updating on carbon dioxide capture in Volume 2 of the IPCC Guidelines*<br><br>Speakers Panel Discussion, Q&A, [30-45 minutes] |
| | 13:00-14:15 | *Lunch break* |
| Day 1 | 14:15 – 15:40 | **Inorganic carbon - Presentations (15 minutes each)**<br><br>Karen Scrivener (Ecole Polytechnique Federale de Lausanne), *$CO_2$ Uptake by Cement Based Materials: Principles, estimation, unknowns and future trends*<br><br>Jens Hartman (Universität Hamburg), **[On-line]** *Enhanced weathering and ocean alkalinity enhancement – TBC*<br><br>Anu Khan (carbon180) *Jurisdiction-Level Monitoring for Enhanced Weathering: Infrastructure, Data, and Maintenance Needs*<br><br>Andrew Lenton (CSIRO) *CDR in territorial waters: the challenges and opportunities*<br><br>Speakers' Panel Discussion: Q&A |
| | 15:40-16:00 | *Afternoon tea* |
| | 16:00-16:30 | **Biogenic – Presentations (15 minutes each)**<br><br>Claudia Kammann, (Hochschule Geisenheim University), *State of Biochar-CDR: Growth of industries, C persistence, CDR co-benefits and current C-sink certification and trading schemes.* |

| | | |
|---|---|---|
| | | Speakers' Panel Discussion: Q&A |
| | 16:30-18:00 | **General (15 minutes each)**<br><br>Mihri Ozkan (University of California), **[On-line]** *Advancing Direct Air Capture: Empirical Foundations and Methodological Innovations*<br>*for Emission Reduction*<br><br>Omkar Patange (IIASA) and Amit Garg (Indian Institute of Management) *The feasibility of developing new or updated IPCC default methods (and default emission factors) for various emerging technologies*<br><br>Steve Smith (University of Oxford) *Current CDR activity and gaps in existing IPCC Guidelines*<br><br>Freya Chay – (Carbon Plan) *Open scientific questions across carbon removal approaches*<br><br>Speakers' Panel Discussion: Q&A |

| | | |
|---|---|---|
| Day 2 | 09:00 - 13:00 | **BOG sessions**<br>BOG 1 - engineered capture, utilisation & geological storage<br>BOG 2 - inorganic processes and storage: rock weathering, ocean alkanisation, concrete,<br>BOG 3 - Biogenic processes and storage: soils, ocean fertilisation and blue carbon |
| | 13:00 - 14:30 | *Lunch break* |
| | 14:30 - 17:00 | **BOG sessions**<br>BOG 1: Engineered capture, utilisation & geological storage<br>BOG 2: Inorganic processes and storage<br>BOG 3: Biogenic processes and storage |
| | 17:00 - 18:00 | **Plenary session** |

| | | |
|---|---|---|
| | | Day 2 catch-up, discussion and Q&A<br>Information on reception logistics |
| | 19:00 - | **Reception hosted by the Austrian Government**<br>10er Marie (https://10ermarie.at/) - a bus will be provided by the Austrian Government. |

| | | |
|---|---|---|
| Day 3 | 09:00 - 13:00 | **BOG sessions continued**<br>BOG 1: Engineered capture, utilisation & geological storage<br>BOG 2: Inorganic processes and storage<br>BOG 3: Biogenic processes and storage |
| | 13:00 - 14:30 | *Lunch break* |
| | 14:30 – 18:00 | **Plenary session (Discussion based on reports from BOGs & wrap-up)**<br>Closing remarks |

## Appendix 2. Participants List

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## Appendix 3: List of Acronyms and Abbreviations

| | |
|---|---|
| AD | Activity Data |
| AFOLU | Agriculture, Forestry and Other Land Use |
| AR | IPCC Assessment Cycle |
| BECCS | Bioenergy Carbon Capture and Storage |
| BOG | Break-out Group |
| CCUS | Carbon Capture, Utilisation and Storage |
| CDR | Carbon Dioxide Removal |
| DAC | Direct Air Capture |
| EF | Emission Factor |
| EFDB | Emission Factor Database |
| GHG | Greenhouse Gas |
| HWP | Harvested Wood Product |
| IPCC | Intergovernmental Panel on Climate Change |
| IPPU | Industrial Processes and Product Use |
| KCA | Key Categories Analysis |
| TFB | IPCC Task Force Bureau |
| TFI | Task Force on National Greenhouse Gas Inventories |
| TSU | Technical Support Unit |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |
| US EPA | United States Environmental Protection Agency |
| WG | IPCC Working Group |

BECCS, CCUS, CDR, DAC

Attachment C

# IPCC Scoping Meeting

for a

# Methodology Report

on

# Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage

## Report of the IPCC Scoping Meeting

14-16 October 2024, Copenhagen, Denmark

Task Force on National Greenhouse Gas Inventories

The IPCC Scoping Meeting on a Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage was organized by the IPCC Task Force on National Greenhouse Gas Inventories (TFI) with support from the Government of Denmark. It was held on 14-16 October 2024 in Copenhagen, Denmark.

This meeting report was prepared by the Co-Chairs of the IPCC TFI (Takeshi Enoki and Mazhar Hayat) and the TFI Technical Support Unit (TSU) and subjected to review by the meeting participants.

Supporting material prepared for consideration by the Intergovernmental Panel on Climate Change (IPCC). This supporting material has not been subject to formal IPCC review processes.

Published by the Institute for Global Environmental Strategies (IGES), Hayama, Japan on behalf of the IPCC



Please cite as:

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## Foreword

The IPCC Working Group III (WGIII) contribution to the Sixth Assessment Report (AR6) states that "The deployment of carbon dioxide removal (CDR) technologies to counterbalance hard-to-abate residual emissions is unavoidable if net zero $CO_2$ or GHG emissions are to be achieved".

With this context in mind, the IPCC Panel requested the Task Force on National Greenhouse Gas Inventories (TFI) to develop a Methodology Report for the preparation of national greenhouse gas inventories on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage (Dec. IPCC-LX- 9).

The *2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines)* already provides methods for the estimation of emissions and removals from some of these CDR activities and also for activities relating to carbon capture, utilisation and storage (CCUS). After 20 years a review of these methods is timely, however, given the development of new science and empirical data and because of the emergence of new technologies for CDR.

IPCC Methodology Reports are prepared by the IPCC TFI and should not be conflated with IPCC Assessment Reports, which are the business of the IPCC Working Groups. This Methodology Report will be like other IPCC TFI Methodology Reports such as the *2006 IPCC Guidelines* and will be designed to ensure that the methodologies available to governments to estimate anthropogenic emissions and removals reflect the latest technological trends and the latest science.

Questions about the potential deployment, legal/social/environmental/sustainability impacts or challenges of implementation of CDRs will be addressed as per current practice through the work of the Assessment processes of the IPCC Working Groups. This TFI Methodology Report will make no judgement about the desirability or otherwise of these CDR technologies only that, should they be deployed, governments will estimate the associated emissions and removals applying methods and approaches that comply with IPCC TFI principles of transparency, accuracy, time series consistency, comparability and completeness.

The first step in the development of the Methodology Report on CDR technologies and CCUS has been to convene a Scoping Meeting to produce an outline of the Report in accordance with IPCC procedures.

The Scoping Meeting was held on 14-16 October 2024 in Copenhagen, Denmark.

As Co-Chairs of the IPCC TFI we are pleased to present this Meeting Report of that Scoping Meeting.

The recommendations in this Report will be considered by the IPCC in early 2025 and, following the decision of governments, a Methodology Report will be prepared through the course of four Lead Author Meetings with the final report to be considered by the IPCC by the end of 2027.

We would like to thank all those involved in the Scoping Meeting namely the experts, the members of TFB and the members of TSU for their contributions toward making this meeting a success.

In particular, we would like to express our sincere gratitude to the Government of Denmark and the Danish Meteorological Institute for their generous support in hosting this meeting.

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## Executive Summary

The Intergovernmental Panel on Climate Change (IPCC) decided that the Task Force on National Greenhouse Gas Inventories (TFI) should produce an IPCC Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage at its 60th Session on 16-19 January 2024 in Istanbul, Türkiye (Decision IPCC-LX-9).

The first step in the development of a Methodology Report on Carbon Dioxide Removal Technologies Carbon Capture Utilization and Storage has been to convene the Scoping Meeting to produce an outline of the Methodology Report in accordance with the Appendix A to the Principles Governing IPCC Work, which contains the procedures for the preparation, review, acceptance, adoption, approval and publication of IPCC reports.

Preparation for the Scoping Meeting started in June 2024 with a call for nomination of experts issued to IPCC Member States and Observer Organizations by the IPCC Secretary. Invitees to the meeting were selected by the Bureau of TFI (TFB) from the nominations received on the basis of their expertise while addressing geographical representation and gender balance.

The participants of the Scoping Meeting recommend the title of the Report to be *2027 Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage: (Supplement to the 2006 IPCC Guidelines).*

Other elements of the outline for this Methodology Report are included in this Meeting Report as follows:

- Draft Terms of Reference for *2027 Methodology Report on* Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage is presented in **Appendix 1**;
- Draft Table of Contents is presented in **Appendix 2**;
- Draft Instructions to Experts and Authors is presented in **Appendix 3;** and
- The Work plan recommended by the TFB is presented in **Appendix 4**.

The recommendations and documents in Appendix 1 to Appendix 4 will constitute the basis of the TFI proposal for the outline for the *2027 Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage: (Supplement to the 2006 IPCC Guidelines)* to be presented to the IPCC-62 in early 2025 for the consideration by governments.

A summary of Meeting discussions is included in sections 1-5 of this Report.

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## Glossary

**Removals -** are the consequence of sink activities (*2006 IPCC Guidelines Glossary*).

**Sink -** means any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere (*UNFCCC*)[1].

**Reservoir -** means a component or components of the climate system where a greenhouse gas or a precursor of a greenhouse gas is stored (*UNFCCC*)[2].

**Emissions -** means the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time (*UNFCCC*).

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

**Anthropogenic emissions and removals -** means that greenhouse gas emissions and removals included in national inventories are a result of human activities (*2019 Refinement to the 20006 IPCC Guidelines Vol 1.1.1 page 1.5*).

In the *AFOLU* sector, 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 1.5*).

**Managed land** is land where human interventions and practices have been applied to perform production, ecological or social functions (*2006 IPCC Guidelines Vol 4.1.1 page 1.5*).

In the case of wetlands, the *2006 IPCC Guidelines* restricted managed wetlands to those lands where the water table is artificially changed (i.e. lowered or raised). Further, the Wetlands Supplement extends this coverage also to include wetlands created (e.g. constructed), or where emissions and removals from coastal wetlands are attributed to specified human activities. *(IPCC 2013 Wetlands Supplement O.8*).

**National Greenhouse Gas Inventories -** a greenhouse gas inventory 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*).

<u>TSU Note</u>: **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*.

**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*).

**Coastal wetlands** may extend to the landward extent of tidal inundation and may extend seaward to the maximum depth of vascular plant vegetation (*IPCC 2013 Wetlands Supplement 4.1.1 page 4.6*).

**Changes in soil carbon stocks** combines the change in soil organic C stocks for mineral soils and $CO_2$ emissions from organic soils; and stock changes associated with soil inorganic C pools[3] *(2019 Refinement to the 2006 IPCC Guidelines Vol 4.2.3.3 page 2.29.*

**IPCC classification system –** greenhouse gas emission and removal estimates are divided into main sectors, which are groupings of related processes, sources and sinks.[4] High level categories include:

1. Energy
   - *A. Fuel Combustion*

[1] Examples of sink activities include Direct Air Capture technologies and photosynthesis.

[2] including terrestrial, coastal waters and ocean bodies, geological storage and storage in products.

[3] For Tier 3 only.

[4] According to type of process.

- *B. Fugitive Emissions from fossil fuel extraction and distribution;*
- *C. Carbon Dioxide Capture, Transport and Storage*

2. Industrial Processes and Product Use (IPPU)

3. *Agriculture, Forestry and Other Land Use* (*AFOLU*)

4. *Waste*

The *AFOLU* sector is sub-divided into estimation of non-$CO_2$ emissions from Agriculture (livestock and from soil management) and the mainly carbon stock changes occurring on managed lands:

- *Forest Land*
- *Cropland*
- *Grassland*
- *Wetlands*
- *Settlements*
- *Other land.*

TSU Note: This classification system is designed to assist national inventory compilers to enhance transparency and to report anthropogenic emissions and removals **when and where** they occur.

TSU Note: ***IPCC Guidelines*** should be taken to include the *2019 Refinement to the 2006 IPCC Guidelines* (IPCC 2019), the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* and the *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.*

## 1. Introduction

The IPCC decided that the Task Force on National Greenhouse Gas Inventories (TFI) should produce an IPCC Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage (CDR CCUS) at its 60th Session on 16-19 January 2024 in Istanbul, Türkiye (Decision IPCC-LX-9).

The Scoping Meeting to make recommendations for an outline for this Methodology Report on CDR and CCUS was held on 14-16 October 2024 in Copenhagen, Denmark.

The nomination letter for the Scoping Meeting was sent by IPCC Secretariat to the IPCC Focal Points and Observer Organisations on 14 June 2024 and 612 nominations were received. The selection of invitees was implemented by the IPCC TFI TFB, in consultation with representatives from the IPCC Bureau. Invitations were issued by the TFI Co-Chairs from 13 August 2024.

The Scoping Meeting was attended by 78 experts including 8 members of the IPCC TFB (the list of participants is provided in **Appendix 6)**.

The Meeting was tasked with considering the title and format of the Methodology Report and to prepare draft Terms of Reference (ToR), draft Table of Contents (ToC) and draft Instructions to Experts and Authors for the Methodology Report.

- ***Terms of Reference (ToR)*** - *The ToR sets out the background, the scope and coverage, the approach and a work plan for the production of the Methodology Report;*
- ***Table of Contents (ToC)*** – *The ToC sets the aggregated outline for chapters of the Methodology Report;*
- ***Draft Instructions to Experts and Authors*** - *These instructions to experts and authors are intended to ensure a consistent and coherent approach across all methodologies, volumes and chapters, including the use of common terminology; and*
- ***Draft Work Plan*** – *the Workplan shows the timeline for production of the Methodology Report.*

Working drafts of these documents were prepared by the Technical Support Unit (TSU) to support the work of participants based on the report of an IPCC Expert Meeting on CDR and CCUS held in Vienna, Austria on 1-3 July 2024 and on scoping documentation for previous TFI Methodology Reports.

The Report of that Expert Meeting, along with presentations by experts, has been published on the TFI website at: CDR_CCUS_EM_Report (iges.or.jp).

The adopted agenda for the Scoping Meeting is presented in **Appendix 5.** The Scoping Meeting was organized into three Plenary sessions and parallel work in two Break-Out Groups (BOGs). The first Plenary session introduced the background and objectives of the meeting; the second Plenary session was aimed at taking stock of the progress of the work of the BOGs and to discuss cross-BOG issues; and the final Plenary session concluded on the title and format and on the documents: ToR, ToC, Instructions to Experts and Authors.

The following two Break Out Groups (BOGs) were organized to facilitate detailed discussions amongst participants:

1. BOG 1 – topics mainly related to the removal and/or capture of carbon dioxide and its storage and other topics outside of Agriculture, Forestry and Other Land Use (*AFOLU*); and
2. BOG 2 – *AFOLU* topics mainly related to the removal of carbon dioxide and storage in soils and water.

Discussions and conclusions of the meeting are summarized in this Report while the draft Outline documents are presented in **Appendixes 1-4.**

The Scoping Meeting presentations (from TSU and BOGs) are available together with this report at https://www.ipcc-nggip.iges.or.jp/public/mtdocs/2410_CDR_CCUS_Scoping.html

## 2. Meeting Discussions

The Meeting participants considered IPCC Guideline concepts presented on Day 1 by the IPCC TFI TSU, drawing from the Background paper made available to participants.

### 2.1 Specific conceptual considerations

The Meeting considered key definitional issues including the meaning of 'removals', 'anthropogenic removals', 'technologies', 'negative emissions' and 'storage' as well 'anthropogenic removals on land'.

#### *Definition of removals*

From the glossary, a sink is any activity that removes carbon dioxide ***from the atmosphere***[5]. It follows that a removal is the consequence of sink activities[6].

Technologies that generate direct air capture will constitute a sink activity because they remove carbon dioxide ***from the atmosphere*** (like a tree).

This case is distinguished from the case where carbon dioxide is captured from an on-site stream of carbon dioxide generated by human activity (for example, capturing a stream of carbon dioxide from the stack of a power plant or from a fossil fuel extraction facility). These activities do not constitute removal activities because they do not remove carbon dioxide ***from*** the atmosphere, although they are nevertheless also valuable because they reduce emissions ***to*** the atmosphere.

The application of these definitions was a source of debate in the Meeting. The participants agreed this issue should be carefully considered by the authors of this Report.

The relevant definitions included in the glossary in this Report are taken from the definitions in the UN Framework Convention on Climate Change (sink) and from the glossary of the *2006 IPCC Guidelines* (removals).

#### *Definition of anthropogenic removals*

From the glossary, anthropogenic removals and emissions means that greenhouse gas emissions and removals included in national inventories are a result of human activities.

It was noted that the IPCC will develop a glossary of definitions for the IPCC Seventh Assessment Report cycle, including definitions for anthropogenic removals and emissions. The need for a coordinated glossary across IPCC working groups/task force was raised. The participants agreed this issue should be carefully considered by the authors of this Report as well as those of the WGs Assessment Reports.

#### *Meaning of technologies*

In Meeting discussions, 'Technologies' was not explicitly defined by participants but was implicitly taken to mean human activities that result in removals or emissions that should be included in national greenhouse gas inventories.

#### *Estimation of anthropogenic removals on land*

According to the *IPCC Guidelines*, anthropogenic removals and emissions on land are ***estimated*** using the managed land proxy – that is, all estimated carbon dioxide removals and emissions on 'managed land' are considered anthropogenic (except for removals and emissions associated with natural disturbances[7]).

---

[5] The UNFCCC definition is used in the IPCC Guidelines.

[6] 2006 IPCC Guidelines.

[7] Natural disturbances in the context of the *AFOLU* sector are non-anthropogenic events or non-anthropogenic circumstances that cause significant emissions and are beyond the control of, and not materially influenced by a country. These include wildfires, insect and disease infestations, extreme weather events and/or geological disturbances, beyond the control of, and not materially influenced by a country. Natural disturbances exclude human activities such as harvesting, prescribed burning and fires associated with activities such as slash and burn (2019 Refinement Vol 4.2.6.1.2 page. 2.69).

***Background note:*** The origins of the managed land proxy concept included in the glossary to this Report can be traced back to the IPCC 2003. The key rationale for this approach is that the preponderance of anthropogenic effects occurs on managed lands. By definition, all direct human-induced effects on greenhouse gas 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 greenhouse gases (e.g., increased N deposition, accidental fire) will be manifested predominately 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 greenhouse gas emissions and removals by sinks tends to average out over time and space. This leaves the greenhouse gas emissions and removals from managed lands as the dominant result of human activity (*2006 IPCC Guidelines*, Volume 1.1 page 1.5). In the report of a recent IPCC TFI Expert Meeting on Reconciling Anthropogenic Emissions from Land Use:

> ..countries - by following the *IPCC Guidelines* for NGHGIs (IPCC 2006, 2019) and its 'managed land proxy' - consider a large part of the land sink to be anthropogenic …. 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.
>
> IPCC Expert Meeting on Reconciling Anthropogenic Land Use Emissions, 9-11 July 2024, Ispra, Italy

### *The negative $CO_2$ emissions artefact*

It was also noted that the notion of 'negative $CO_2$ emissions' is not defined by the *IPCC Guidelines*, being a term used in one instance when aggregating a number of processes into a particular narrative (Bioenergy with carbon capture and storage, BECCS).

In that single case, its function was to record an artificial 'negative $CO_2$ emission' in the *Energy* sector for one part of this BECCS process to cancel the artificial $CO_2$ emission reported in the *AFOLU* sector resulting not from an actual emission process but from the transfer of carbon out of the biomass or HWP pool.

In this case, the function of the negative emissions term was to offset the over-estimation of net emissions recorded in the *AFOLU* sector and should not be conflated with an actual removal from the atmosphere at the point of capture and storage.

Another example occurs in the case of carbon dioxide captured from a process gas stream such as in a smoke stack at a power station. Here the IPCC methods indicate a deduction is recorded for the amount of carbon dioxide captured from the estimated potential emissions – commonly based on analysis of fuel inputs - which, if unadjusted, would result in an overestimation of net emissions. If these emissions had instead been estimated using end-of-pipe direct measurement techniques, then the amount of captured carbon dioxide would have been irrelevant to the estimate of emissions at that facility.

In this case, the function of the deduction for the amount of carbon dioxide captured is to offset the over-estimation of emissions caused by the IPCC estimation method and it does not count for an actual removal from the atmosphere.

### *Treatment of captured and stored $CO_2$*

Currently, the *IPCC Guidelines* only allows for subtraction of captured $CO_2$ at the source against estimated potential emissions, as in the example above, if the captured $CO_2$ is for a long-term storage or otherwise included in the inventory.

The concepts of 'storage' or 'long term storage' are not explicitly defined in the *IPCC Guidelines*. They may need to be reviewed which could have implications for the structure of the inventory if, for example, the concept of storage was extended to include captured $CO_2$ used in products with short lifetimes (such as fuels or beverages). The application of storage concepts was a source of debate in the Meeting. The participants agreed this issue should be carefully considered by the authors of this Report.

## 2.2 Introduction to general inventory concepts in the *IPCC Guidelines*

The Meeting considered the nature of the *IPCC Guidelines* presented on Day 1 by the IPCC TFI TSU, drawing from the Background paper made available to participants.

The main application of the *IPCC Guidelines* is for users to create GHG inventories for international reporting (for example, to the UN Framework Convention on Climate Change (UNFCCC)).

The *IPCC Guidelines* aim to help countries accurately estimate and report anthropogenic GHG emissions and removals reliably and to provide methods and tools for the consistent compilation of GHG inventories over time and across countries.

The *IPCC Guidelines* do not assess the potential of emission reduction measures or mitigation strategies and are not focused on policy recommendations.

### *The IPCC Guidelines offer practical guidance*

The *2006 IPCC Guidelines* achieve their purpose by offering practical guidance to help compilers estimate greenhouse gas emissions and removals.

Individual sectoral chapters of the *2006 IPCC guidelines* offer detailed sections like overview, introduction, and category descriptions to help identify emission sources and removal sinks:

- Clear definitions of emission sources and removal sinks by sector;
- Explanation of how emissions or removals are produced (combustion, chemical, biological, etc.);
- Identification of expected GHGs for each source;
- Sector splits and activity breakdowns for accurate categorization; and
- Cross-references to other sectors to prevent double-counting.

IPCC Guidance is provided as *good practice,* rather than as standardized rules and is flexible, adaptable to each country's national circumstances and encourages continuous improvement.

The Guidelines focus on the best practical estimate, avoids biases and aims to minimize uncertainties, and supports global comparability of inventories even across countries with different data levels.

Flexibility is provided to inventory compilers in the selection of emission or removal estimation methods through the tiered approach, with detailed sections offering methods for different data availability levels:

- Tier 1: Basic methods using default data.
- Tier 2: Intermediate methods with more specific national data.
- Tier 3: Detailed, country-specific methods using complex models and datasets.

Decision trees guide compilers in the selection of the appropriate tier based on significance, data quality and data availability.

### *Importance of transparency*

The IPCC Guidance supports the building of trust in inventories through transparency requiring clear documentation of methods, data, and assumptions. To support the production of inventories that are reliable and transparent, the *2006 IPCC Guidelines* provide the following tools and procedures for GHG's Inventory compilers:

- Tools for identifying all emission sources, sectors and gases, and cross-checks to avoid omissions or double-counting.
- Methods for ensuring consistent datasets and GHG estimates and recalculating past years when methods or data change.
- Guidelines for quantifying uncertainties in activity data, emission factors and GHG estimates, improving reliability.
- Structured QA/QC procedures, including checklists for data reviews and external validations.
- Templates and guidance for reporting GHG estimates and documenting methodologies, assumptions, and recalculations for transparency.

*The IPCC Guidelines should be read in conjunction with the UNFCCC*

The *IPCC Guidelines* already support the reporting of removals from direct air capture.

This is because the Guidelines should be read in conjunction with the UNFCCC, which provides for the reporting of anthropogenic sinks from ***any*** process, activity or mechanism which removes a greenhouse gas from the atmosphere - this includes direct air capture technologies, for example, or the passive carbonation of cement.

The Guidelines support this UNFCCC sink definition by providing for any estimated removal from a previously undescribed CDR technology to be reported under the generic 'other' category provided in the IPCC classification system for all sectors and for a number of categories.

The role of the default estimation methodologies described in the *IPCC Guidelines*, therefore, is better understood as underpinning the scope of a set of minimum anthropogenic emissions and removals that should be reported by inventory compilers – but those do not limit what additional sinks and sources compilers can estimate and report.

The provision of IPCC methodologies for these CDR technologies is intended to underpin the routine reporting of removals from these technologies in national inventories in future.

Debate on this topic was well noted by participants to the Meeting.

## 2.3 Technologies under consideration

The IPCC Working Group III (WGIII) contribution to the Sixth Assessment Report (AR6) provides a summary of the role for CDR technologies in future mitigation pathways (Table TS.7).

The IPCC WGIII identified 12 CDR technologies of importance for the delivery of these pathways. Some of these technologies, like afforestation/reforestation, have been well reviewed for previous updates of the *IPCC Guidelines* and were not considered further.

**Table 1: List of CDR Technologies and CCUS processes under consideration**

| **CDR and CCUS processes** | |
|---|---|
| 1. | Direct air capture |
| **2.** | Carbonation: |
| (i) | Cement |
| (ii) | Industry slags and wastes |
| (iii) | Alkalinization of water bodies |
| (iv) | Enhanced weathering |
| **3.** | Direct removal of $CO_2$ from water bodies |
| **4.** | Enhanced oil, gas or coalbed methane recovery |
| **5.** | Production of $CO_2$ containing products |
| **6.** | Consumption & use of $CO_2$ containing products |
| **7.** | Biochar |
| 8. | Enhancing biomass in coastal waters/wetlands |
| 9. | Other durable biomass products |
| 10. | Wastewater based CDR/CCUS |
| 11. | Open ocean fertilization and alkalinization |
| 12. | Other |

Source: TSU opening presentation, derived from IPCC (2024). IPCC Expert Meeting on Carbon Dioxide Removal Technologies and Carbon Capture, Utilization and Storage Eds: Enoki, T., Hayat, M., Report of the IPCC Expert Meeting, Pub. IGES, Japan.

The participants to the Scoping Meeting considered the list of technologies in Table 1, which was the IPCC WGIII list but amended in light of discussions at the IPCC Expert Meeting held in Vienna, Austria, on 1-3 July 2024. This list of technologies was also added to during the course of the Scoping Meeting.

## 2.4 Assessment Criteria for new source or removal categories

Participants assessed and evaluated CDR technologies (and CCUS processes) and associated potential sinks or source processes for inclusion in the *IPCC Guidelines*, or update of the existing Guidelines, using the following criteria (which draw on the criteria used for the *2019 Refinement of the 2006 IPCC Guidelines)*:

### *1. Gaps in the IPCC Guidance or need for updates*

Participants considered the identification of gaps in the existing *IPCC Guidelines* for specific anthropogenic sinks or sources; and the identification of relevant existing sources and sinks where an update of the Guidelines was considered necessary or desirable.

### *2. Delineation of the sink or source*

Participants considered the delineation of anthropogenic sinks and sources within territorial boundaries as part of the process of considering the feasibility of being able to specify estimation methodologies.

### *3. Current and expected significance of the sink or source*

Participants considered the data requirements to be imposed on inventory compilers since the development of methods for sources or sinks that are expected to be of only minor consequence in future will not have great utility.

### *4. Capacity to generalize tier 1 default values*

Participants considered whether the scientific and empirical evidence exists to parameterise a tier 1 and, in some cases, tier 2 estimation method with confidence and in order to meet the IPCC Tier 1 methodology stipulation that it should be applicable under any national circumstances:

***Background note:***

There should be availability of the necessary activity data to implement the methods (readily available national or international statistics); and there should be ability to specify tier 1 default values: sufficient availability of data to calculate a global (at least) value from a sample large enough to have it as a central value; and which should be expected to produce unbiased estimates, so far as can be judged. There is no quantitative threshold for the number of empirical studies required to support the establishment of a default factor.

*Instances of non-specification of tier 1 method*

In some instances, where no global default values can be produced by authors according to the relevant criteria, the *IPCC Guidelines* provides the methodology only as a higher order method. Examples include for carbon capture and storage, soil inorganic carbon and for biochar (the *2006 IPCC Guidelines* Vol 2: 5.7 page 5.13 , *2006 IPCC Guidelines* Vol 4: page 2.37 and *2019 Refinement to the 2006 IPCC Guidelines* Vol 2: Annex 2.A page 2.82).

*Instances of methods assigned to appendices*

Once a drafting process is launched authors may still conclude, after due consideration, that the emissions or removals remain poorly understood and that there is insufficient information available to develop reliable, globally applicable, default methods and emission factors for a particular source or sink. This drafted text may not be lost but placed in appendices in the *IPCC Guidelines* as basis for future methodological development.

A national inventory can be considered complete without the inclusion of estimates for these sources in the appendices, although countries may use appendices as a basis for estimation of GHG emissions, if country specific data are available.

Examples from past drafting processes of methods that were ultimately not included in the main chapters of the Guidelines, but in appendices include Fugitive emissions from wood pellet production; Fugitive emissions from biomass to liquid and biomass to gas conversion; Fluorinated compounds emissions from textile, carpet, leather and paper Industries, and Organic and dissolved inorganic carbon loss from peatlands and drained organic soils.

These methods may be subject to further consideration at future iterations of methodological work.

### 5. Feasibility of being able to specify higher tier methods

Participants considered the feasibility of being able to specify higher tier methods for identified CDR technologies and CCUS activities.

### 6. Feasibility of verification activities

Participants considered the possibility of guidance being provided for inventory compilers as to how they may be able to devise appropriate **verification** activities to strengthen the robustness confidence of the estimated emissions and removals.

## 3. Sectoral Discussions

The Table of Contents (TOC) structure set out in Appendix 2 provides for two new IPCC Sectors:

- *IPCC Sector 5: Carbon Dioxide Capture, Transport, Utilization and Storage;* and
- *IPCC Sector 6: Direct Removal of $CO_2$ from Waterbodies. Alkalinity Enhancement of Waterbodies*.

The creation of *IPCC Sector 5, Carbon Dioxide Capture, Transport, Utilization and Storage* brings together methods that cover the chain of activities for capture, transport, utilization and storage of carbon dioxide into one new IPCC Sector. Methods for direct air capture – a removal - (chapter 3) and carbon capture from process gas streams – a reduction in emissions - (chapter 2) are specified separately but with a recognition that, once carbon dioxide is captured, methods used to describe emission processes for transport, utilisation and storage should be identical.

Elements relating to carbon dioxide capture from process streams, transport, injection and storage are not new but have been relocated from the *IPCC Sector 1.C (Energy)* and also will be updated. Participants agreed that since carbon dioxide may be captured from sources in other IPCC Sectors – such as from *Industrial Processes and Product Use (IPPU)* or from *Waste* – that it was no longer appropriate to allocate emissions from carbon dioxide capture, transport, injection and storage to the *Energy Sector* alone.

The creation of *IPCC Sector 6: Direct Removal of $CO_2$ from Waterbodies. Alkalinity Enhancement of Waterbodies* incudes new CDR technologies that are explicitly designed to influence the carbon stock reservoirs in the waterbodies and consequently in the atmosphere.

### 3.1 Carbon capture, utilization and geological storage and IPPU issues

BOG1: Co-facilitators: Zhu Songli (China) and Ole-Kenneth Nielsen (Denmark)

Rapporteur: Joni Jupesta (Indonesia)

BOG 1 initially considered issues including Direct Air Capture, carbon capture, utilisation and storage, carbonation processes (cement, metal industry wastes and slag), removal of $CO_2$ from water bodies, cross-boundary issues.

Participants evaluated relevant CDR technologies against the assessment criteria set out in Section 2.4.

#### *Listing of new technologies*

Elements listed by participants under the new IPCC Sector 5 *Carbon Dioxide Capture, Transport, Utilization and Storage* include:

- Carbon dioxide capture from process gases
- Direct air capture
- Carbon dioxide utilization
- Carbon dioxide transport; and
- Carbon dioxide injection and geological storage.

'Direct Air Capture (DAC)' refers to a technological process of removing carbon dioxide from the atmosphere.

In relation to Direct Air Capture, participants recognized a gap in the current *IPCC Guidelines* for Greenhouse Gas Inventories, which do not yet provide guidance on this technology. DAC is projected to play a more significant role in future carbon removal strategies, though participants noted the challenges of developing a generalized Tier 1 approach due to technological complexity. Instead, the development of higher-tier methods may be more feasible and provide greater accuracy. Verification activities, essential for tracking effectiveness, would need to be defined through standardized monitoring plans to support DAC's inclusion

Evidence assembled from empirical literature to support the assessments in relation to Direct Air Capture is provided in Section 4 Technology 1.

The participants recommended that new guidance be developed in *IPCC Sector 5, Volume 6, Chapter 3 Direct Air Capture.*

'Carbon dioxide capture from process gases' refers to capture of carbon dioxide from anthropogenic sources such as process gases.

In relation to Carbon dioxide capture from process gases, participants noted that existing guidance in the *2006 IPCC Guidelines* addresses aspects of CCS, though further updates are warranted to reflect advances in technology and usage. Developing new Tier 1 approaches is challenging due to the specialized nature of CCS and CCU; higher-tier methods may be more appropriate to achieve reliable estimates. Participants highlighted the need for robust verification activities supported by well-defined monitoring plans which would help enhance the reliability of emissions data for CCS and CCU.

Evidence assembled from empirical literature to support the assessments in relation to Carbon dioxide capture from process gases' is provided in Section 4 carbon capture, utilization, and storage.

The participants recommended that updated guidance be developed for a re-located category in IPCC Sector 5, Volume 6, Chapter 2 Carbon capture from process gases.

Once captured, the carbon dioxide captured under DAC or carbon capture from process gases would be subject to the methods for utilization, transport, injection and storage listed in the TOC as Volume 6 chapters 4, 5 and 6.

'Carbon dioxide utilization' refers to possible ways of $CO_2$ utilization, e.g. enforced carbonation of industrial and mining wastes, critical mineral extraction, mineralisation (surface), synthetic fuels. It also refers to tracking of captured $CO_2$, national carbon dioxide balance matrix (sources of captured $CO_2$ vs. final use and short- and long-term storage).

Evidence assembled from empirical literature to support the assessments in relation to the utilization of carbon dioxide in the mining industry is provided in Section 4 Technology 2 (ii).

The participants recommended that new and updated guidance be developed for a category in IPCC Sector 5, Volume 6, Chapter 4 Carbonation dioxide utilization.

In addition, the participants recommended that updated guidance be developed for a re-located category in IPCC Sector 5, Volume 6, Chapter 5 Carbon dioxide transport and Chapter 6 Carbon dioxide injection and geological *storage.*

'Carbonation of cement' (Table 1 Technology 2 (i)) refers to the passive carbonation of cement.

In considering this technology, participants considered that there was a gap in the Guidelines and that the delineation of the category could be broadened to include passive carbonation of lime-based structures. The category could be broadened to include all life stages from initial curing to construction to final disposal of the cement or lime-based structure (as wastes).

Not included in this category would be enforced or catalysed carbonation processes such as occur in the mining industry as these are covered in the new IPCC Sector 5 (carbon dioxide utilization (Volume 6, chapter 4).

Participants considered the feasibility of methods and verification. While some research exists to support the development of a Tier 1 approach, higher-tier methodologies may offer improved accuracy and applicability. Verification should be implemented through monitoring plans to track carbonation efficiency and durability

Evidence assembled from empirical literature to support the assessments is provided in Section 4 Technology 2 (i).

The participants recommended that new and updated guidance be developed for a category in IPCC Sector 2, Volume 3, Chapter 11 Carbonation of cement and lime-based struc*tures*.

#### *Updated or additional guidance*

Production of $CO_2$ containing products (Table 1 Technology 5) refers to the production of products containing carbon dioxide, for example, synthetic e-fuels. These production processes include the use of carbon dioxide.

In considering the production of $CO_2$ containing products, participants noted that these processes, such as the synthesis of e-fuels, present a unique pathway for utilizing captured carbon. The current *IPCC Guidelines* allow for the subtraction of captured $CO_2$ at the source only if it is intended for long-term storage or otherwise accounted for in the inventory. Expanding guidance to include $CO_2$ used in products with shorter lifetimes, such as fuels and beverages, could significantly impact inventory sectors like *Energy* and *Industrial Processes and Product Use*. This may necessitate additional guidance to manage cross-sectoral impacts and ensure accurate accounting.

Evidence assembled from empirical literature to support the assessments is provided in Section 4 Technology 5 and Technology 6.

The participants recommended that new and updated guidance in relation to the production of products containing or derived from captured $CO_2$ in IPCC Sector 2, Volume 3, Chapter 3 Chemical Industry IPCC Sector 1, Volume 2, Chapter 2, Stationary Combustion and Chapter 5 Fugitive Emissions be developed.

In addition, participants recommended that new guidance in relation to the consumption of products containing or derived from captured $CO_2$ in IPCC Sector 2, Volume 3, Chapter 9 Consumption and use of $CO_2$ containing products be developed, depending on decisions made in relation to Carbon Capture and Utilization (in volume 6).

Further consideration will be also required by authors as to the treatment of $CO_2$ containing products which may impact the current guidance offered for production of industrial products (IPPU); production and combustion of synthetic fuels (*Energy*) or disposal of $CO_2$ containing products (Waste).

#### *Evaluation of omitted or referred technologies*

In relation to the removal of $CO_2$ from waterbodies, participants acknowledged that this technology is not covered in the current *IPCC Guidelines* but shows potential as a novel $CO_2$ removal approach. ‘Removal of $CO_2$ from waterbodies’ was considered further by BOG 2.

## 3.2 *Agriculture, Forestry and Other Land Use (AFOLU)* and related Issues

BOG 2: Co-facilitators: Stephen Ogle (United States of America) and Jongikhaya Witi (South Africa). Rapporteur: Dan Zwartz (Australia).

BOG 2 considered *AFOLU* chapters and issues relating to soils and water bodies: Soils (biochar, enhanced weathering and inorganic carbon, other), biomass products other than Harvested Wood Products; coastal wetlands (seagrass, tidal marshes, macro algae, enhanced alkalinization); wastewater-based CDR/CCUS; cross-boundary issues and open water bodies (ocean fertilization, enhanced alkalinization).

Participants evaluated relevant CDR technologies against the assessment criteria set out in Section 2.4.

#### *Listing of new technologies*

Elements that BOG 2 listed under the new IPCC Sector 6 Direct Removal of $CO_2$ from Waterbodies, Alkalinity Enhancement of Waterbodies include:

- Direct Removal of $CO_2$ from Waterbodies; and
- Alkalinity Enhancement of Waterbodies.

'Direct Removal of $CO_2$ from waterbodies' (Table 1, Technology 3) refers to a technological process composed by three parts (i) extraction of carbon dioxide from water bodies (ii) indirect removals of carbon dioxide by those water bodies because of their increased capacity to absorb additional carbon dioxide from the atmosphere and (iii) a requirement that the carbon dioxide extracted under part (i) is stored and either transferred and injected into permanent storage or utilised.

In relation to Direct Removal of $CO_2$ from waterbodies participants noted that there was a gap in the *IPCC Guidelines*; that the activity could be significant; that higher tier methods would be feasible but that it was unlikely to be feasible to derive a Tier 1 methodology and more information was required to determine whether it was feasible to derive verification activities.

Evidence assembled from empirical literature to support the assessments is provided in Section 4 Technology 3.

The participants recommended that new guidance be developed in a new *IPCC Sector 6, Volume 7, Chapter 2 Direct Removal of $CO_2$ from Waterbodies*.

'Alkalinity enhancement of waterbodies' (Table 1, Technology 2 (iii)) refers to a process composed by two parts (i) adding alkalinity to the surface within territorial waters to bind dissolved $CO_2$ in long-lasting precipitates, so enhancing the capacity of waterbodies to store dissolved $CO_2$; (ii) *indirect removals of carbon dioxide by those water bodies because of their increased capacity to absorb additional carbon dioxide from the atmosphere.*

In relation to alkalinity enhancement of waterbodies the participants noted that there was a gap in the *IPCC Guidelines*; that the activity could be significant; that higher tier methods would be feasible but that more information was required to determine whether it was feasible to derive a tier 1 method and verification activities. Participants also agreed that alkalinity enhancement may consider wastewater effluent and brine from desalinization processes and restoration of coastal wetlands.

Evidence assembled from empirical literature to support the assessments is provided in Section 4 Technology 2 (iii).

The participants recommended that new guidance be developed in a new IPCC Sector 6 Volume 7, Chapter 3 Alkalinity Enhancement of Waterbodies.

### Updated or additional guidance

Enhanced Rock Weathering (ERW) (Table 1, Technology 2 (iv)) refers to a process composed by three parts (i) adding mineral components to the soil to speed up the chemical reaction between CO2 dissolved in soil waters, and mineral components in the soils which results in (ii) additional precipitation of $CO_2$ in mineral components residing, across time, in the soil, in the terrestrial waters and eventually into the ocean (iii) the lower carbon content of terrestrial waters allows waterbodies to increase their capacity to *absorb additional carbon dioxide from the atmosphere*.

In relation to enhanced weathering, the participants noted that the soil inorganic carbon is a component included in existing *IPCC Guidelines* as a tier 3 method while liming, which involves similar processes, is already covered as a $CO_2$ source. A gap exists, however, regarding other rock amendments (such as silicate rock as a soil amendment). Significance of this activity is small currently but could grow significantly for CDR. A Tier 1 methodology already exists for liming; although there may not be enough information to develop Tier 1 methodology, including emissions factors, to encompass all other rock/mineral additions to soils as well as the interaction with the natural rock weathering considering the small but growing literature. However, the development of Tier 3 methods was considered feasible, although associated with verification measurements, mainly consisting of analysis of inorganic C content in soils and in the circulating water.

The CDR Technology of biochar (Table 1, Technology 7) refers to the application of biochar to agricultural soils, and the related impacts on the responsiveness of soil carbon stock changes to various management activities.

In relation to biochar, the participants noted that the gap in the *IPCC Guidelines* related to the lack of Tier 1 EFs, although there is material in appendix 4 of chapter 2, Volume 4 of the *2019 Refinement of the 2006 IPCC Guidelines* that could be used as a basis for the development of Tier 1 EFs. There was a need to consider the range of available biochar feedstocks, processes of carbonification of feedstocks, non-soil uses of biochar and relationship between biochar and methods for harvested wood products, including for trade, and methods for nitrous oxide emissions from fertilizer use as well as for methane emissions from rice cultivation. The process was likely to be significant in the future, given recent market growth, and the update of the methods contained in the 2019 Refinement as well as the provision of Tier 1 EFs were considered to be feasible.

Background Note: Biochar refers to a solid material generated by heating biomass to a temperature in excess of 350 °C under conditions of controlled and limited oxidant concentrations to prevent combustion….using processes that can be classified as either pyrolysis ..or gasification.. (IPCC 2019 Refinement). Methods for the estimation of emissions from the production of biochar are already provided in Volume 2, Chapter 4.3 of the 2019 Refinement of the *2006 IPCC Guidelines*.

Biochar is less reactive to the atmosphere than biomass. As in the case explained in section 2.3, this provides for a benefit of slowing of expected emission release and which, because of the IPCC estimation processes deployed, the production of Biochar may require counting in the *AFOLU* sector. This may require the transfer of the C stocks from the biomass C pool, including annual biomass, to a long-lasting C pool, and its subsequent trade, if any, and its use as soil amendment, which requires its transfer to soils organic matter C pool, or its alternative use as a product – for example, for construction, $CO_2$ capture, feedstock in industrial processes, or feed integrate-(see also "Other Biomass durable products).

Evidence assembled from empirical literature to support the assessments is provided in Section 4 Technology 2 (iv) and Technology 7.

Participants recommended that updated guidance be developed for the existing chapters:

- Chapters 2, 4 ,5, 6, 7, 8 and 9 Volume 4 the *2019 Refinement of the 2006 IPCC Guidelines* - Generic Methodologies Applicable to Multiple Land-Use Categories, Forest Land, Cropland, Grassland, Wetlands, Settlements, Other Land
    - in order to address enhancing soil carbon sinks in croplands and grasslands for CDR: Update in relation to reference stocks and default factors for soil organic carbon estimates and enhancing soil carbon sinks on managed land for CDR: Update to add enhanced weathering into the Tier 3 soil inorganic carbon and relationship to soil organic carbon; update biochar application in soils to develop a Tier 1 method and update of the Tier 2 & 3 methods

- Chapter 4 Volume 4 the *2006 IPCC Guidelines* – Cropland [Rice Cultivation]
    - Enhancement of soil carbon for biochar amendments: Update Tier 1 default factors to estimate impact of biochar amendments on methane emissions from rice cultivation and provide guidance for Tier 2 and Tier 3.

- Chapter 11 Volume 4 the *2006 IPCC Guidelines* – $N_2O$ Emissions from Managed Soils, and
- $CO_2$ Emissions from Lime and Urea Application

- Enhancement of soil carbon for biochar amendments: Update Tier 1 default factors to estimate impact of biochar amendments on soil $N_2O$ emissions from N inputs in managed soils, and provide guidance for Tier 2 and Tier 3.

Enhancing biomass in coastal waters/wetlands (Table 1, Technology 8) refers to the enhancement of carbon sinks for CDR mainly through revegetation or enhanced sedimentation in coastal waters/wetlands.

In relation to the enhancement of carbon sinks in coastal wetlands the participants noted that there were either gaps in the *IPCC Guidelines* or need for updates including for the restoration/revegetation of additional coastal wetlands ecosystems (e.g. seagrass, mangroves, tidal marshes, coastal sabkhas and other tidal wetlands) as well as for seaweeds (macro-algae); that the category could be well delineated; that the enhancement activity could be significant; that Tier 1 and higher tier methods would be feasible and that verification activities could be designed, for example, using satellite technologies.

Evidence assembled from empirical literature to support the assessments is provided in Section 4 Technology 8.

The participants recommended that new and updated guidance be developed for the existing Chapter 4 of the Wetlands Supplement – Coastal Wetlands for the existing activities that result in carbon dioxide removals - as an update of factors in relation to mangroves, tidal marshes and seagrass in coastal waters - and new guidance for activities that result in carbon dioxide removals in other coastal wetland types not yet covered by IPCC guidance.

In addition, new guidance on carbon export from organic soils for the existing Chapters 2, 3, and 4 of the Wetlands Supplement was recommended.

Other durable biomass products (Table 1, Technology 9) refer to the treatment of biomass products not currently considered to be covered by the methods provided for harvested wood products but, as HWP, to store their carbon stocks longer than for a single year.

In relation to durable biomass products the participants noted that an update in relation to other durable biomass products for CDR could include the development of factors for other durable products (e.g., biochar products) and guidance for the trade and for higher tier methods, and transfers from other pools.

Evidence assembled from empirical literature to support the assessments is provided in Section 4 Technology 9.

The participants recommended that new and updated guidance be developed for Chapter 12 Volume 4 the *2006 IPCC Guidelines* – HWP and other durable biomass products.

### *Evaluation of omitted technologies*

BOG 2 concluded that it was premature to list the following technologies in the Table of Contents:

- Wastewater based CDR/CCUS (including biomass uptake on constructed wetlands for wastewater and $CO_2$ capture).
- Ocean fertilisation.

In relation to biomass uptake in constructed wetlands for wastewater treatment (Table 1, Technology 10), while the participants acknowledged that there was a gap in the *IPCC Guidelines*, they concluded that the activity was not significant and that more information was required to determine whether it was feasible to derive a tier 1 method, higher tier methods, and verification activities.

In relation to direct capture of $CO_2$ at wastewater plants (Table 1, Technology 10), while the participants acknowledged that there was a gap in the *IPCC Guidelines*, they concluded that the activity is just a subset of the activities included in new Sector 6.

In relation to ocean fertilisation (Table 1, Technology 11), while the participants acknowledged that there was a gap in the *IPCC Guidelines*, they concluded that it was not clear whether the category could be delineated consistent with the principles of national inventories. They also concluded that research results indicated that the activity does not result in significant carbon storage across time.  Activity data was not available to determine a Tier 1 method and that more information was required to determine whether it was feasible to derive higher tier methods and verification activities.

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### *Technology 4: Enhanced oil, gas or coalbed methane recovery*

See under carbon capture, utilization and storage.

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### *Technology 6: Consumption of $CO_2$ containing products*

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## 5. Conclusions

The objective of this Scoping Meeting was to produce the outline of a Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage in accordance with the Appendix A to the Principles Governing IPCC Work, which contains the procedures for the preparation, review, acceptance, adoption, approval and publication of IPCC reports.

The following outcomes of the Scoping Meeting, as recommended to be used by the TFB for its submission for an outline of a Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage to the IPCC Panel, were produced:

- The title:

  *2027 Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage: (Supplement to the 2006 IPCC Guidelines*)*

- Draft Terms of Reference for *2027 Methodology Report on* Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage is presented in **Appendix 1**;

- Draft Table of Contents is presented in **Appendix 2**;

- Draft Instructions to Experts and Authors is presented in **Appendix 3;** and

- The Work plan is presented in **Appendix 4**.

The recommendations and documents in Appendix 1 to Appendix 4 will constitute the basis of the TFI proposal for the outline for the *2027 Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage: (Supplement to the 2006 IPCC Guidelines*)* to be presented to the IPCC-62 in early 2025 for the consideration by governments.

# Appendices

## Appendix 1. Terms of Reference (ToR)

**Draft Terms of Reference**

**2027 Methodology Report on Carbon Dioxide Removal Technologies,**
**Carbon Capture, Utilization and Storage**
**(Supplement to the 2006 *IPCC Guidelines**)**

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*The reference to the 2006 *IPCC Guidelines* for National Greenhouse Gas Inventories, and thus the notation *2006 IPCC Guidelines*, includes the following three methodological reports:

- *2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines)*
- *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement)*
- *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (2019 Refinement*).

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**Background**

1. At the 60th Session (IPCC-60) held in January 2024 (Istanbul, Türkiye) the IPCC decided that the Task Force on National Greenhouse Gas Inventories (TFI) will hold an Expert Meeting on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage and provide a Methodology Report on these by the end of 2027 (Decision IPCC-LX- 9).

2. IPCC TFI held the Expert Meeting in July 2024 (Vienna, Austria) and the Scoping Meeting in October 2024 (Copenhagen, Denmark). These meetings considered Carbon Dioxide Removal (CDR) methods mentioned in the AR6 WGIII Report as a starting point for discussion and noted that several CDR activities have been already covered by the existing *IPCC Guidelines*.

3. The Scoping Meeting produced the draft Table of Contents of the new Methodology Report, which is outlined in Annex 1.

**Scope**

4. *The IPCC Guidelines* already cover issues related to Afforestation/Reforestation, Soil carbon sequestration in croplands and grasslands, Peatland and coastal wetland restoration, Agroforestry, Improved Forest Management, Biochar amendments, Carbon Capture and Storage from process gases.

5. The aim of the new Methodology Report is to provide an updated and sound scientific basis for supporting the preparation and continuous improvement of national greenhouse gas inventories in relation to estimation and reporting of carbon dioxide removal technologies, carbon capture, utilization and storage. In order to achieve the overall aim, the new Methodology report will:

- provide new methodological guidance for carbon dioxide removal technologies, carbon capture utilization only where currently there are gaps in the existing guidelines or where new removal technologies have emerged that could provide scientifically sound and empirically robust methods, activity data, removal factors and other parameters;

- provide, where needed, updated guidance and information of the existing guidance in the *2006 IPCC Guidelines* in relation to carbon dioxide removal technologies, carbon capture and storage.

6. This work will not revise the *2006 IPCC Guidelines* but will update and provide new guidance for the *2006 IPCC Guidelines* where gaps or out-of-date science have been identified. The Methodology Report will not replace the *2006 IPCC Guidelines*, but will be used in conjunction with the *2006 IPCC Guidelines*.

7. Generally, national inventories should include greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction [*2006 IPCC Guidelines*, Volume I, Chapter 8.2.1]

**Approach**

8. The result of this work will be an IPCC Methodology Report "*2027 Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage (Supplement to the 2006 IPCC Guidelines*)".

9. The authors will follow Annex 2 "Instructions to Experts and Authors" to ensure a consistent and coherent approach across all the volumes or chapters, including the use of common terminology.

10. Annex 3 provides the timetable for this task. Literature will be considered up to a cut-off date at the start of the Government/Expert Review.

## Appendix 2. Table of Contents (ToC)

**Draft Table of Contents**

**2027 Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage (Supplement to the 2006 IPCC Guidelines)**

**Introductory Note**

*2027 Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage (Supplement to the 2006 IPCC Guidelines*) will be a single Methodology Report comprising an Overview Chapter and seven volumes following the format of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories (2006 IPCC Guidelines*).

Overview Chapter
Volume 1: General Guidance and Reporting
Volume 2: Energy
Volume 3: Industrial Processes and Product Use
Volume 4: Agriculture, Forestry and Other Land Use
Volume 5: Waste
Volume 6: Carbon Dioxide Capture, Transport, Utilization and Storage
Volume 7: Direct Removal of CO2 from Waterbodies. Alkalinity Enhancement of Waterbodies

The structure of the Methodology Report is the same as that of the 2006 IPCC Guidelines so as to make it easier for inventory compilers to use this Methodology Report with the 2006 IPCC Guidelines.
For those Chapters where update or new guidance is expected, a description is provided below.
Also, authors should develop modifications for Chapters, if deemed necessary to ensure consistency with the updates or new guidance made in the other Chapters.
In addition, authors should develop updates or produce new Worksheets, where necessary.

**Overview Chapter**

**Glossary**

**Volume 1: General Guidance and Reporting (Update)**

**Chapter 1 Introduction**

- *Consequential updates based on the new/updated guidance*

**Chapter 4 Methodological Choice and Identification of Key Categories**

- *Consequential updates based on the new/updated guidance*

**Chapter 8 Reporting Guidance and Tables**

- *Update in relation to categorization of new source/sink categories or recategorization of existing (e.g. 1.C). Update of all reporting tables, clarifying that the $CO_2$ emissions are adjusted by $CO_2$ capture (negative quantities) to derive net $CO_2$, explanations to reporting* *tables: fugitive emissions during international $CO_2$ transport; $CO_2$ from biomass fuels in international transport, $CO_2$ from CCU-products/e-fuels I international transport, $CO_2$ captured during international transport, $CO_2$ from biomass in IPCC sectors 1B & 2, 3A and 4, how to report carbon capture in all sectors, differentiating fossil/CCU; biomass & atmospheric origins*

**Volume 2: Energy (Update)**

**Chapter 2 Stationary Combustion & Chapter 3 Mobile Combustion**

- *Placeholder: Depending on the decisions made in relation to CCU, there might be a need for additional guidance in these chapters, e.g. in relation to new emission factors for combustion of fuels based on captured $CO_2$.*

**Chapter 4 Volume 2 of the 2006 IPCC Guidelines – Fugitive Emissions**
**Chapter 4 Volume 2 of the 2019 Refinement to the 2006 IPCC Guidelines – Fugitive Emissions**

- *Clarification in relation to the emissions from transport, injection and sequestering of $CO_2$ in relation to enhanced oil, gas, and coal-bed methane recovery*
- *Placeholder: Depending on the decisions made in relation to CCU, there might be a need for additional guidance in this chapter, e.g. in relation to new emission factors for the production of fuels based on captured $CO_2$*

**Volume 3: Industrial Processes and Product Use (New and Update)**

**Chapter 3 of the 2006 IPCC Guidelines – Chemical Industry**
**Chapter 3 of the 2019 Refinement of the 2006 IPCC Guidelines – Chemical Industry (Update)**

- *Guidance in relation to the production of products containing or derived from captured $CO_2$.*

**Chapter 9 of the 2006 IPCC Guidelines – Consumption and Use of CO2 containing products**
**Chapter 9 of the 2019 Refinement of the 2006 IPCC Guidelines – Consumption and Use of CO2 containing products**
**(New)**

- *Placeholder: Depending on the decisions made in relation to CCU (in Volume 6), there might be a need for additional guidance on emissions arising from the consumption and use of $CO_2$ containing products*

**Chapter 10 Carbonation of cement and lime based structures**

Covering all life stages. Excluding enforced carbonation (covered in Volume 6)

**Volume 4: Agriculture, Forestry and Other Land Use (Update and New)**

**Chapters 2, 4 ,5, 6, 7, 8 and 9 Volume 4 the 2019 Refinement of the 2006 IPCC Guidelines - Generic Methodologies Applicable to Multiple Land-Use Categories, Forest Land, Cropland, Grassland, Wetlands, Settlements, Other Land**
**(Update)**

- *Enhancing soil carbon sinks in croplands and grasslands for CDR: Update in relation to reference stocks and default factors for soil organic carbon estimates.*
- *Enhancing soil carbon sinks on managed land for CDR: Update to add enhanced weathering into the Tier 3 soil inorganic carbon and relationship to soil organic carbon; update biochar application in soils to develop a Tier 1 method and update of the Tier 2 & 3 methods.*

**Chapter 4 Volume 4 the 2006 IPCC Guidelines – Cropland [Rice Cultivation] (Update)**

- *Enhancement of soil carbon for biochar amendments: Update Tier 1 default factors to estimate impact of biochar amendments on methane emissions from rice cultivation, and provide guidance for Tier 2 and Tier 3.*

**Chapter 11 Volume 4 the 2006 IPCC Guidelines – $N_2O$ Emissions from Managed Soils, and $CO_2$ Emissions from Lime and Urea Application (Update)**

- *Enhancement of soil carbon for biochar amendments: Update Tier 1 default factors to estimate impact of biochar amendments on soil N2O emissions from N inputs in managed soils, and provide guidance for Tier 2 and Tier 3.*

**Chapters 2, 3, 4 of the Wetlands Supplement (New)**

- *Enhancement of carbon stocks in organic soils for CDR: new guidance on carbon export from organic soils.*

**Chapter 4 of the Wetlands Supplement – Coastal Wetlands (Update and New)**

- *Enhancement of carbon sinks for CDR: Update factors in relation to mangroves, tidal marshes and seagrass in coastal waters.*
- *New guidance on other coastal wetland types not in previous IPCC Guidelines.*

**Chapter 12 Volume 4 the 2006 IPCC Guidelines – HWP and other durable biomass products (New and Update)**

- *Update in relation to other durable biomass products for CDR: Develop factors for other durable products (e.g., biochar products) and guidance for higher tier methods, and transfers from other pools.*

**Volume 5: Waste (Update)**

**Chapter 5 Volume 5 the 2006 IPCC Guidelines - Incineration and Open Burning of Waste (Update)**

- *Placeholder: Depending on the decisions made in relation to CCU (in Volume 6), there might be a need for additional guidance on emissions arising from incineration of $CO_2$ containing products*

**Volume 6 Carbon Dioxide Capture, Transport, Utilization and Storage (IPCC Sector 5) (New and Update)**

**Chapter 1. Introduction (New)**

- *The basic concepts and terms and definitions related to CCUS should be addressed inter alia: technology, removal, short- and long-term storage, "negative" emissions.*

**Chapter 2 Carbon Dioxide Capture from process gases (Update)**

**Chapter 3 Direct Air Capture (New)**

**Chapter 4. Carbon Dioxide Utilization (New)**

- *Possible ways of $CO_2$ utilization, e.g. enforced carbonation of industrial and mining wastes, critical mineral extraction, mineralisation (surface), synthetic fuels*
- *Tracking of captured $CO_2$, national carbon dioxide balance matrix (sources of captured $CO_2$ vs. final use and short- and long-term storage).*

**Chapter 5. Carbon Dioxide Transport (Update)**

- *Update in relation to all sub-categories ($CO_2$ transport (ship/rail/pipeline/truck) and cross-border transfers)*

**Chapter 6. Carbon Dioxide Injection and Geological Storage (Update)**

- *Update in relation to all sub-categories (injection, long term storage, other)*
- *Mineralisation (subsurface)*

**Volume 7. Direct Removal of $CO_2$ from Waterbodies. Alkalinity Enhancement of Waterbodies (IPCC Sector 6) (New)**

**Chapter 1. Introduction**

**Chapter 2. Direct Removal of $CO_2$ from Waterbodies**

- *New guidance on enhancing carbon sinks by capture of CO2 from water with durable storage or other utilization.*

**Chapter 3. Alkalinity Enhancement of Waterbodies**

- *New guidance on enhancing carbon sinks by increasing alkalinity in waterbodies.*

## Appendix 3. Instructions to Experts and Authors

**Instructions to Experts and Authors**

**2027 Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage (Supplement to the 2006 IPCC Guidelines)**

1. Work on a Methodology Report will be guided by the IPCC procedures for the Preparation, Review, Acceptance, Adoption, Approval and Publication of the IPCC Reports (Appendix A to the Principles Governing the IPCC Work[8]). This document is consistent with the IPCC procedures and applies to all experts engaged in the production of a new Methodology Report.
2. In this document the term "experts" covers Co-Chairs, members of the TFI Bureau (TFB), technical support unit (TSU) Staff, Coordinating Lead Authors (CLAs), Lead Authors (LAs), and Review Editors (REs) as well as Contributing Authors (CAs) and Expert Reviewers.
3. These notes are intended as guidance to experts contributing to a new Methodology Report. They are intended to ensure a consistent and coherent approach across all the volumes or chapters and to promote common terms used.

### Confidentiality

4. Authors meetings are closed meetings. Any discussions are confidential except for any published report of the meeting. This is to ensure that experts participating in the meetings can express themselves and discuss issues freely and openly.
5. The IPCC considers the drafts of a new Methodology Report, prior to acceptance, to be pre-decisional, provided in confidence to reviewers, and not for public distribution, quotation or citation.
6. The TSU will keep drafts of a new Methodology Report sent for the IPCC review, any comments received on them and the responses by authors. All written expert and government review comments will be made available to reviewers on request. These will be made available on the IPCC website as soon as possible after the acceptance by the Panel and the finalisation of the report.

### Conflict of Interest

7. It is important that all experts involved in the IPCC activities avoid any conflict of interest or the direct and substantial appearance of a conflict of interest. It is recognised that many experts in Emission Inventories are employed by, or funded by, parties with some interest in the outcome (e.g. most inventory compilers are funded by national governments or industry). It is therefore important to be open and transparent about financial and other interests.
8. The IPCC implements a Conflict of Interest (COI) Policy[9] that applies to all individuals directly involved in the preparation of IPCC reports, including senior IPCC leadership (IPCC Chair and Vice-Chairs), other Bureau and Task Force Bureau members, authors with responsibilities for report content (CLAs, LAs), Review Editors and staff of the TSU. The overall purpose of this policy is to protect the legitimacy, integrity, trust, and credibility of the IPCC and of those directly involved in the preparation of reports, and its activities.
9. Before an individual is appointed as a CLA, LA and RE for a new Methodology Report, the TFB will request the individual to complete a Conflict of Interest Disclosure Form ("the COI Form") contained in Annex B to the COI Policy which will be submitted to the TSU. The TFB will then evaluate the form to determine whether the individual has a conflict of interest that cannot be resolved.
10. All CLAs, LAs and REs will inform the TSU annually of any changes in the information provided in their previously submitted COI Form. The TFB will evaluate the revised information.

[8] https://www.ipcc.ch/site/assets/uploads/2018/09/ipcc-principles-appendix-a-final.pdf
[9] https://www.ipcc.ch/site/assets/uploads/2018/09/ipcc-conflict-of-interest-2016.pdf

11. All COI Forms and any records of the deliberations of the COI Expert Advisory Group, deliberations and/or decisions of the COI Committee in relation to conflict of interest issues in respect of specific individuals and any information disclosed by individuals for the purposes of the COI Policy will be transferred to the Secretariat after they have been reviewed and will be securely archived by the Secretariat and retained for a period of five years after the end of the assessment cycle during which the relevant individual contributed, after which the information will be destroyed. Subject to requirement to notify the existence of a conflict of interest to others, the information referred to above will be considered confidential and will not be used for any purpose other than consideration of conflict of interest issues under these Implementation Procedures without the express consent of the individual providing the information.

**Responsibilities of authors and other experts**

12. The role of authors is to impartially assess ALL the available literature and to describe the best methodologies available. Experts should be impartial. Authors should review all literature available up to a cut-off date to be decided by the TFB as part of the agreed work plan.
13. After drafting the report authors will be asked to consider all comments received on the drafts and to adjust and revise the text accordingly. They should document their responses. If they do not accept a comment this should be explained. Review Editors should check whether the accepted changes were fully incorporated in the revised text.
14. Responsibilities and duties of authors and other experts are currently explained in more detail in the IPCC procedures for the Preparation, Review, Acceptance, Adoption, Approval and Publication of the IPCC Reports (Appendix A to the Principles Governing the IPCC Work).

**Literature**

15. The use of literature should be open and transparent. In the drafting process, emphasis is to be placed on the assurance of the quality of all cited literature. Priority should be given to peer-reviewed scientific, technical and socio-economic literature if available.
16. It is recognized that other sources provide crucial information for IPCC Reports. These sources may include reports from governments, industry, and research institutions, international and other organizations, or conference proceedings. Use of this literature brings with it an extra responsibility for the author teams to ensure the quality and validity of cited sources and information as well as providing an electronic copy. In general, newspapers and magazines are not valid sources of scientific information. Blogs, social networking sites, and broadcast media are not acceptable sources of information for IPCC Reports. Personal communications of scientific results are also not acceptable sources.
17. For any sources written in a language other than English, an executive summary or abstract in English is required.
18. All sources will be integrated into a reference section of an IPCC Report.
19. For more details of the procedure on the use and referencing of literature in IPCC Reports, see Annex 2 to the IPCC procedures for the Preparation, Review, Acceptance, Adoption, Approval and Publication of the IPCC Reports (Appendix A to the Principles Governing the IPCC Work).

**Principles of the new Methodology Report**

20. Guidance in the new Methodology Report should be understandable and easy to implement. Lead authors should make efforts to balance the need to produce a comprehensive self-contained report with reasonable limits to the length and detail of the guidance. In particular:
    a. The guidance should follow a cookbook approach by providing clear step by step instructions. It should not try to be a textbook. Detailed background information on emission processes, scientific studies, etc. is generally referenced rather than included.
    b. Lead authors must consider relevant scientific developments and national methods used by countries in their inventories.
    c. Authors should bear in mind that the target audience is a diverse group of readers who are primarily concerned with the elaboration of national inventories. For this reason, the

emphasis should be on ensuring clear communication of practical and understandable guidance.

21. This work aims to cover all IPCC inventory sectors with categories where the science is considered to be robust enough to provide guidance for a Tier 1 methodological approach and have a relative[10] contribution to the global/regional emissions of the species, using the significance and prioritization criteria as shown below.

Significance and prioritization criteria

- Significance of the category and the species within the sector on a global/regional scale. Categories significant only for a limited number of particular countries, currently or in the foreseeable future, may not meet this criterion.
- Sufficient data availability and maturity of scientific advances to provide a basis for methodological development, including:
  - Ability to develop default emission and removal factors and parameters
  - Feasibility of obtaining the necessary data to implement the methods
- Relevant for IPCC emissions scenarios and pathways to net zero emissions

22. The general structure, approach and definitions used in the *2006 IPCC Guidelines*, such as tiered approach and decision trees will be followed. Annexes may be used where necessary to contain additional data to support the methodologies, although large numbers of annexes will probably not be necessary. Appendices are not ruled out where scientific knowledge is insufficient for countries to agree full methodologies, but please avoid as far as possible work on areas that have to be relegated to an appendix. Appendices should be sub-titled by "Basis for future methodological development".
23. The general structure should include the following elements: Methodological issues (Choice of method, Choice of emission factors, Choice of activity data), Completeness, Developing a consistent time series and Recalculations, Uncertainty assessment, Quality Assurance/Quality Control (QA/QC) and Reporting and Documentation, Worksheets.
24. Only Chapters identified in the draft Table of Contents are to be updated or new guidance should be provided, as proposed. However, authors should develop modifications for those Chapters, if deemed necessary to ensure consistency with updates or new guidance made in the other Chapters.

**Definitions**

25. The following terms will be used throughout the new Methodology Report, and it is essential that all Lead Authors have a common understanding of their meaning and relevance.
26. Tier A - Tier refers to a description of the overall complexity of a methodology and its data requirements. Higher tier methods are generally more complex and data-intensive than lower tier methods. The guidance for each category should contain at least a Tier 1 method, and in many cases there will be a Tier 2 and Tier 3. The general expectation is that Tier 2 and Tier 3 methods will both be consistent with good practice guidance for key categories, although in some cases Tier 3 will be preferred.
27. Tier 1 approaches are simple methods that can be applied by all countries in all circumstances. Default values for the emission and removal factors and any other parameters needed must be supplied (see below for documentation needed).
28. Tier 2 methods should in principle follow the same methodological approach as Tier 1 but allow for higher resolution country specific emission and removal factors and activity data. In some categories, this may not be the case. These methods should better replicate the parameters

[10] i.e. not insignificant

affecting the emissions. Country specific emission and removal factors are needed and possibly more parameters will also be needed.

29. Tier 3 methods give flexibility either for country specific methods including modelling or direct measurement approaches, or for a higher level of disaggregation, or both. This is a more complex method, often involving a model. This will replicate many features of nation emissions and require specific parameters for each country.

30. Default information is data that is appropriate for use where there is no better detailed, country specific information. If appropriate, authors may specify regional default data. Users of the guidelines should be encouraged to try to find better country specific data. Default data are appropriate for Tier 1 methods and the guidelines should contain all the default values needed. Emission and removal factors for higher tiers need not be specified because it is a function of higher tier methods to find data reflecting national circumstances. Default information is included primarily to provide users with a starting point from which they can develop their own national assumptions and data. Indeed, national assumptions and data are always preferred because the default assumptions and data may not always be appropriate for specific national contexts. In general, therefore, default assumptions and data should be used only when national assumptions and data are not available.

31. Decision Trees. A decision tree is a graphical tool to assist countries in selecting from the IPCC methods.

32. Key categories are inventory categories which individually, or as a group of categories (for which a common method, emission and removal factors and activity data are applied) are prioritised within the national inventory system because their estimates have a significant influence on a country's total inventory in terms of the absolute level, the trend, or the level of uncertainty in emissions. Key category analysis should be performed species by species. The appropriate threshold to define key categories should be considered by authors.

33. Sector refers to the sectors of the guidelines, these are divided into categories and subcategories.
    a. Sector 1
    b. Category 1.A
    c. Sub-category 1st order 1.A.1
    d. Sub-category 2nd order 1.A.1.a
    e. Sub-category 3rd order, 1.A.1.a.i

34. Worksheets. These will be printed versions of spreadsheet tables, that, when filled in, enable the user to perform the emission estimation. They should contain all the calculations and written text with any formulae. Additional worksheets may be required to compile the results of the worksheets into the reporting tables.

35. Reporting Tables are tables that present the calculated emission inventory and sufficient detail of other data used to prepare the inventories for others to understand the emission estimates.

36. Usage:
    a. "Good Practice" is defined in the 2019 Refinement as follows: "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".

The concept mentioned above should be applied to all species dealt with in this report.

b. 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.

c. “Shall” should not be used. Either say “Good Practice is…” or say what needs to be done or what should be done. These all indicate what needs to be done to comply with Good Practice.

d. "Be encouraged to" indicates a step or activity that will lead to higher quality inventory but are not required for ensuring consistency with the *IPCC Guidelines*.

e. “Recommend” should not be used. In the GPG2000, the word “recommend” was avoided and “Suggested” was used instead.

f. “Inventory agency” is the body responsible for actually compiling the inventory, perhaps from contributions from a number of other bodies while “inventory compiler” is the person actually compiling the inventory,

**Reporting Tables and worksheets**

37. Worksheets reflect the application of tier 1 methods only, due to the varied implementation of higher tier methods by countries. Lead authors should stress the importance of documentation and archiving of particular types of information of relevance to each category, although advice may be given of what needs to be reported for transparency at higher Tiers.

**Emission and Removal factors and methods**

38. Authors should provide default emission or removal factors and parameters. In doing this work, they should draw on the widest possible range of available literature, scientific articles and country reports. Where default values for emission and removal factors or ancillary parameters cannot be provided for a robust methodology set to be a Tier 1 method, authors may decide to add the methodology as a higher tier method rather than Tier 1 setting the good practice for inventory compiler to use their own data.

39. All data reported in the guidance as IPCC default values shall be justified by authors by providing TSU with all background data used, and the source of those data, as well as all information on the method applied to derive the default values from the background data, as needed to replicate the calculation, in a timely manner as drafts are being developed. Background data should be compiled in the attached form (Appendix 1) to facilitate the upload in the Emission Factor Database (EFDB). Lead authors should be familiar with the draft cross-cutting guidance on data collection in Volume 1 and the guidance on cross-cutting issues in this note on terms, data types, data demands of methods and stratification requirements. Default data should also meet the EFDB evaluation criteria – robustness, documentation, and applicability[11].

40. Authors should develop guidance to provide additional information on rationale, references and background information on parameters used for estimating of default values where such information is available (similar to Annexes in Chapter 10, Volume 4, of the 2019 Refinement), with a view to enhancing the transparency and applicability of default values presented in the new Methodology Report.

41. Single IPCC default emission and removal factors might not be ideal for any one country, but they can be recommended provided that regional factors are unavailable, and the defaults are representative of typical conditions as far as can be determined. It may be necessary or appropriate to provide a range of default emission and removal factors along with clear guidance about how countries should select from within the range. Lead authors may also provide multiple default emission and removal factors, disaggregated by region, technology (including abatement and removal technologies), or another relevant classification scheme.

42. It is important to provide more default emission and removal factors that reflect the unique conditions of developing countries. In general, default emission and removal factors for Tier 1

[11] EFDB evaluation criteria: https://www.ipcc-nggip.iges.or.jp/EFDB/documents/EFDB_criteria.pdf

should represent emissions without category-specific mitigation measures, as well as relevant abatement technologies for which data are available.

43. Users of the guidelines should be encouraged to develop and use country specific data. Emission and removal factors for higher tiers need not be specified in the Methodology Report. Default information is included primarily to provide users with a starting point from which they can develop their own national assumptions and data. Indeed, national assumptions and data are always preferred because the default assumptions and data may not always be appropriate for specific national contexts.
44. The basic principle concerning national methods will continue to apply – countries are encouraged to use national data or methods so long as they are consistent with the *IPCC Guidelines*.
45. Authors should consider consistency in treatment by the exporting and the importing country on reporting of national total net emission when imported biomass is used in BECCS, biochar and other biomass products taking into consideration avoidance of double counting and completeness
46. Authors should exclude natural background when estimating GHG emissions/removals that are not carbon stock changes in C pools listed in Table 1.1 (Volume 4, *AFOLU*) and in the HWP pool.
47. Methods and emission factors for direct $CO_2$ removal and alkalinity enhancement will need to specify waterbodies, such as rivers, lakes, oceans, and others.
48. Alkalinity enhancement may consider wastewater effluent and brine from desalinization processes.
49. Methods and emission factors for direct $CO_2$ removal from water bodies, increased alkalinity and enhanced weathering should consider downstream storage of inorganic carbon.
50. Examples of coastal wetland systems that have not yet been considered in previous *IPCC Guidelines* are Tidal flats; tidal marsh-coastal sabkhas, seaweeds (macro-algae), subtidal sediments, and clarify definitions with consideration of Ramsar classes.
51. Coastal and inland wetlands guidance may consider management for CDR including restoration and other activities.
52. Enhanced weathering may include adding rock, mine tailings and other alkaline materials to land.
53. Consider including carbonate lime additions in soils in the updated guidance on enhanced weathering for soil inorganic carbon.

### Boxes

54.Consistent with the *2006 IPCC Guidelines*, the new Methodology Report may contain Boxes, which should not be used to provide methodological guidance, but for information purposes or providing examples.

### Decision trees

55.Consistent with the format and structure of the *2006 IPCC Guidelines*, the new Methodology Report may contain a decision tree for some sub-categories to assist countries in selecting from the IPCC methods. These decision trees link the choice of IPCC methods to national circumstances via specific questions about data availability and status as a key category[12].

56.To ensure consistency in decision tree logic and format across categories, lead authors should adhere to the following requirements:

a. The decision trees should be based on a series of questions with clear yes/no answers, and two subsequent branches along yes/no paths.
b. The decision trees should start with assessing data availability for the highest tier method, and then direct countries step-wise towards lower tier methods if activity data, emission and removal factors or other parameters are not available.
c. The decision tree should indicate the lowest tier method that is judged to be appropriate for

[12] The most appropriate choice of estimation method (or tier) may also depend on national circumstances, including the availability of resources and advice on this will be given in the cross-cutting volume.

estimating emissions from a key category.

d. If data are not available for the method referred to in c, the 'No' response should direct the reader to the question "Is this a key category?" If the answer to this is 'Yes', the decision tree should recommend that the country collect the necessary data to implement a higher tier method. If the answer is 'No', then the decision tree can recommend a lower tier method. There is no need to deal with the case for a key category where a country does not have the resources to gather additional data needed to implement higher Tier methods. This is dealt with in Volume 1 of the *2006 IPCC Guidelines.*

e. The branches of the decision trees should end in 'out-boxes' that correspond to specific tiers identified in the guidance for that category and are labelled by Tier. Lead authors may also recommend out-boxes for hybrid tiers.

f. Lead authors may develop separate decision trees for different sub-categories. Alternatively, they may include decision tree options for selecting different tiers for different sub-categories. This second option is appropriate if it is advantageous to recommend a higher tier method only for significant sub-categories rather than for the entire category. Decision trees that use the 'significance' criterion must include the "25-30% rule"[13], as reassessed by authors.

57.Additional Formatting Guidelines (see example):

Decision trees should be drafted in separate files. The TSU will integrate these files into the main text at a later date.

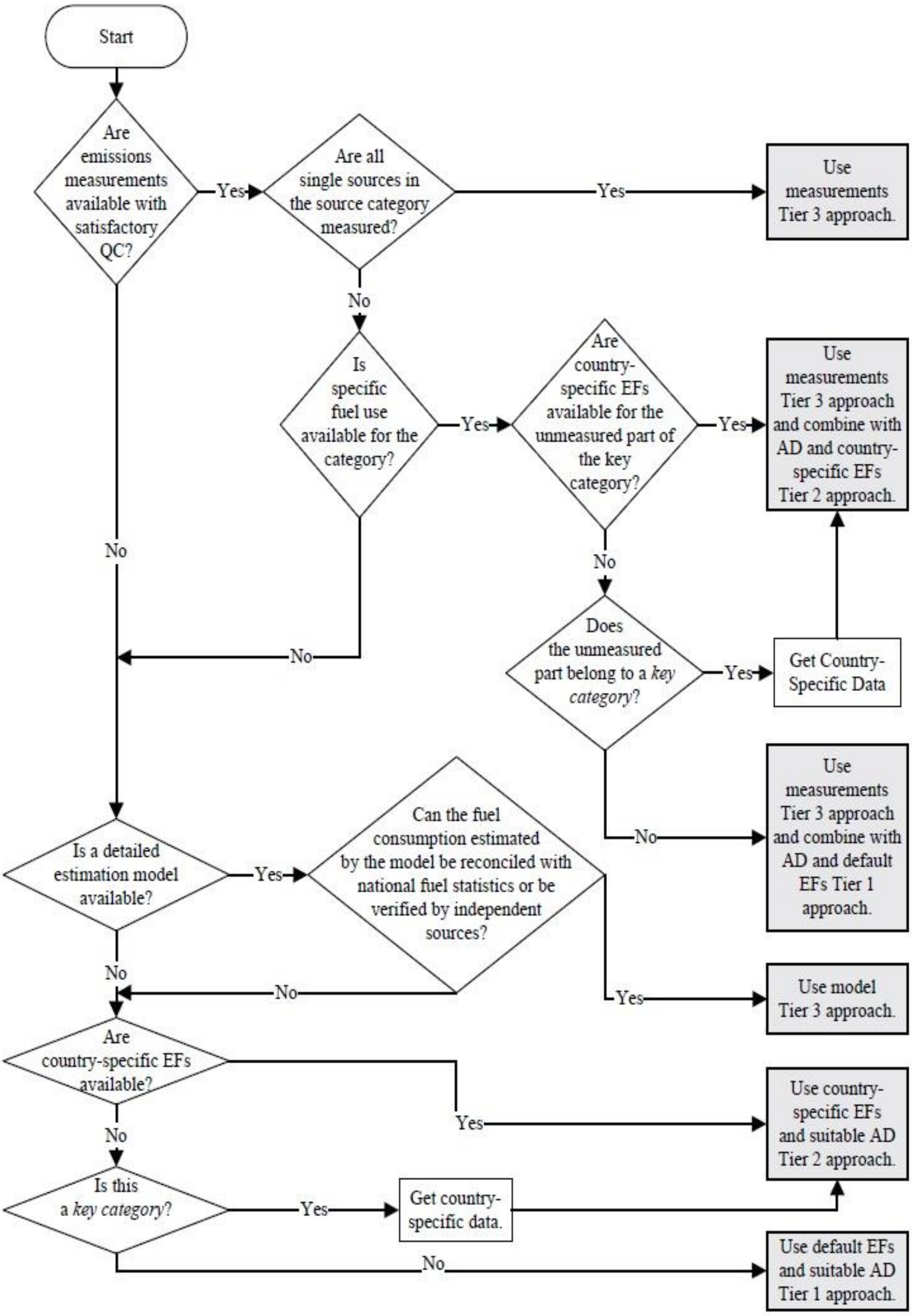
Decision trees should NOT ask the question: "Does this source occur in the country?" This is because decision trees will only be used for sources which occur.

There should be a "START" box. "Diamonds" should be used for questions/decisions. "Squares" should be used for all other information. The out-boxes should be individually numbered. The text font should be Times New Roman 10pt. Text should be centered within the boxes.

[13] As defined in the 2019 Refinement (i.e., a significant sub-category is one that makes up more than 25-30% of emissions from a category).

**Example. Decision tree for estimating emissions from fuel combustion**

**Figure 1.2 Generalised decision tree for estimating emissions from fuel combustion**




Note: See Volume 1 Chapter 4, "Methodological Choice and Key Categories" (noting section 4.1.2 on limited resources) for discussion of *key categories* and use of decision trees.

**Units**

58.SI units shall be used throughout: in text, equations, worksheets and tables.  Emissions have to be expressed in mass units and units have to be used consistently within each sector. When similar activity data is used for different sectors same units need to be used (CLAs have to take care about such harmonisation). Conversion factors have to be provided (for example to estimate $N_2O$ from $N_2$). Where input data available may not be in SI units conversions should be provided.

59.Standard abbreviations for units and chemical compounds should be used.

***Standard equivalents***

| | |
|---|---|
| 1 tonne of oil equivalent (toe) | 1 x $10^{10}$ calories |
| $10^3$ toe | 41.868 TJ |
| 1 short ton | 0.9072 tonne |
| 1 tonne | 1.1023 short tons |
| 1 tonne | 1 megagram |
| 1 kilotonne | 1 gigagram |
| 1 megatonne | 1 teragram |
| 1 gigatonne | 1 petagram |
| 1 kilogram | 2.2046 lbs |
| 1 hectare | $10^4$ $m^2$ |
| 1 $calorie_{IT}$ | 4.1868 joule |
| 1 atmosphere | 101.325 kPa |

## Appendix 4. Workplan

**Workplan**

**2027 Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture, Utilization and Storage (Supplement to the 2006 IPCC Guidelines)**

| Date | Action | Comments |
|---|---|---|
| October 2024 | Scoping Meeting | Prepare ToR, ToC, Workplan and Guidance to authors |
| October 2024 | TFB36 Meeting | Adoption of Outcomes of the Scoping Meeting and Submission to IPCC |
| 1st half 2025 | IPCC-62 | IPCC Plenary approves ToR, ToC, Workplan and Guidance to authors |
| 1st half 2025 | Call for Nomination of Authors and Review Editors | IPCC invites nominations from governments and international organizations |
| 1st half 2025 | Establishment of the Steering Committee | TFB select members to join TFI Co-Chairs in the Steering Group *(to ensure consistency across all the volumes and continuity with the earlier IPCC inventory reports)* |
| 1st half 2025 | Selection of Coordinating Lead Authors, Lead Authors and Review Editors | Selection by TFB considering expertise and geographical and gender balance |
| 2nd half 2025 | 1st Lead Author Meetings | LAM1 to develop zero order draft (ZOD) |
| 2nd half 2025 | 2nd Lead Author Meeting | To develop first order draft (FOD) for review |
| Jan-Feb 2026 (8 weeks) | Expert Review | 8 weeks review by experts |
| 2026 | Science Meeting | A small meeting of CLAs and some LAs to discuss specific issues that require intensive discussion to reinforce the writing process |
| March 2026 | 3rd Lead Author Meeting | To consider comments and produce second order draft (SOD) for review |
| July 2026 | Literature cut-off date (one week before SOD Review) | Peer-reviewed papers accepted by the cut-off date (even if not yet published) will be considered. Non-peer-reviewed documents which are made publicly available by the cut-off date. |
| August-September 2026 (8 weeks) | Government & Expert Review | 8 weeks review by governments and experts |
| December 2026 | 4th Lead Author Meeting | To consider comments and produce final draft (FD) |
| March-April-May 2027 | Government Review | Distribute to governments for their consideration prior to approval (at least 4 weeks prior to the Panel) |

| | | |
|---|---|---|
| July 2027 | Adoption/acceptance by IPCC | Final draft submitted to IPCC Panel for adoption/acceptance |
| 2nd half 2027 | Publication | Electronic means |

## Appendix 5. Agenda of the Scoping Meeting

# IPCC Scoping Meeting
# Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage

**Moltkes Palæ**
**Dronningens Tværgade 2, 1302 København K,**
**Copenhagen, Denmark**
**14-16 October 2024**

# Preliminary Agenda

| | | |
|---|---|---|
| Day 1 | 9:00 - 9:30 | Registration |
| | 9:30 - 10:00 | Welcome<br>- Marianne Thyrring, Director General of the Danish Meteorological Institute, Government of Denmark<br>- IPCC TFI Co-Chairs (Takeshi Enoki and Mazhar Hayat) |
| | 10:00 - 13:00 | **Plenary session 1**<br>**<u>Presentations and discussion</u>**<br>1. Introduction<br>Objectives of the Meeting / Background (Rob Sturgiss, TSU)<br>2. Introduction to IPCC Guidance (Andre Amaro, TSU)<br>3. Expected outcome of the Scoping Meeting (Pavel Shermanau, TSU)<br>Recommendation on the title and format of the Methodology Report<br>Draft Terms of Reference (TOR)<br>Draft Table of Contents (TOC)<br>Draft Instructions to Experts and Authors<br>*(Outcomes of the meeting will be included in the meeting report and will be considered by the TFB to make a proposal to IPCC-62)*<br>Q&A |
| | 13:00 - 14:30 | *Lunch break* |
| | 14:30 – 18:00 | **Break-out group (BOG) session**<br>**<u>Consideration of the Table of Contents</u>**<br>**BOG1:** Direct air capture, carbon capture, utilisation and storage, carbonation processes (cement, metal industry wastes and slag), removal of $CO_2$ from oceans, cross-boundary issues.<br>**BOG2:** *AFOLU* Chapters: Soils (biochar, enhanced weathering and inorganic carbon, other), biomass products other than HWP; coastal wetlands (seagrass, tidal marshes, macro algae, enhanced alkalinization); wastewater-based CDR/CCUS; |

| | | |
|---|---|---|
| | | cross-boundary issues and open water bodies (ocean fertilization, enhanced alkalinization).<br><br>Given the number and diversity of issues under consideration, BOG chairs may decide to establish sub-BOGs. |

18:00: Reception hosted by the Government of Denmark.

| | | |
|---|---|---|
| Day 2 | 09:30 - 13:00 | **BOG session (*continuation*)**<br>• BOG1, BOG2 and any sub BOGs |
| | 13:00 - 14:30 | *Lunch break* |
| | 14:30 - 18:00 | **Plenary Session 2**<br>**Reports from BOGs, Cross-cutting issues, Formal docs**<br>- Report from BOGs on ToC<br>- Discussion of cross-BOG issues<br>- Discussion of TOR, Instruction to Experts and Authors, Workplan |
| Day 3 | 09:30 - 13:00 | **BOG session (*continuation*)**<br>• BOG1, BOG2 and any sub BOGs |
| | 13:00 - 14:30 | *Lunch break* |
| | 14:30 – 18:00 | **Plenary session 3**<br>**Finalization of docs & wrap-up**<br>• Discussion and finalization of the documents to be recommended to the Task Force Bureau<br>• Closing remarks |

Coffee break: 11:00 – 11:30 and 15:30 – 16:00 every day

## Appendix 6. List of Participants

**IPCC Scoping Meeting**
**Methodology Report on Carbon Dioxide Removals and Carbon Capture, Utilization and Storage**
**2027 Supplement to the 2006 IPCC Guidelines**

**Copenhagen, Denmark**
**14-16 October 2024**

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## Appendix 7. List of Acronyms and Abbreviations

| | |
|---|---|
| AD | Activity Data |
| *AFOLU* | Agriculture, Forestry and Other Land Use |
| AR | IPCC Assessment Cycle |
| BOG | Break-out Group |
| EF | Emission Factor |
| EMEP | European Monitoring and Evaluation Programme |
| GHG | Greenhouse Gas |
| HWP | Harvested Wood Product |
| IPCC | Intergovernmental Panel on Climate Change |
| IPPU | *Industrial Processes and Product Use* |
| TFB | IPCC Task Force Bureau |
| TFI | Task Force on National Greenhouse Gas Inventories |
| ToC | Table of Contents |
| ToR | Terms of Reference |
| TSU | Technical Support Unit |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |

Attachment D

# 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

Supporting material prepared for consideration by the Intergovernmental Panel on Climate Change (IPCC).

This supporting material has not been subject to formal IPCC review processes.

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.

This meeting report was prepared jointly by the Co-Chairs of the IPCC TFI (Takeshi Enoki and Mazhar Hayat), as well as the Technical Support Unit (TSU) of the TFI and the Scientific Steering Committee.

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Joana Melo (JRC - European Commission) helped summarizing the information in this report.

This meeting report was subjected to review by the meeting participants.

Published by the Institute for Global Environmental Strategies (IGES), Hayama, Japan on behalf of the IPCC


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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.

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# 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.

[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

[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.

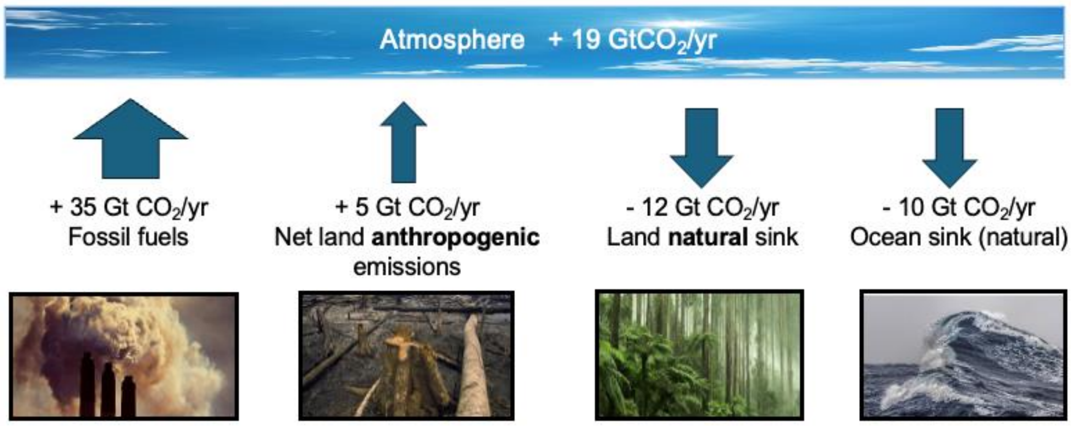



Figure 1. The global carbon budget (2013-2022): sources and sinks of anthropogenic emissions (Global Carbon Project, 2024). Numbers are from Friedlingstein et al. (2023), excluding the 'budget imbalance' required to make all numbers sum to zero.

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).

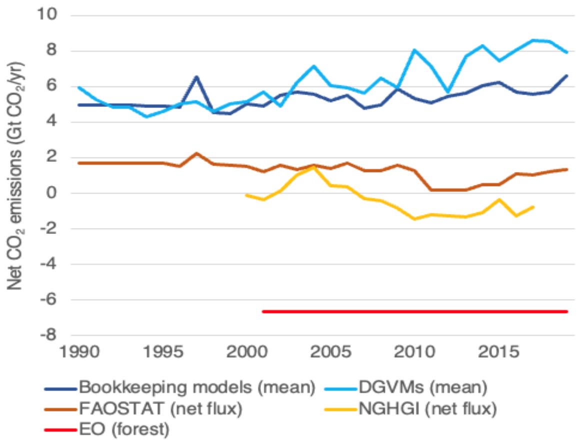
A striking difference is the gap of about 6-7 Gt $CO_2$/yr between the global models from the Global Carbon Budget (Bookkeeping models and Dynamic Global Vegetation Models, DGVMs) and the NGHGIs. According to the available literature, this difference is largely explained by different definitions of anthropogenic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

[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).

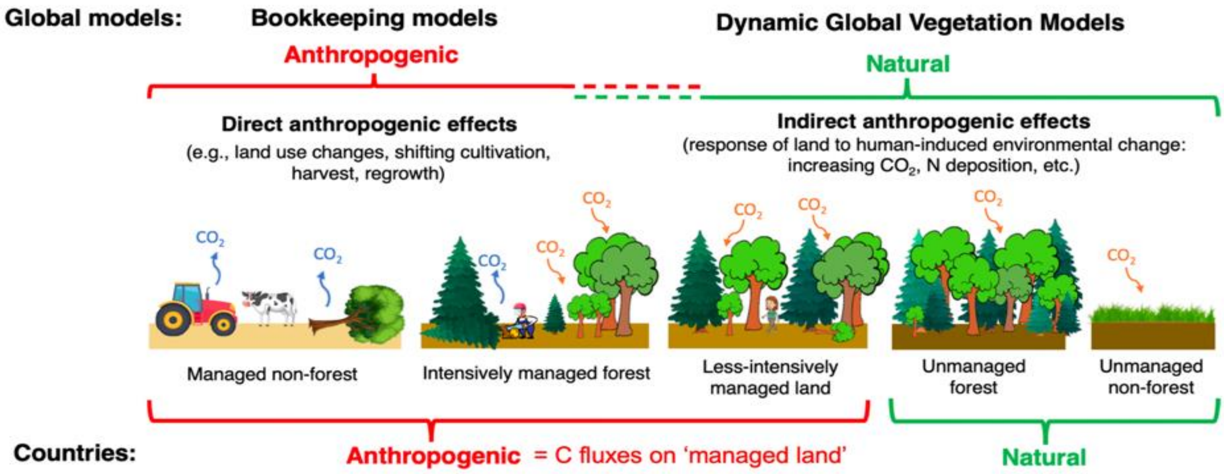



Figure 3. Conceptual illustration of the different approaches for estimating anthropogenic and natural land $CO_2$ fluxes by global models used in the Global Carbon Budget (Bookkeeping models and Dynamic Global Vegetation Models) and by countries' national GHG inventories. See Grassi et al. (2023) for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

[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.

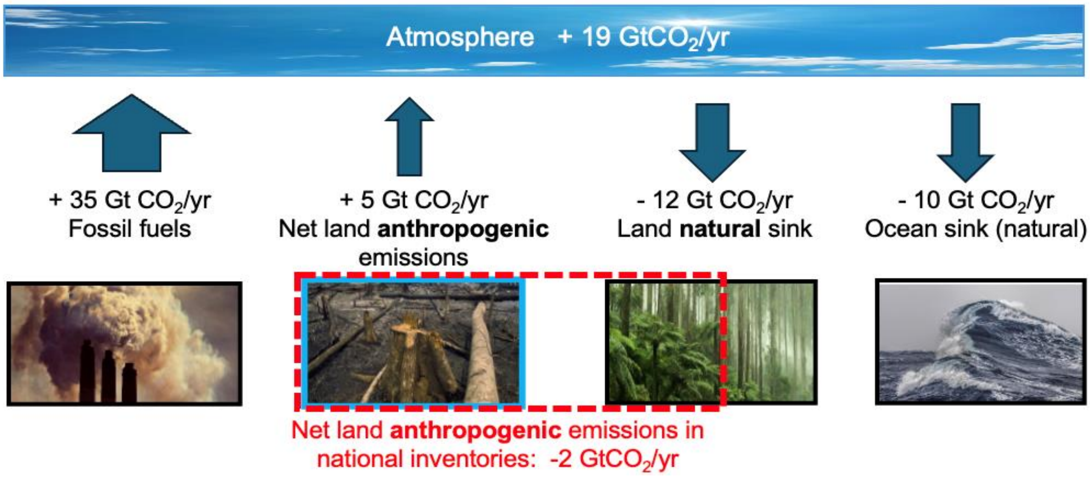



Figure 4. The global carbon budget, as in Figure 1, adapted to highlight the different system boundaries of net land anthropogenic emissions by global models (blue box) and national inventories (red box).

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.

Recommendations:

- 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).

[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).

[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<br>• *Director Alessandra Zampieri (JRC – Sustainable Resources Directorate)*<br>• *Acting Deputy Director General Yvon Slingenberg (DG CLIMA, online)*<br>• *Jim Skea (IPCC chair, online)*<br>Background on the IPCC Task Force on National Greenhouse Gas Inventories (TFI) - *Takeshi Enoki, Mazhar Hayat, Co-Chairs of IPCC TFI*<br>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<br>*Chaired by Thelma Krug (Chair of GCOS Steering Committee)*<br>• Land use in the Paris Agreement and in the Global Stocktake - *Dirk Nemitz (UNFCCC secretariat)*<br>• The managed land proxy in the IPCC Guidelines and previous IPCC meetings - *Maria Sanz (IPCC TFB, Basque Centre for Climate Change) and Thelma Krug*<br>• Overview of current reporting in National GHG inventories - *Joana Melo (JRC)*<br>• Global Forest Resources Assessment 2025: what's new and how can it help estimating forest emissions - *Marieke Sandker (FAO)*<br>• 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<br>*Chaired by Sonia Seneviratne (WGI Vice-Chair)*<br>• The Global Carbon Project and RECCAP – *Glen Peters (CICERO)*<br>• Estimating the terrestrial global carbon budget by global models - *Julia Pongratz (Munich University) and Mike O'Sullivan (Exeter University)*<br>• Discussion |
| | 15:15-15:45 Coffee break | |
| | **Plenary** 15:45-16:45 | Land use emissions in the IPCC AR6 - WGIII<br>*Chaired by Jan Fuglestvedt (WGIII Vice-Chair)*<br>• Emission scenarios with Integrated Assessment Models and links with Earth System Models - *Detlef Van Vuuren (Utrecht University)*<br>• Land-related mitigation options - *Stephanie Roe (WWF)*<br>• Role of the land use sector in NDCs - *Rosa Roman-Cuesta (JRC)*<br>• Discussion |
| | 16:45-17:45 | Reconciling land use emissions between global models and national inventories<br>*Chaired by Andy Reisinger (Australian National University)*<br>• Reconciliation efforts done so far - *Giacomo Grassi (IPCC TFB, JRC) and Thomas Gasser (IIASA)*<br>• Impacts of different definitions of $CO_2$ removal for net zero and remaining carbon budget - *Glen Peters (CICERO)*<br>• 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<br>Role of Earth Observation (EO) for estimating land use emissions<br>*Chaired by Alessandro Cescatti (JRC)*<br>• Satellite remote sensing for land characterisation - *Martin Herold (GFZ Potsdam)*<br>• Use of remote sensing to produce biomass maps: the case of Brazil – *Jean Pierre Ometto (INPE)*<br>• Revised geospatial monitoring of 21st century forest carbon fluxes by Global Forest Watch - *Nancy Harris (World Resource Institute)*<br>• New tools for estimating emissions from land use - *Sassan Saatchi (JPL, California Institute of Technology)*<br>• Combining satellite biomass and disturbances observations to project current and future carbon sink - *Philippe Ciais (LSCE)*<br>• 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)*<br>• Discussion: how can EO links with other communities and support the reconciliation efforts?<br>• 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.:<br>- 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;<br>- Challenges related to the conceptual comparability of emissions/removals across communities;<br>- '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<br>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:<br>- 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.<br>- Earth Observation: time series consistency, spatial resolution, use/accessibility of ground data, verification, masking results with managed areas, etc.<br>- 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<br>Discussion |
| | 16:00-16:30 Coffee break | |
| | **Plenary** 16:30-17:00 | Final Discussion and next steps – *Greet Maenhout and Giacomo Grassi (JRC)*<br>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** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **World regions** | | | | | | | |
| | | **Developed countries** | **Developing + EIT countries** | **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)

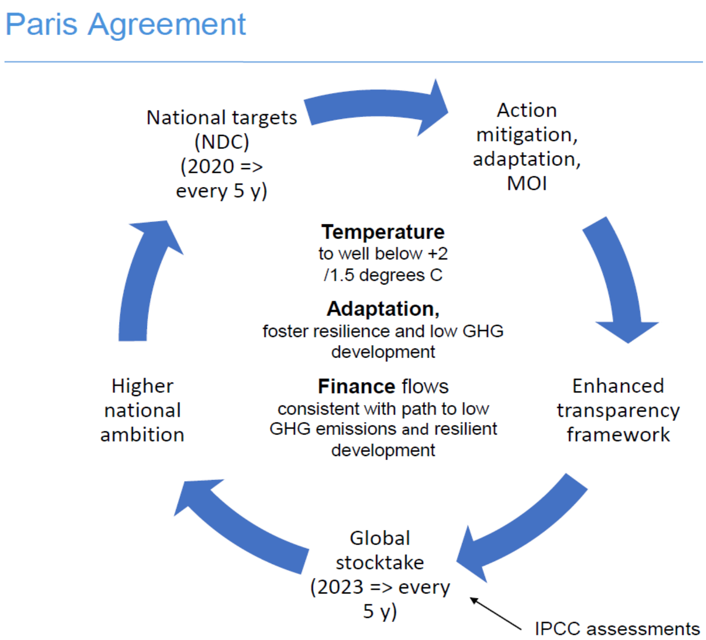
| Last name | First name | Country | Affiliation | presence/ online | Cat. |
|---|---|---|---|---|---|
| AGYEI KYEI | Kwame | Ghana | Forestry Commission of Ghana | in person | IE |
| ARAGAO | Luiz | Brazil | National Institute for Space Research | in person | IE |
| BALSAMO | Gianpaolo | Switzerland | 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-.



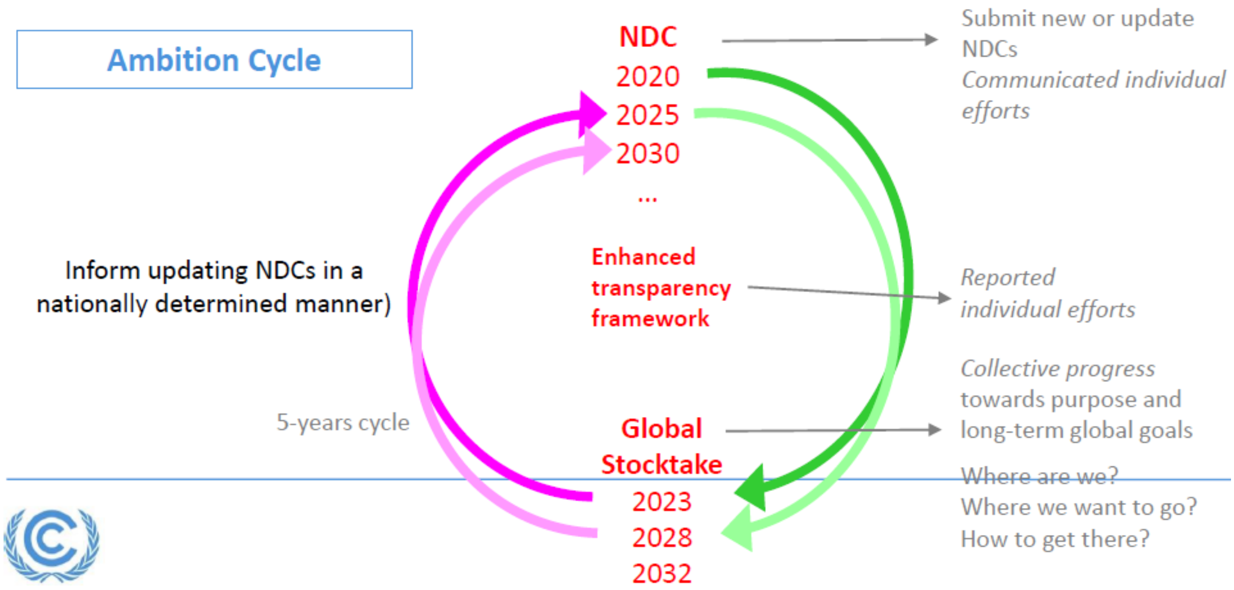

The four elements/processes/mechanisms are all self-implemented by country Parties to the Paris Agreement and are implemented within a sequence of five-year cycles, in which each country Party acts singularly in designing and implementing its mitigation actions as well as jointly with all others in assessing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

[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].

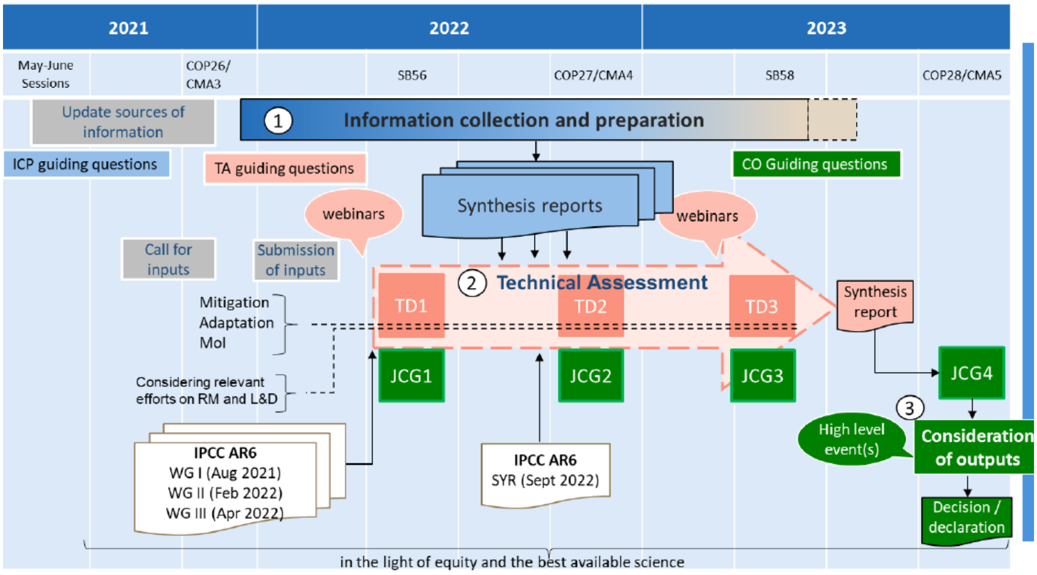
[14] https://unfccc.int/topics/global-stocktake/events-and-inputs/unfccc-and-constituted-bodies-synthesis-reports-and-webinar-for-the-technical-assessment-component

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

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

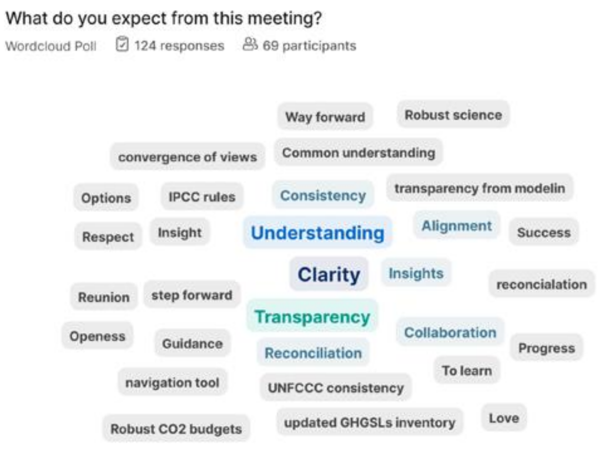
[19] https://unfccc.int/documents/461466

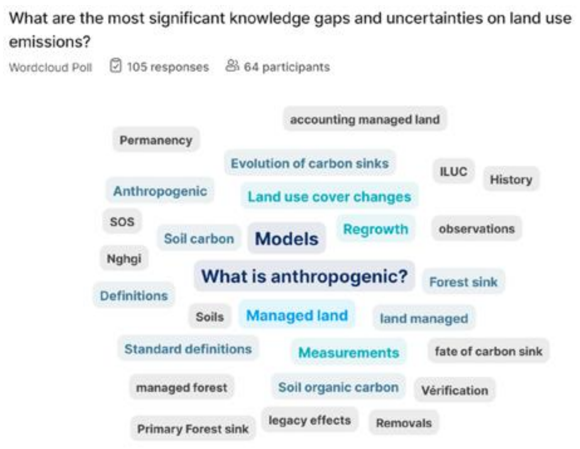
[20] https://unfccc.int/documents/461517

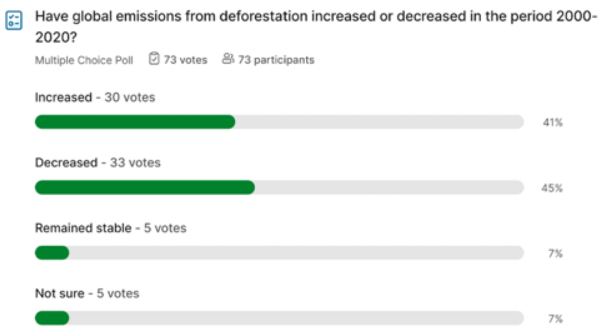
# Annex 4: Material presented during the Expert Meeting

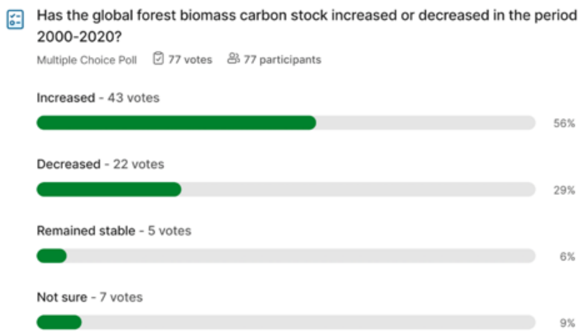
## Annex 4a. Results of the polls

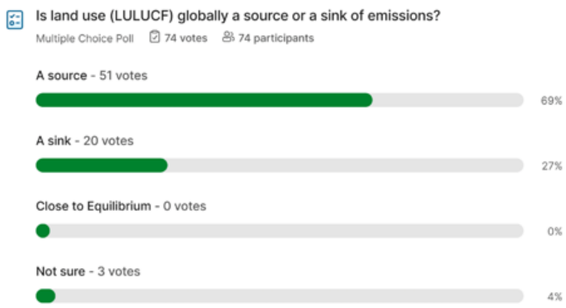
### Initial polls (day 1)



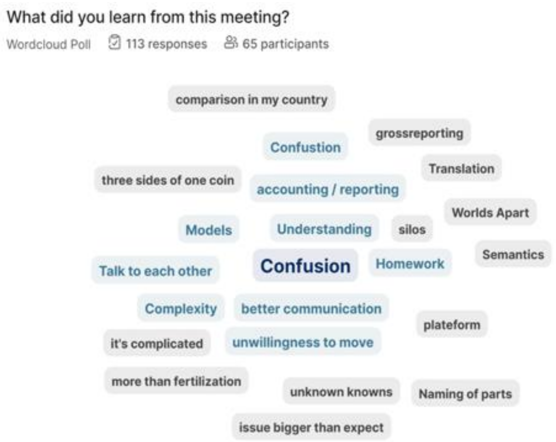




## Final polls (day 3)





# 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$^{o}$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.

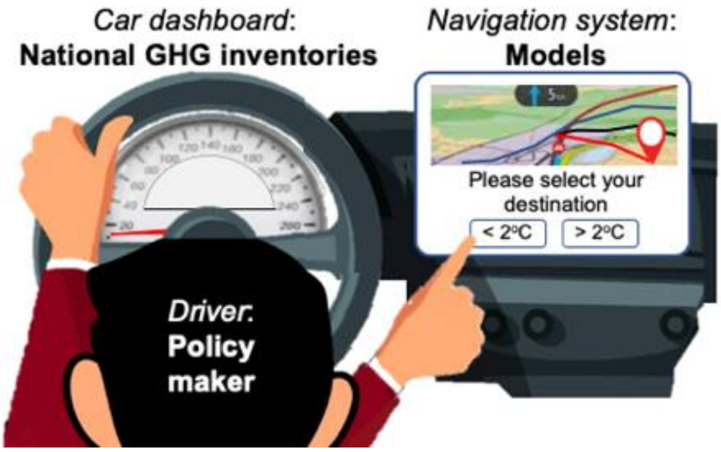
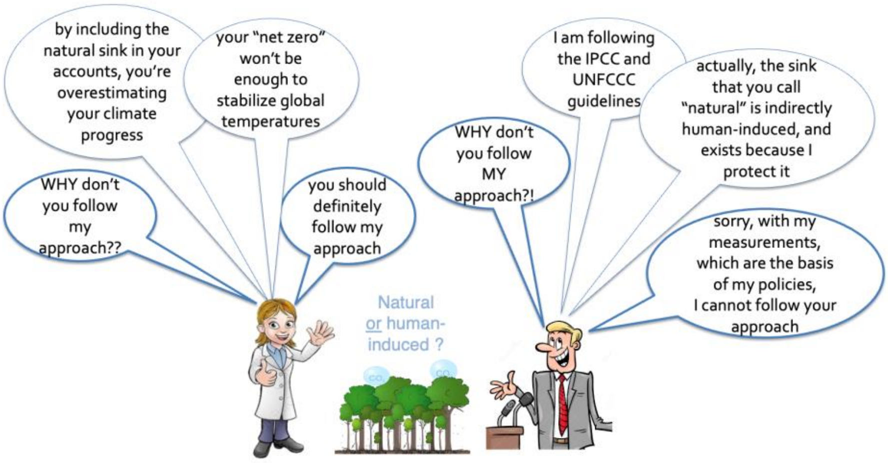


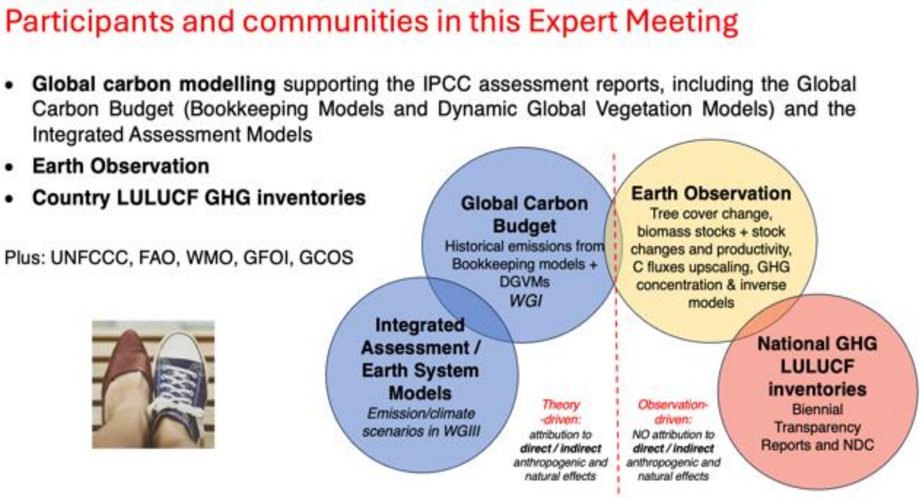

Figure: analogy between the functioning of the Paris Agreement and a car.

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.




## 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).

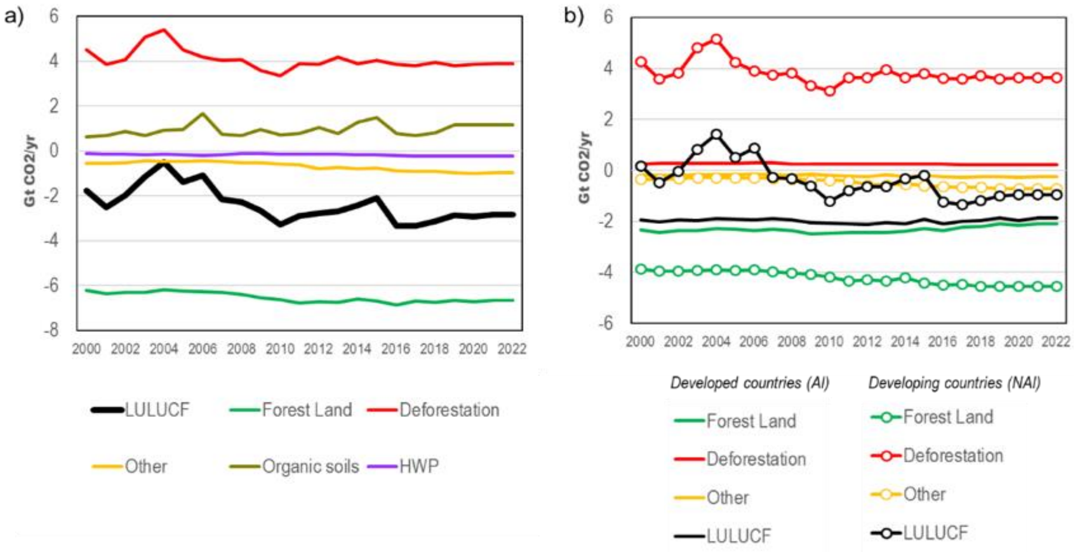



Figure: global trend 2000–2022 of $CO_2$ fluxes from the aggregation of NGHGI for the various land uses and land-use change categories (a) and $CO_2$ fluxes split by categories and by developed (Annex I, AI) and developing (non-Annex I, NAI) countries (b). Update of Figure 2 in Grassi et al. (2022).

### 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).

**<u>Afternoon:</u>**

## 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.

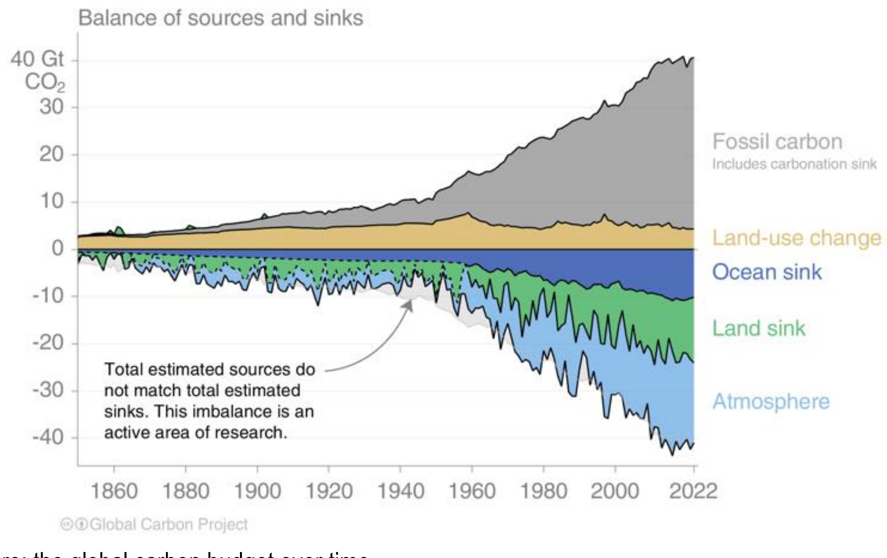



Figure: the global carbon budget over time.

### 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.

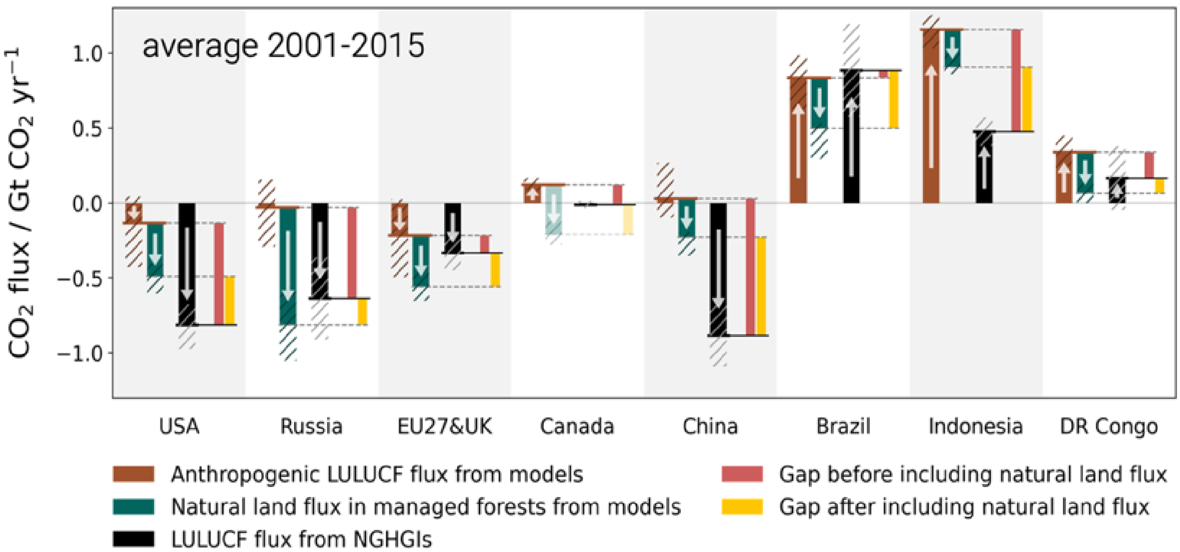



Figure: translation of bookkeeping models results to NGHGI approach (Schwingshackl et al., 2023)

**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.

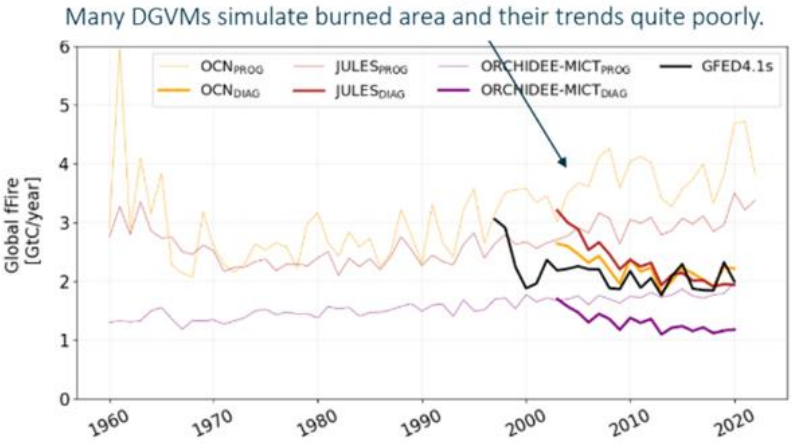



Figure: global fires emission from selected DGVMs.

## 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.

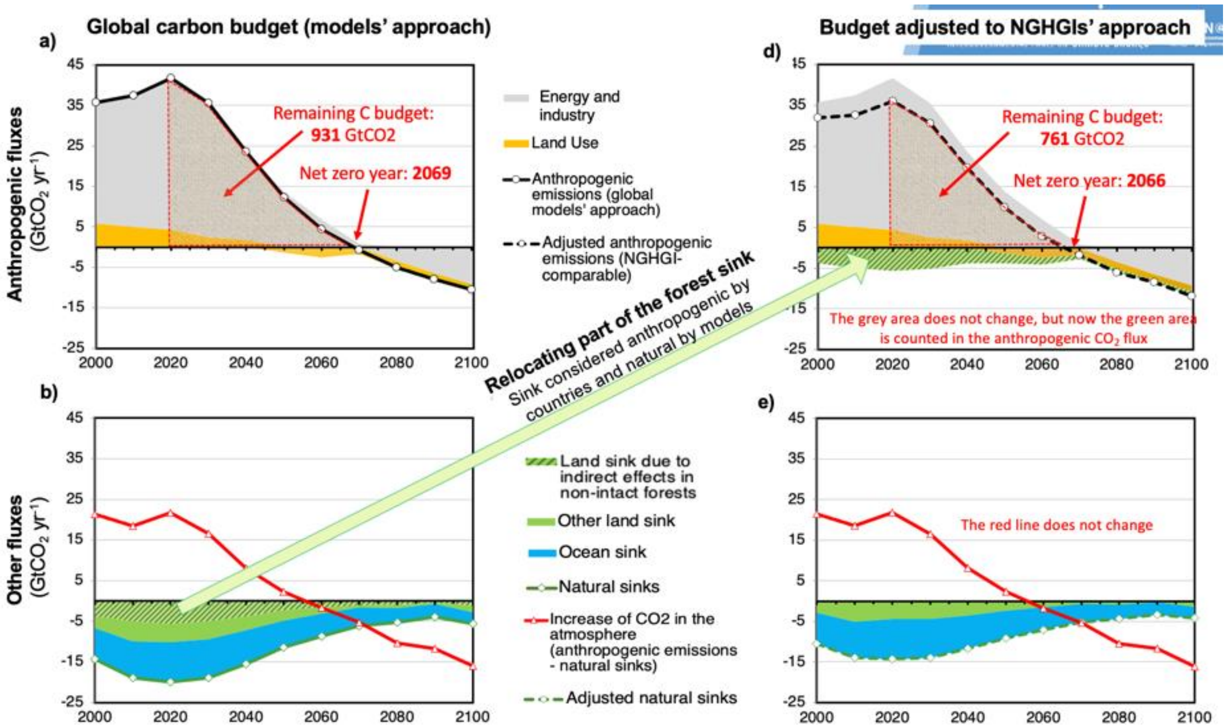



Figure: Indication of how the data from global models (left) can be made consistent with UNFCCC reporting by redefining some of land sink in forest area from natural (models) to anthropogenic (UNCCC), Grassi et al (2021).

## 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.

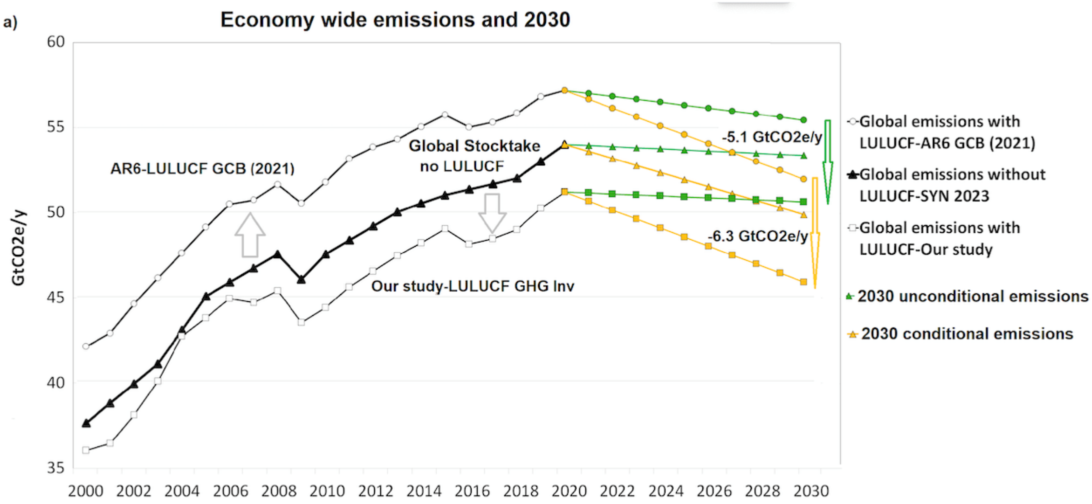



Figure: Economy-wide historical emissions including and excluding the LULUCF sector (2000-2020), and 2030 projections under three different scenarios. i) Historical and 2030 emissions excluding LULUCF in the Global Stocktake (SYN2023). Including LULUCF: i) historical emissions using data from the Global 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).

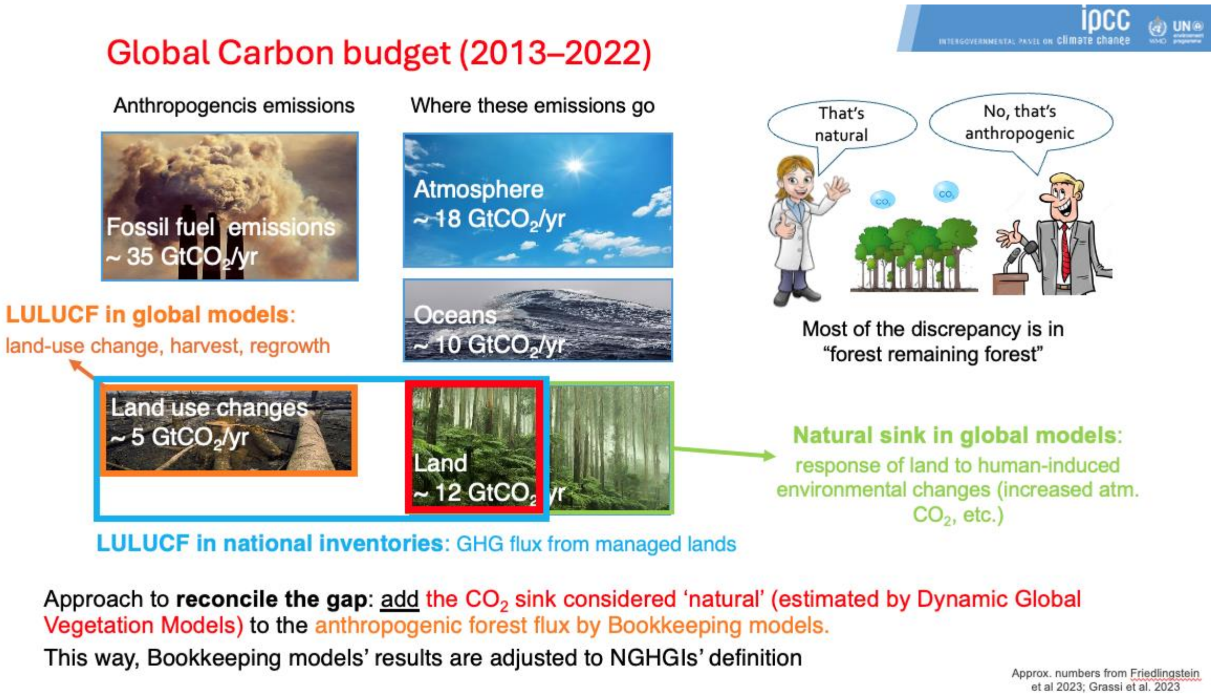



Figure: approach to reconcile land use emissions between global models and national inventories.

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.

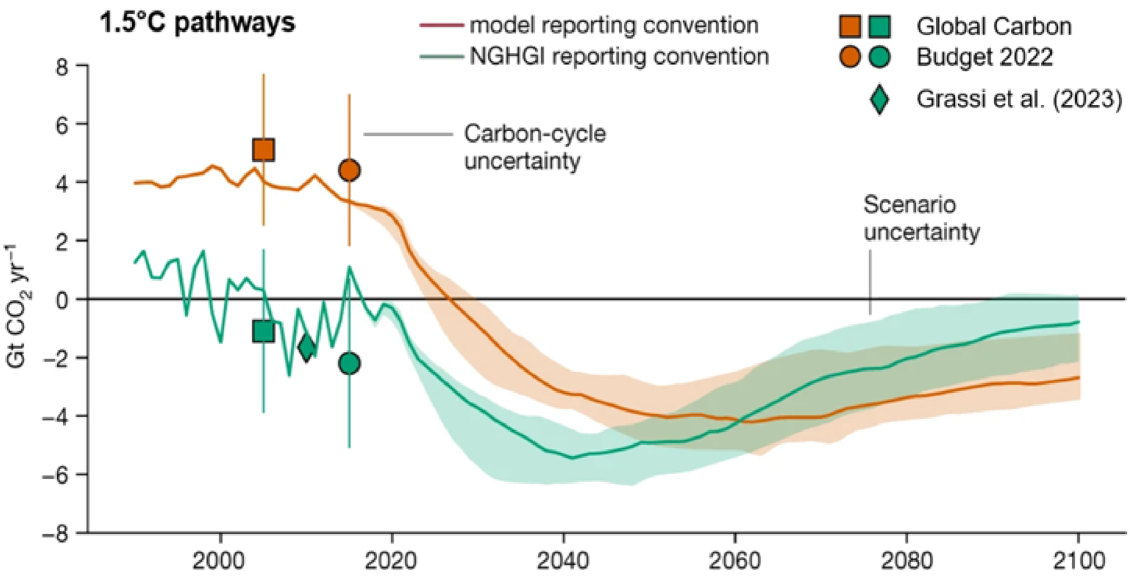



Figure: Illustration of the future land use CO2 fluxes under both conventions in 1.5°C compatible scenarios. The difference between the two curves is the indirect effect over managed land. The masking effect appears when the two curves cross: the indirect effect becomes a source of $CO_2$ despite intense 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').

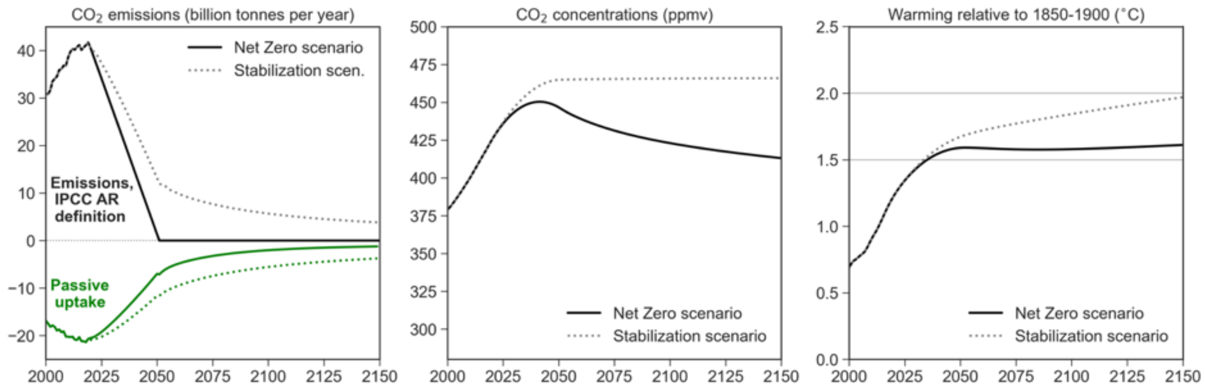



Figure: Impact of ambiguity in the definition of removals in net zero. Achieving net zero $CO_2$ emissions only halts $CO_2$-induced warming if the definition of removals excludes 'passive' $CO_2$ uptake (i.e. *indirect* $CO_2$ effects).

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.

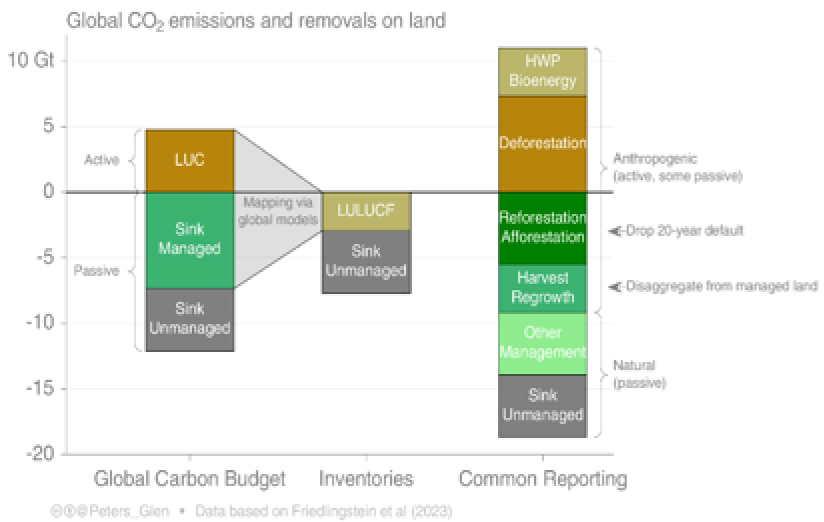



Figure: disaggregation of land emission and removals

# 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.

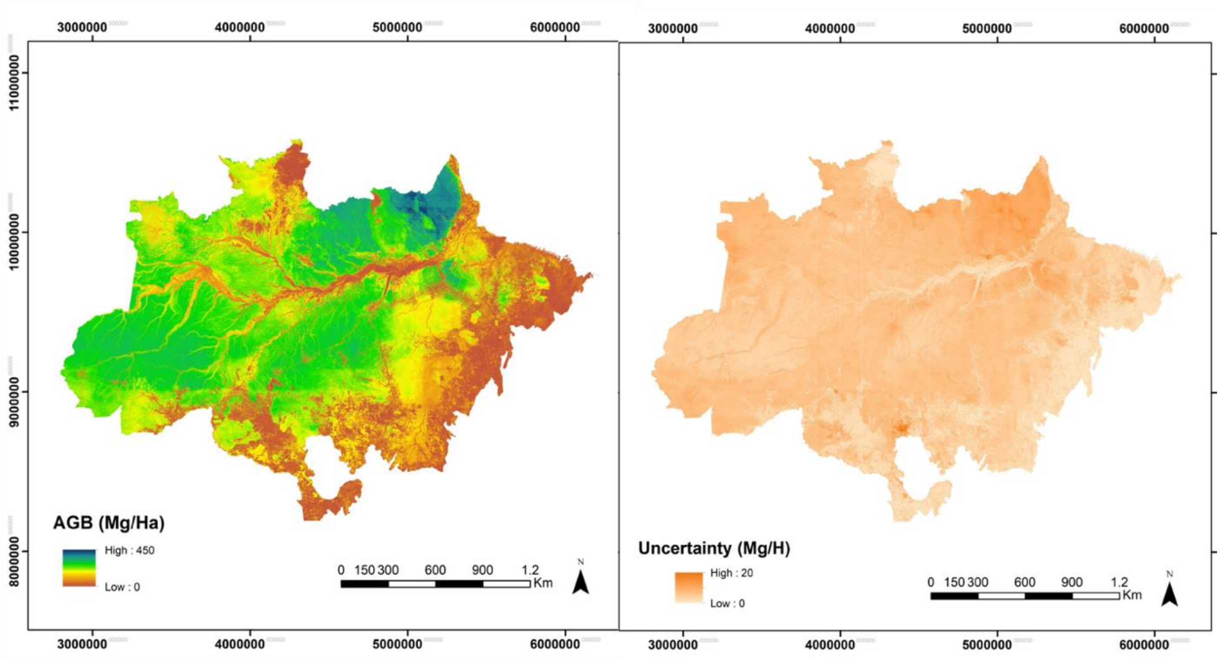



Figure: Above-ground biomass map at 250-m resolution for the Brazilian Amazon (left panel) with corresponding uncertainty (right panel).

**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.

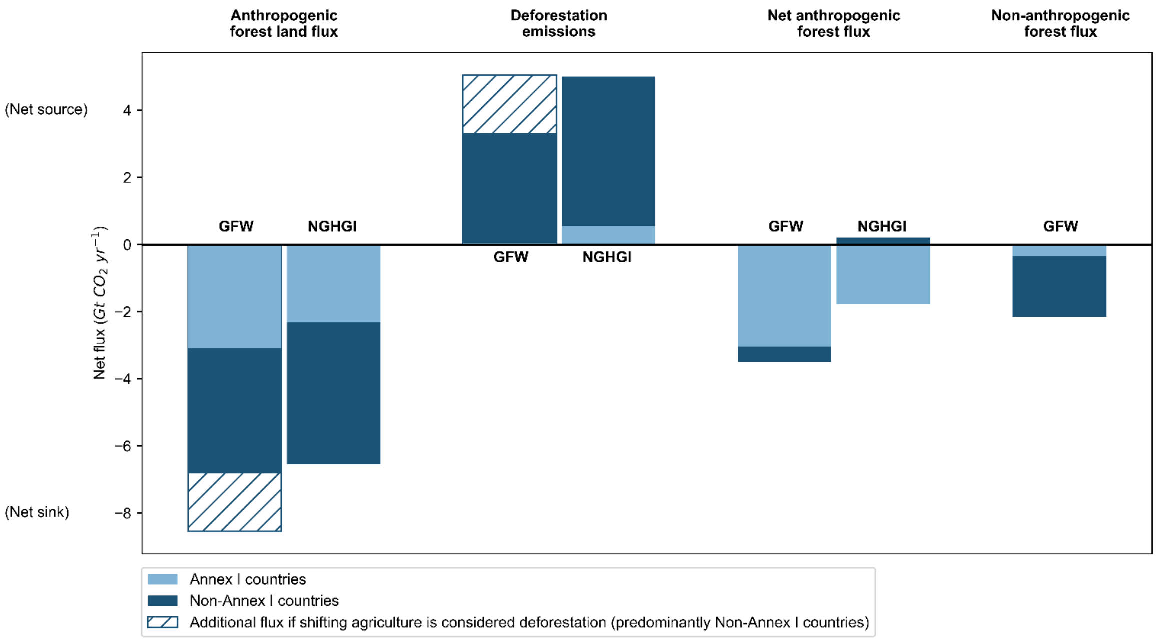



Figure: comparison of average annual forest carbon fluxes (2001–2022) between national greenhouse gas inventories (NGHGI) and the updated GFW flux model.

## 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.

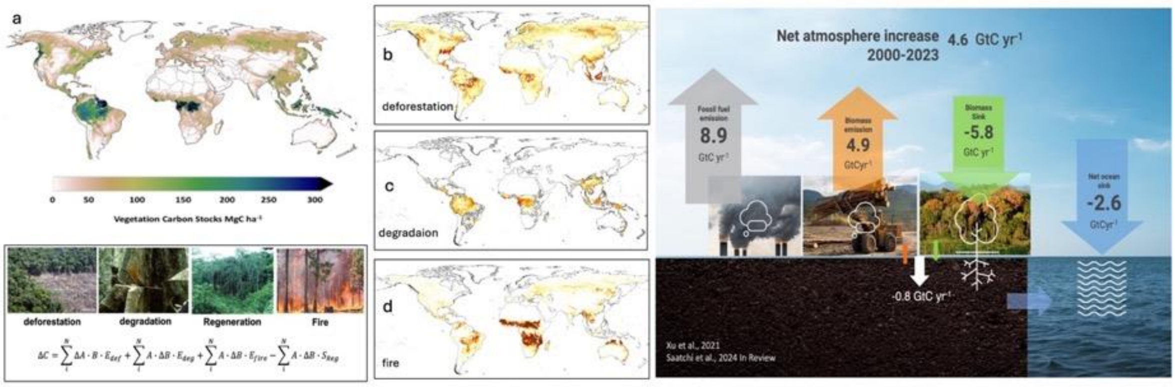



Figure: The new tools integrated in the jurisdictional MRV system include (a) carbon stocks at 100 m spatial resolution from 2000-2023, (b) estimates of deforestation and forest clearing, (c) forest degradation, (c) forest and savanna fires all at 30 m resolution to calculate the stock changes and emissions 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.

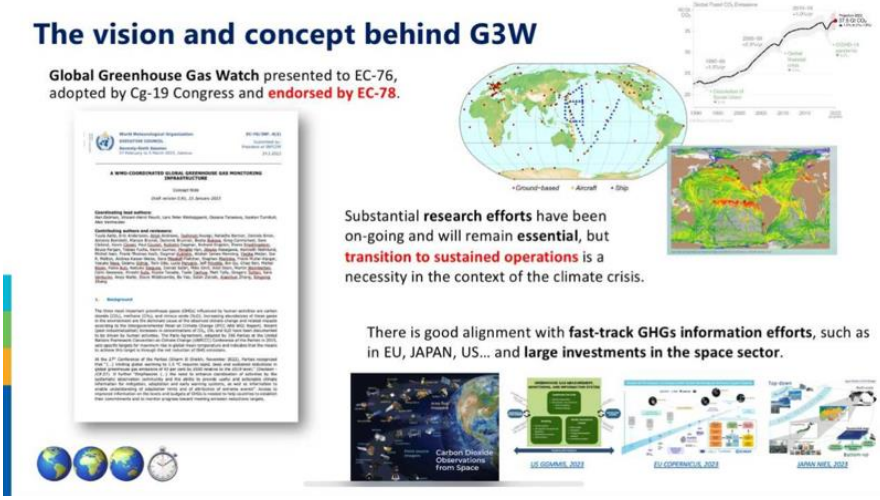



Figure: vision behind the G3W

**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.

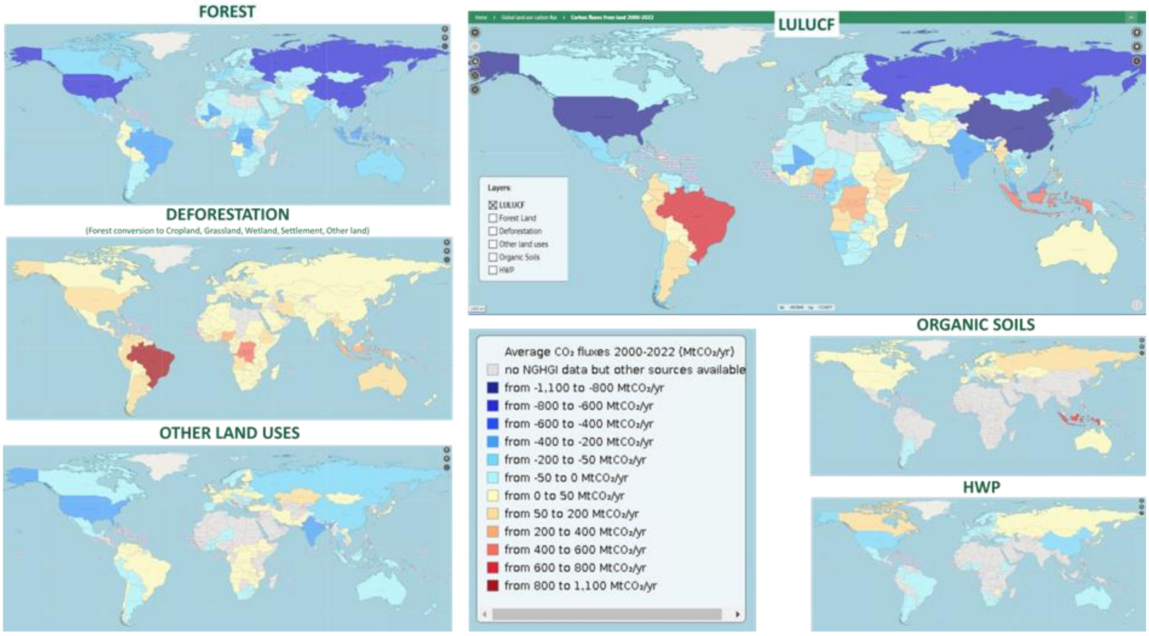



Figure. Spatial distribution of the 2000–2022 average of $CO_2$ fluxes from the aggregation of National GHG inventories (NGHGI) for the various land uses and land-use change (LULUCF) categories: Forest, Deforestation, Other land uses (cropland, grassland, wetlands, settlements, other land), organic soils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

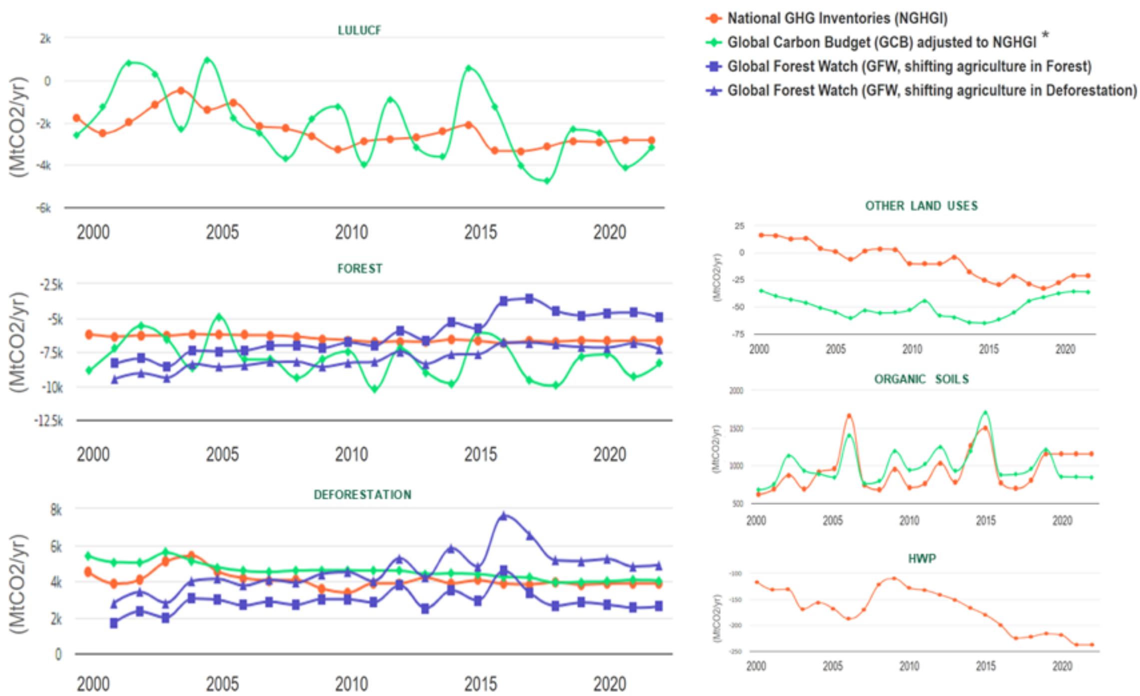



Figure. Global trend for the period 2000–2022 of $CO_2$ fluxes for the various land uses and land-use change (LULUCF) classes (Forest, Deforestation, Other land uses, organic soils, harvested wood products) from: 1) the aggregation of NGHGIs (orange); 2) the Global Carbon Budget (GCB, green, * Forest 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

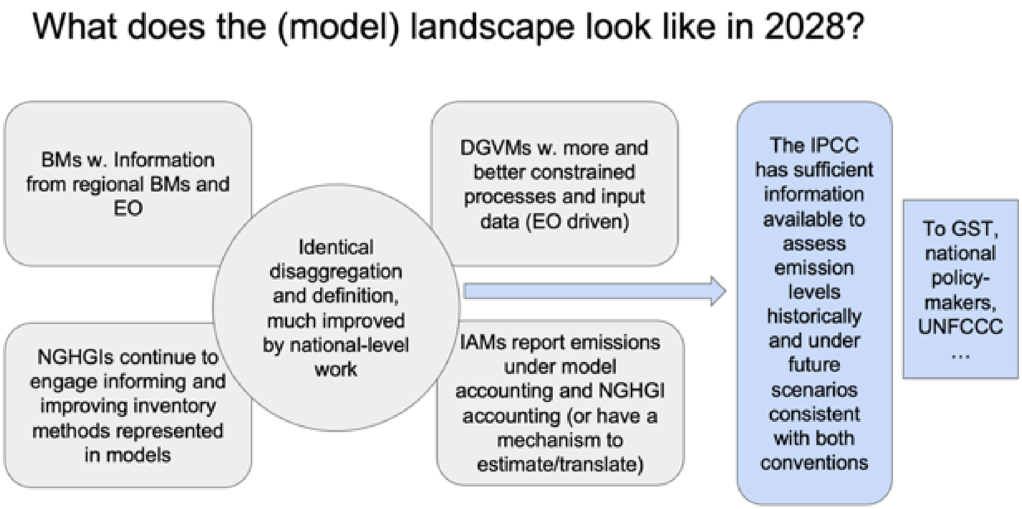



Figure: What does the (model) landscape look like in 2028? (BOG2C: Global Models)

## 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).

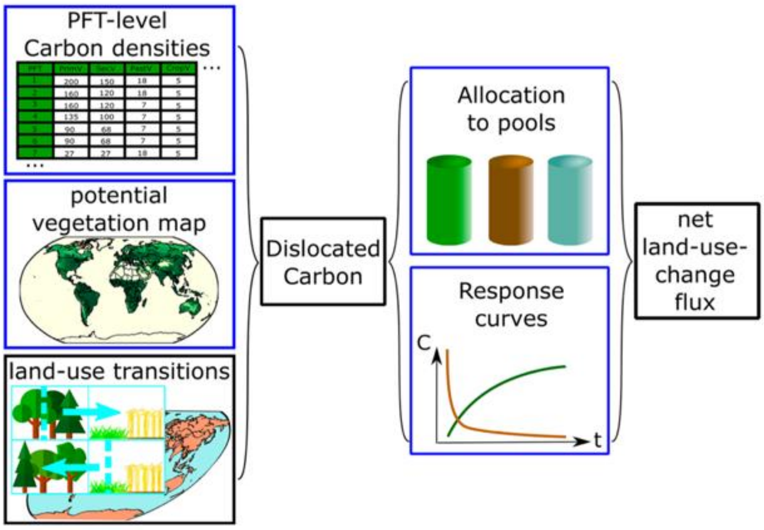



Figure 5.1.1: Schematic description of a typical bookkeeping model, using here the bookkeeping model BLUE as an example (figure from Bastos et al., 2021). Plant Function Type (PFT).

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.

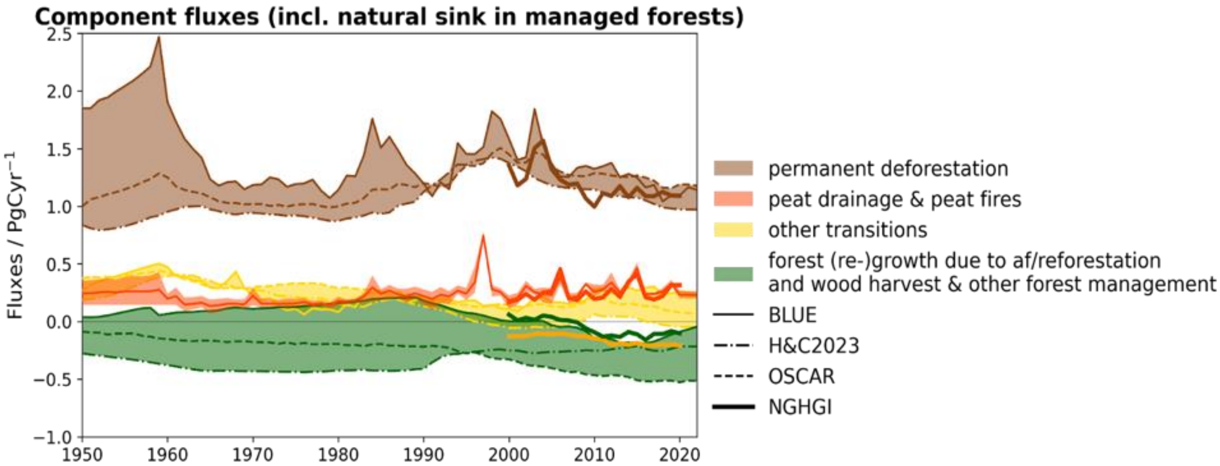



Figure 5.1.2: Various ELUC component fluxes for the three GCB2023 bookkeeping models (shown since 1950, but data available from 1850 onwards). Emissions from peat drainage and peat fires are added from external datasets (see Friedlingstein et al. 2023). The NGHGIs are shown for comparison, for the period 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.

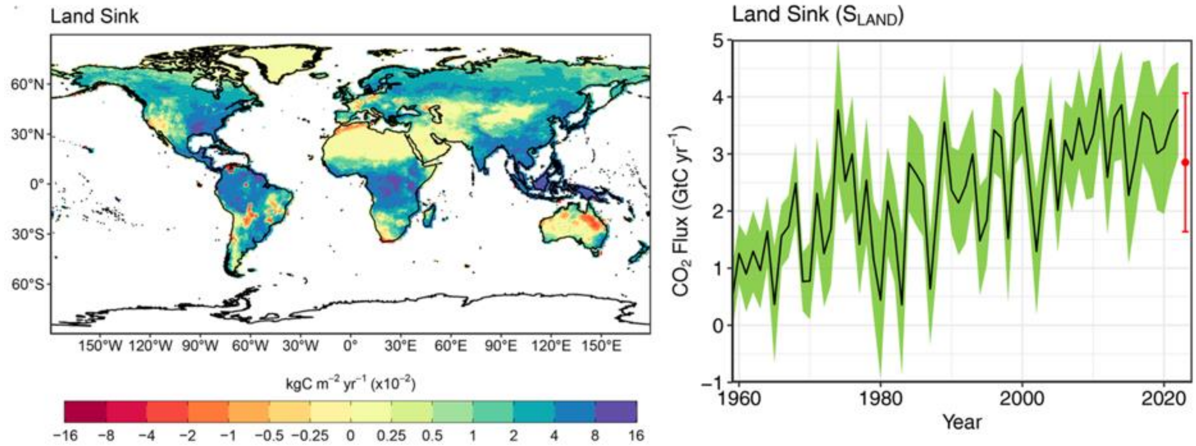



Figure 5.1.3: SLAND averaged over 20 DGVMs from the GCB2023. Left: decadal average 2013–2022, right: time series (mean with standard deviation across DGVMs). Positive values are fluxes from the atmosphere to land (i.e., a sink), negative values a source. SLAND amounts to 12.3±3.0 $GtCO_2$ (3.3±0.8 GtC)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

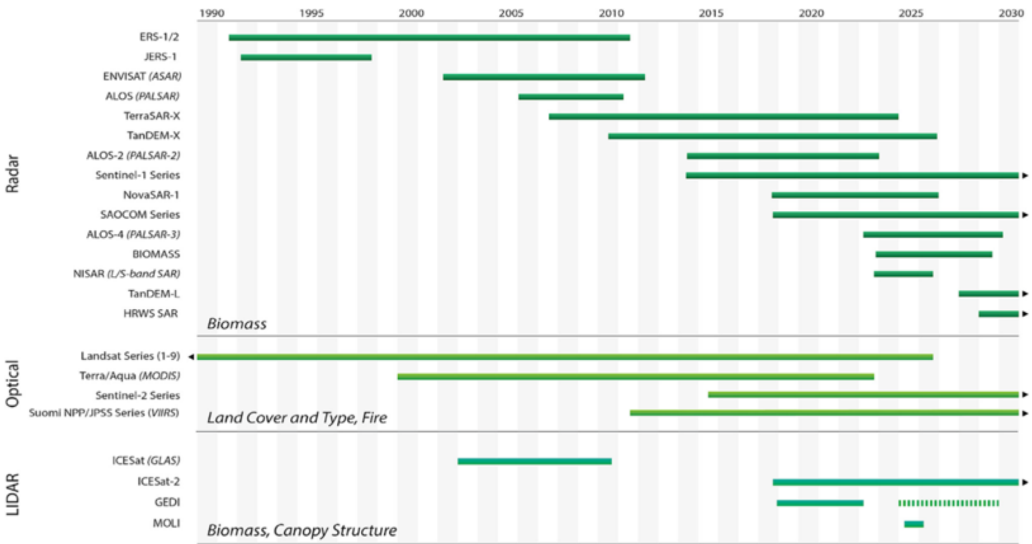



Figure 5.2.1. Different CEOS Earth observation satellite sensors/missions supporting land cover, use, fire and biomass information needs and their (estimated) lifespans (from Ochiai et al., 2023).

**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.

[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)

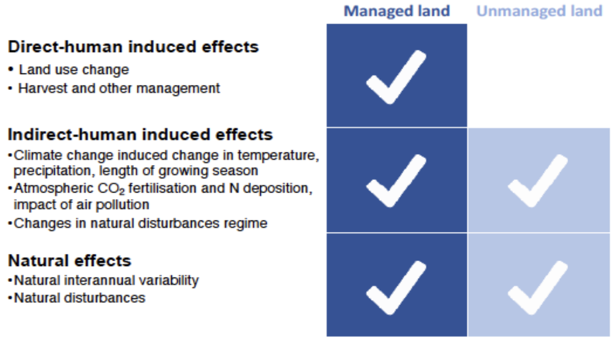
In the early 2000s, in response to a request of the UNFCCC, the IPCC held several meetings on the issue of anthropogenic GHG emissions and removals from land use. The IPCC's first meeting (in 2002) developed a work plan for a possible IPCC report to provide a framework for factoring out direct human 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).




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.

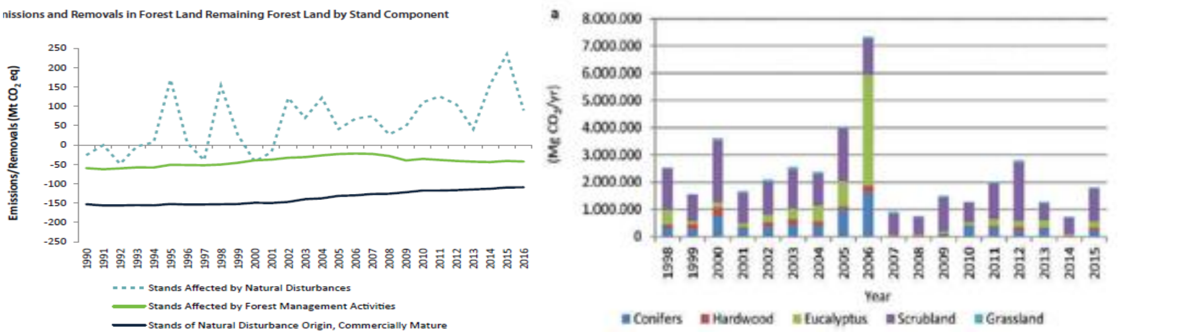
In the LULUCF sector, the application of the MLP means that IAV can be caused by both anthropogenic and natural causes. The three main causes of IAV in GHG emissions and removals in the LULUCF sector are (1) natural disturbances (such as wildfires, insects or pests, windthrow, and ice storms), which 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.

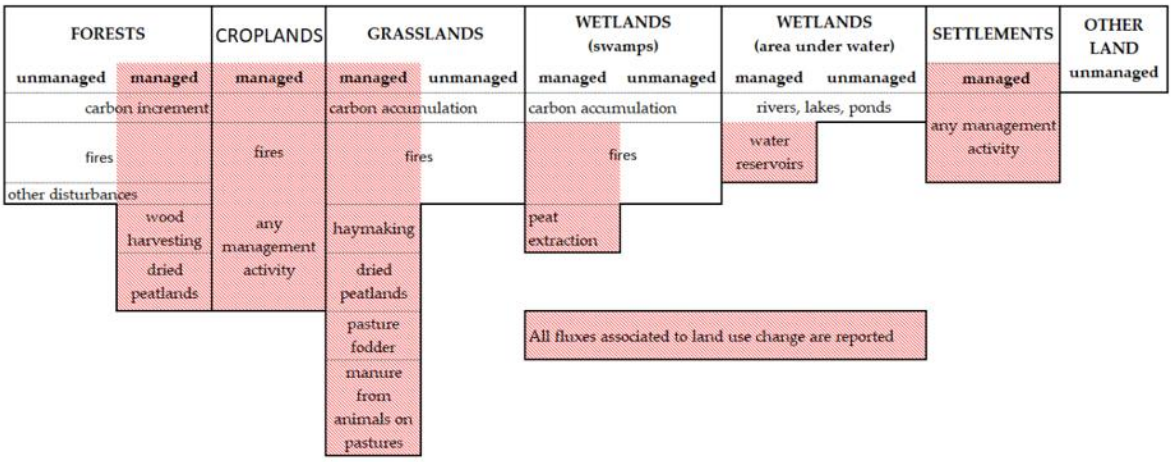



Figure 5.3.1. Illustrative example of emissions and removals on lands to be reported in GHG Inventories (shaded in red). Source: based on Romanovskaya and Korotkov (2024).

## 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

[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.

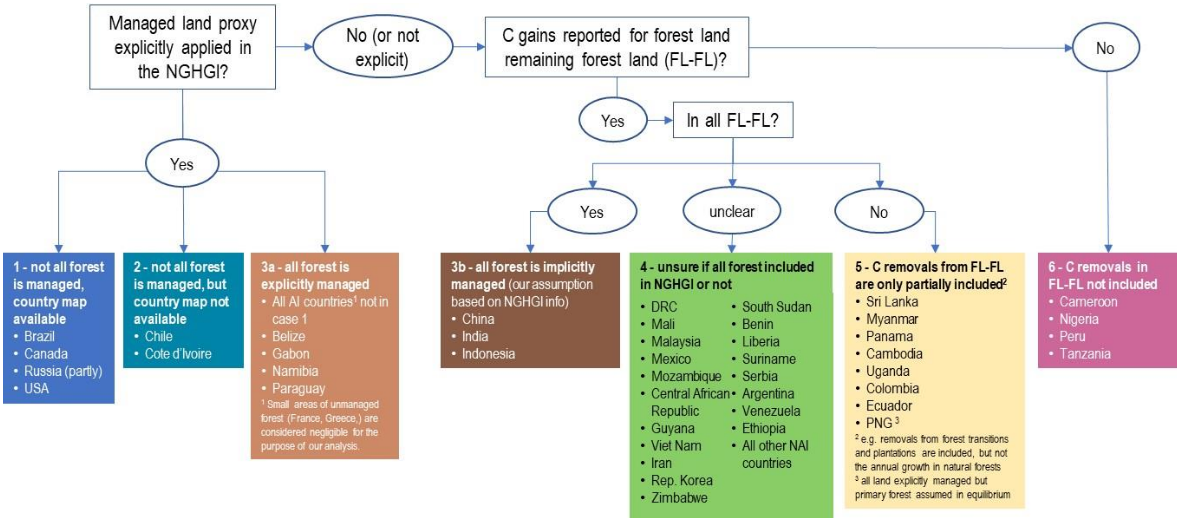
Many non-Annex I countries, however, do not make use of the managed land proxy or not explicitly, despite the fact that some have primary, intact forests that may not be subject to human interventions or practices.

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.<br>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.<br>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:<br>• 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<br>• 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 $CO_2$ 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).<br>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.<br>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.<br>(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.<br><br>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).<br><br>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).<br><br>(NIR, 2023 Canada) |
| Russian Federation | In Russia about 53% of lands are considered as managed. Unmanaged land (47% of the territory) include:<br><br>12% of forest land (23% of total forest land);<br><br>1% of grasslands (17% of total grassland);<br><br>13% of wetlands (99% of total wetlands);<br><br>21% of other land about 90% of which is tundra.<br><br>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.<br><br>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".<br><br>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.<br><br>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.<br><br>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.<br><br>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.<br><br>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<br><br>spatially tracked until pre-disturbance levels are reached to ensure completeness and balance in reporting.<br><br>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<br><br>out interannual variability due to natural causes over space (scaling from plots to region) and time (averaging between periodic re-measurements).<br><br>(NIR, 2023 Australia volume I)<br><br>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
- Gidden et al. (2023). Why resolving how land emissions are counted is critical for tracking climate progress https://www.carbonbrief.org/guest-post-why-resolving-how-land-emissions-are-counted-is-critical-for-tracking-climate-progress/