IPCC Expert Meeting

Carbon Dioxide Removal Technologies and Carbon Capture Utilization and Storage

Background paper

1-3 July 2024, on-line and in Vienna, Austria

IPCC Task Force on National Greenhouse Gas Inventories

INTERGOVERNMENTAL PANEL ON climate change

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 Background paper was prepared by the Co-Chairs of the IPCC TFI (Takeshi Enoki and Mazhar Hayat) and the TFI Technical Support Unit (TSU).

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 Background paper to the IPCC Expert Meeting Eds: Enoki, T., Hayat, M., Report of the IPCC Expert Meeting, Pub. IGES, Japan.

IPCC Task Force on National Greenhouse Gas Inventories (TFI)
Technical Support Unit

℅ Institute for Global Environmental Strategies
2108 -11, Kamiyamaguchi
Hayama, Kanagawa
JAPAN, 240-0115

https://www.ipcc-nggip.iges.or.jp

ISBN 978-4-88788-279-9

This is the original version of the Background paper distributed to participants. This publication superseded the version published initially on 26/9/24.

Contents

List of Figures

Overview

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 *2006 IPCC Guidelines* (IPCC 2006) for the preparation of national inventories provides methods for the estimation of emissions from carbon capture, utilisation and storage activities, however, after 20 years, a review is timely given the emergence of new technologies and new empirical data.

With this task in mind, the IPCC Panel at its 60th Session, in January 2024, requested the Task Force on National Greenhouse Gas Inventories (TFI) to develop a Methodology Report for the preparation of national greenhouse gas inventories on CDR activities (Decision IPCC-LX- 9).

This Expert Meeting was mandated by the IPCC Plenary and will be the first step along that journey of preparing an IPCC Methodology Report on Carbon Dioxide Removal Technologies and Carbon Capture Utilization and Storage activities.

Later in the year a formal Scoping Meeting will be held to make recommendations on the Scope of the Methodology Report for consideration by the IPCC Panel in early 2025. Following the decision of governments, a Methodology Report shall be prepared through the course of 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 will aim to collect evidence and information about gaps in the existing 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 and CCUS technologies. The meeting will also aim to identify knowledge gaps and any specific areas or issues to be prioritized in the development of methodologies.

This Background paper provides an introduction to some key IPCC inventory concepts; criteria against which new proposals might be considered; a brief description of some of the CDR processes under review and an introduction to the IPCC Guidelines' treatment of some of the key elements of removals, capture, utilisation and storage. This material will be extensively augmented by presentations and contributions by participants for consideration by the Expert Meeting over the course of discussions.

The outcome of this Expert Meeting will be summarized in a report by the TFI Co-chairs based on contributions by participants to the meeting. The Meeting Report will include materials prepared during Break Out Group discussions and considered by the Expert Meeting plenary and will be published alongside materials submitted by presenters and contributors.

This Meeting Report and related material will be used to inform the Scoping Meeting and the future development of the Methodology Report.

1. Introduction to General Inventory Concepts

1.1 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].

TSU Note**: Removals** - are the consequence of sink activities. One removal corresponds to 1 tonne of carbon dioxide removed from the atmosphere and, if by human activities, is counted as a negative contribution to the national total net carbon dioxide emissions in a national inventory (if expected to be stored for more than 1 year in an AFOLU C pool, or in a non-biological reservoir (e.g. geological storage)).

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].

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

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

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 seagrass meadows the guidance estimates emissions and removals associated with changes linked to a specific human activity, rather than estimating emissions and removals from that coastal wetland type as a whole *(IPCC 2013 Wetlands Supplement O.8*)[3].

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*).

---

[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] One example where the Managed Land Proxy is not applied.

TSU Note: **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 organic soils; and stock changes associated with soil inorganic C pools[4] *(2019 Refinement to the 2006 IPCC Guidelines Vol 4.5.3.3 page 5.43 and see also Vol 2.3.3.1 page 2.28)*.

IPCC classification system – greenhouse gas emission and removal estimates are divided into main sectors, which are groupings of related processes, sources and sinks.[5] High level categories include:

1. Energy
    - A. Fuel Combustion
    - B. Fugitive Emissions from fossil fuel extraction and distribution;
    - C. Carbon Dioxide Capture, Transport and Storage
2. Industrial Processes and Product Use
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 refer to the *2019 Refinement to the 2006 IPCC Guidelines* (IPCC 2019), which principally updated the *2006 IPCC Guidelines* in the Fugitive 1.B,

[4] For Tier 3 only.
[5] According to type of process.

AFOLU and wastewater sectors, while relevant guidance for other sectors (1.A, 1.C, 2) was largely unchanged.

1.2 Conceptual considerations

1.2.1 Are countries able to report CDR activities currently?

Recently, the IEA argued the following:

> the latest IPCC Guidelines for National Greenhouse Gas Inventories do not include an accounting methodology for DAC, meaning that CDR associated with DAC cannot be counted towards meeting international mitigation targets under the United Nations Framework Convention on Climate Change.

Executive summary – Direct Air Capture 2022 – Analysis - IEA

This IEA statement, however, is based on a wrong understanding of the role of the IPCC Guidelines.

The IPCC Guidelines should be read in conjunction with the UN Framework Convention on Climate Change (UNFCCC).

Under the UNFCCC compilers are able to prepare national inventories of anthropogenic emissions and removals consistent with the definitions specified in the Convention.

From the glossary the UNFCCC 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 or, for example, the carbonation of concrete[6].

The IPCC Guidelines support this definition by also providing for **any** sinks to be reported under a number of 'other' categories in the IPCC classification system (see Section 3.1).

The role of the default methodologies in the IPCC Guidelines is better understood as underpinning the scope of a set of minimum anthropogenic sources and sinks that should be reported by inventory compilers.

While the IEA statement is factually incorrect, it nevertheless may still be the case that now might be an opportune time for aspects of the IPCC Guidelines, which are approaching their 20 year anniversary, to be updated, clarified and elaborated.

1.2.2 Distinguishing direct air capture removals from capture of carbon dioxide generated by human activities

From the glossary, a sink is any activity that removes carbon dioxide from the atmosphere.

Direct air capture will constitute a sink activity because it removes carbon dioxide from the atmosphere (like a tree).

[6] See the national inventory report 2024 of Japan, for example.

This case should be 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 sink activities because they do not remove carbon dioxide from the atmosphere. Nor is there an emission in this case if the captured carbon dioxide is transported to a place of permanent storage.

1.2.3 The negative CO_2 emissions artefact

Negative CO_2 emissions are not defined by the IPCC Guidelines, being a term used in one instance in the IPCC Guidelines[7] when aggregating a number of processes into one narrative. Consider, as an example, an aggregate BECCS process with biofuels from perennial biomass includes:

- a sink from the biological removal process (and which is estimated and reported in the AFOLU sector and is reflected in a C stock gain);
- a transfer of carbon from the AFOLU sector to the Energy Sector as biofuel[8] (which is reported as a C stock loss in the AFOLU sector and interpreted as a CO_2 emission);
- the use of the biomass to produce energy and the capture of the resulting CO_2; and
- injection of captured CO_2into a storage site or reservoir (assume this is preserved in a stock of carbon in a permanent storage site).

That is, descriptions of the BECCS processes tend to aggregate:

a) a sink activity on the land which removes carbon from the atmosphere; and

b) a storage activity that does not affect either emissions or removals.

Therefore, in the inventory, in aggregate, the chain of activity known as BECCS processes causes a net removal from the atmosphere (through net photosynthesis). In its simplest form, it's the same outcome as is achieved by using wood for very long-standing wood products (HWP) in a well-preserved wooden-house.

The function of the artificial 'negative CO_2 emission' in the Energy sector for one part of this process is simply to cancel the artificial CO_2 emission reported in the AFOLU sector resulting not from an emission process but from the transfer of carbon out of the biomass or HWP pool[9].

---

[7] 2006 IPCC Guidelines Vol 2: 5.3 page 5.8.

[8] Limited for the most part to those produced from/made of perennial biomass, e.g. fuelwood.

[9] An alternative perspective is that the 'negative CO_2 emission' is needed to counter the zero-carbon-rating of biomass combustion, since CO_2 emissions from biomass combustion are not recorded at the point of combustion in the Energy Sector – as is done for all other fuel combustion activities – but in the AFOLU sector when carbon is transferred out of the biomass or HWP pool. In the case of annual biomass, the explanation is that the "negative CO_2 emissions" is an artefact to count in the Energy sector if the CO_2 removals that occurred on the land that were not reported in the AFOLU sector by assumption (although in practice these sink processes may be modelled explicitly and reported in the land sector, in which case there would be no need for the negative emissions offset).

1.2.4 Certification and accounting

> **Internationally agreed approaches to the certification and accounting of DAC are needed.** The development of agreed methodologies and accounting frameworks based on life cycle assessment (LCA) for DAC – alongside other CDR approaches – will be important to support its inclusion in regulated carbon markets and national inventories.
>
> Executive summary – Direct Air Capture 2022 – Analysis - IEA

The IPCC Guidelines do not produce life cycle assessments or methodologies for the purpose of regulating carbon markets or to engage in the development of accounting frameworks for the assessment of compliance with national targets[10]. Nonetheless, life cycle assessments may be prepared by others using aggregations of the methods developed by the IPCC, while domestic carbon markets may also anchor their regulations in the methods developed by the IPCC in this process. In this sense, the development of IPCC methodologies for CDR technologies may provide support for other analyses and also for market mechanisms.

1.3 Pathways for CDR and CCUS activities

Some of the principal pathways for emissions and removals from CDR and CCUS activities are illustrated in Figure 1, distinguishing between capture that removes carbon dioxide from the atmosphere and capture of a stream of carbon dioxide generated by human activities.

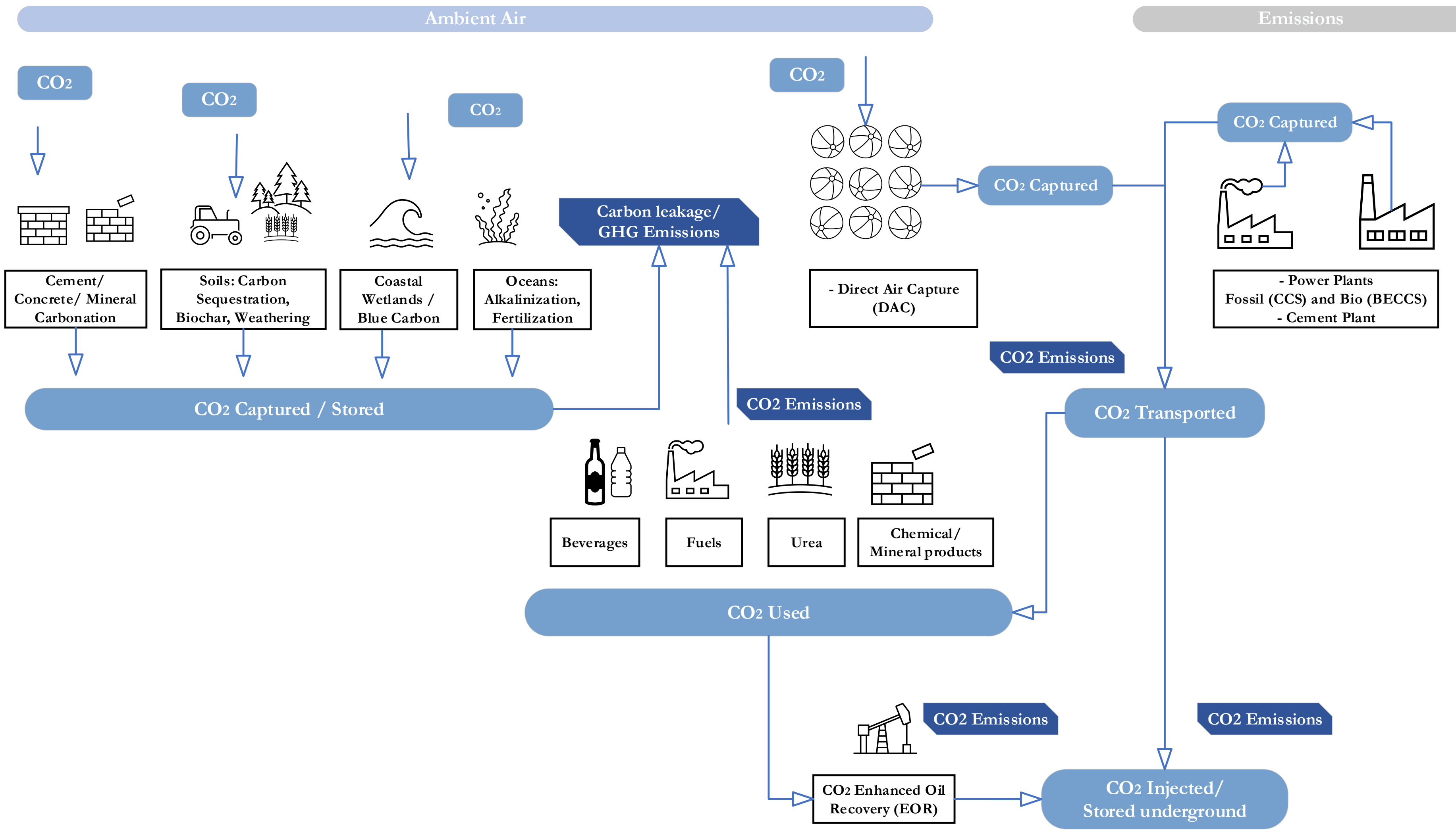
Long-term storage of carbon dioxide outside of the atmosphere occurs either in geological deposits; or in the waterways and oceans; or for terrestrial locations or products, in the vector in which has been captured. This applies to carbon derived from biological carbon dioxide removals, for example, forest biomass, HWP or soils, as well as non-biological, for example, the carbonation of concrete.

The relative importance of these storage locations in the global carbon balance was assessed by IPCC WGI in the AR6 process (Figure 2). This Figure also provides the IPCC assessment of the relative importance of the aggregate carbon fluxes between the atmosphere and land and the atmosphere and waterways (and also between land and waterways).

Geological storage can take place in natural underground reservoirs such as oil and gas fields, coal seams and saline water-bearing formations utilizing natural geological barriers to isolate the carbon dioxide from the atmosphere. Ocean storage of captured carbon dioxide includes processes to dissolve carbon dioxide or to pump liquid carbon dioxide to the sea floor, which would be maintained in place by the pressure from the waters above.

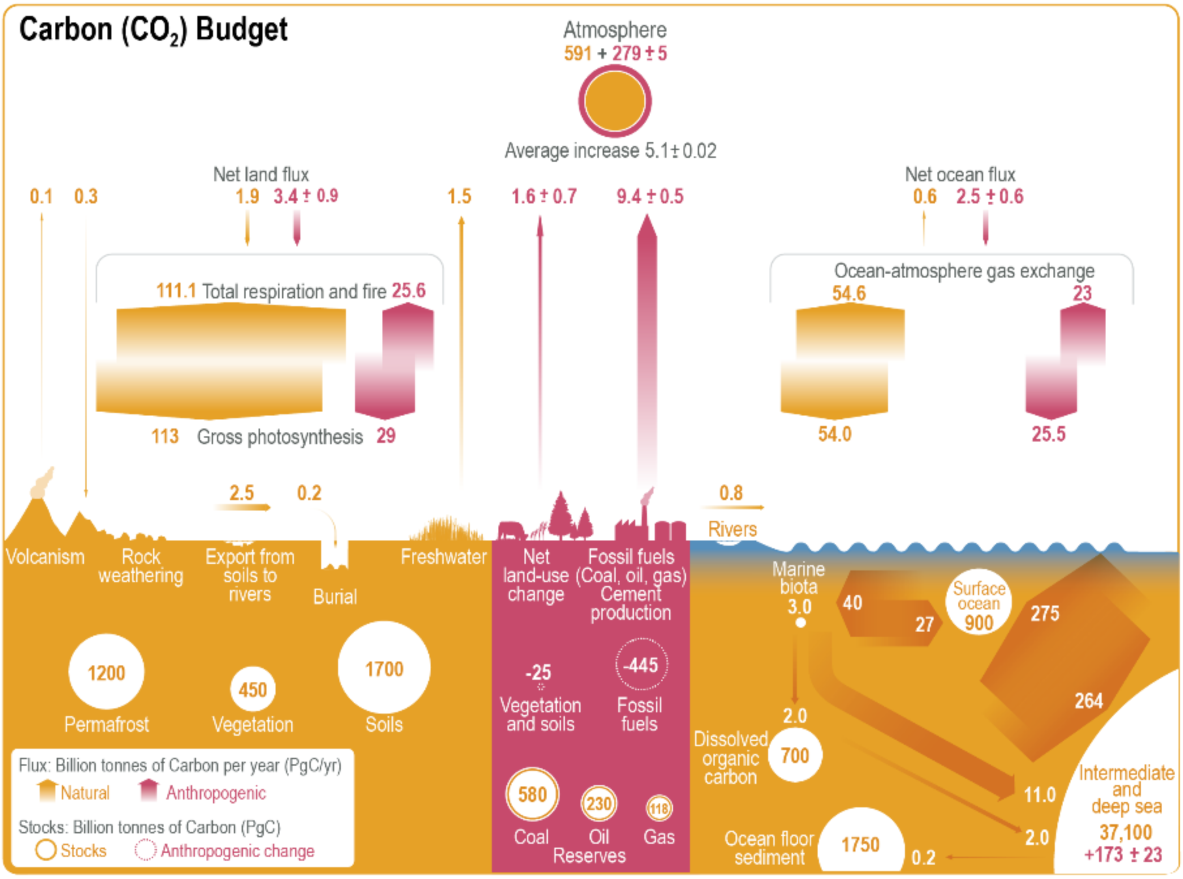
[10] Guidance is provided for greenhouse gas inventory arrangements and management, data gathering, compilation, and reporting. Reporting refers to the presentation of emission inventory estimates in tables or other formats used to communicate inventory information. The guidance is relevant but not prescriptive with respect to the reporting of national inventories under international agreements, and the use of reported information under these agreements (*2019 Refinement to the 2006 Guidelines* Overview, O.6)

Figure 1 Conceptual pathways of carbon dioxide removals, generation, capture and storage



Source: IPCC TFI TSU

Figure 2 IPCC WGI assessment of the global reservoirs and fluxes of carbon due to anthropogenic and natural fluxes



Source: IPCC 2021 – IPCC WGI AR6 Figure 5.12. Note that the delineation of these fluxes into anthropogenic and natural processes reflects the views of those IPCC authors and does not necessarily align with the principles of the IPCC Guidelines for preparation of national greenhouse gas inventories.

1.4 IPCC Methodological guidance basics

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[11].

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.

[11] There are some exceptions including emissions from biomass combustion (and two methods used for HWP).

1.4.1 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 [12] 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.

1.5 Possible criteria for assessing new methods

Preparatory to production of the new Methodology Report, it is necessary to consider the desirability of the IPCC preparing new methods for additional sources or sinks or to elaborate the existing methods for relevant existing sources or sinks. To that end, criteria for assessing the desirability need to be carefully considered. This Expert Meeting is invited to come up with a proposal on such criteria to inform the upcoming Scoping Meeting. The following criteria, which draw on the criteria used for the *2019 Refinement of the 2006 IPCC Guidelines* [13], may be evaluated or augmented by the Meeting:

[12] IPCC defaults may also be regional in tier 2 methods.
[13] *2019 Refinement to the 2006 IPCC Guidelines* Overview page O.7

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[14] 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.

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.

1.5.1 Gaps in the IPCC Guidance

See Section 2.

1.5.2 Delineation of the sink or source: anthropogenicity and estimation methods

Experts will need to consider the delineation of what constitutes an anthropogenic sink as part of the process of considering the feasibility of being able to specify estimation methodologies.

Where the sink also involves a natural process, or is influenced by natural processes, a judgement needs to be made as to whether the sink may be attributed to anthropogenic activity alone, or not (see Figure 2 for the IPCC's assessment of the relative importance of these stocks and flows).

Currently the IPCC Guidelines offer two approaches to the delineation of anthropogenic emissions and removals.

In general, the IPCC provides for sinks to be considered to be anthropogenic due to the application of the Managed Land Proxy principle– in which all CO_2 emissions and all removals on 'managed land' are considered to be anthropogenic - if it is not possible to disentangle anthropogenic perturbations from natural fluxes in the observed data. This also allows for one

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

solution to the estimation task since estimated anthropogenic net removals will align with measured or observed increases in carbon stocks over time[15][16].

For biogenic carbon in seagrass in coastal waters, however, the IPCC did not offer this possibility[17]. Here, the methodology only offers a deliberate human activity-based emission factor approach for the estimation of sinks and rules out the application of the Managed Land Proxy in this case.

For new proposals for methods in relation to organic carbon - the fertilisation of coastal waters, for example - a judgement will need to be made as to whether the new method should specify the application of the Managed Land Proxy used for terrestrial forests or restrict the method to an activity-based approach as was used for seagrass.

In particular, experts will need to consider whether operational methods to disentangle the anthropogenic perturbation to natural GHG fluxes are able to be designed as IPCC guidance or, where this is not considered to be operationally possible, to consider whether the IPCC methodology should include all emissions and sinks over the area subject to the activity.

Similar judgements will need to be made for methods in relation to enhancing natural inorganic carbon removals.

It is possible to specify both approaches in the Methodology and allow national inventory compilers to make choices over estimation methods that confer different judgements as to what constitutes anthropogenic.

For example, in the *2019 Refinement to the 2006 IPCC Guidelines*, two different approaches to the estimation of emissions and sinks from an existing CDR activity are offered:

> The method used in Equation 2.4 is called the Gain-Loss Method, because it includes **all processes** that bring about changes in a pool. An alternative stock-based approach is termed the Stock-Difference Method, which can be used where carbon stocks in relevant pools are **measured** at two points in time to assess carbon stock changes, as represented in Equation 2.5.
>
> IPCC Refinement to the 2006 IPCC Guidelines Vol 4: 2.2.1 page 2.10

The former method provides for the modelling of gains and losses from the carbon stock (which may be modelled in a way that disentangles some of the anthropogenic perturbation from the natural fluxes) while the latter, mass balance approach relies on measurements/observations of the actual stock of carbon at two points in time.

[15] In practice countries that rely on measurement approaches to estimate changes in carbon stocks tend to implement this principle in full (ie assume that all carbon stock increases are anthropogenic) whereas countries that model the changes in carbon stocks for particular carbon pools based on activity data inputs may disentangle anthropogenic from natural fluxes, as well as fluxes caused by carbon dioxide fertilisation.

[16] With an additional simplifying assumption that loss of carbon is essentially lost to the atmosphere.

[17] More formally, re-establishment of seagrass meadow vegetation on undrained soils. Another example relates to the treatment of peatlands, which are assumed to be in equilibrium unless peat extraction activities have been undertaken.

1.5.3 Expected significance of the sink or source

Experts should consider the data requirements to be imposed on inventory compilers. Methods for sources or sinks that are expected to be of only minor consequence in future will not have great utility.

1.5.4 Generalising tier 1 default values: robustness of available scientific evidence

Experts should consider whether the scientific and empirical evidence exists to parameterise a tier 1 and, in some cases, tier 2 estimation method with confidence. There is no quantitative threshold for the number of empirical studies required to support the establishment of a default factor. An example where robust scientific evidence for carbon dioxide removal processes has been considered to exist, however, relates to the estimation of removals from forest biomass (where there are many, many measurements and empirical analyses).

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 sometimes provides the methodology only as a higher order method.

For example, for carbon capture and storage, for biochar and for soil inorganic carbon, the 2006 IPCC Guidelines say this:

> Although the Summary for Policymakers of the SRCCS suggests that properly selected geological storage sites are likely to retain greater than 99 percent of the stored CO_2 over 1000 years and may retain it for up to millions of years, at the time of writing, the small number of monitored storage sites means that there is insufficient empirical evidence to produce emission factors that could be applied to leakage from geological storage reservoirs.
>
> 2006 IPCC Guidelines Vol 2: 5.7 page 5.13

> Biochar Amendments to Organic Soils: No methods are provided in this guidance for estimating the impact of amending organic soils with biochar. Compilers may be able to develop a Tier 3 method for estimating the impact of biochar C amendments to organic soils.
>
> 2019 Refinement to the 2006 IPCC Guidelines Vol 2: Annex 2.A page 2.82[18]

> Soil inorganic C The effects of land-use and management activities on soil inorganic C stocks and fluxes are linked to site hydrology and depend on specific mineralogy of the soil. Further, accurate estimation of the effects requires following the fate of discharged dissolved inorganic C and base cations from the managed land, at least until they are fully captured in the oceanic inorganic C cycle. Thus, a comprehensive hydrogeochemical analysis that tracks the fate of dissolved CO2, carbonate and bicarbonate species and base cations (e.g., Ca and Mg) applied to, within, and discharged from, managed land over the long term is needed to accurately estimate net stock changes. Such an analysis requires a Tier 3 approach.
>
> 2006 IPCC Guidelines Vol 4: page 2.37

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

[18] See also Volume 4 Chapter 2 Appendix 4.

available to develop reliable, globally applicable, default methods and emission factors for a particular source or sink.

This material is not 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 because of perceptions as to a lack of "robustness", "empirical science" or "maturity" 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.

1.5.5 Feasibility of being able to specify higher tier methods

Experts should consider the feasibility of being able to specify higher tier methods for identified CDR sinks and CCUS activities.

As an example, for carbon dioxide removal on terrestrial forest lands, additional guidance is provided for inventory compilers in relation to the specification of tier 3 methods in the *2019 Refinement to the 2006 IPCC Guidelines* Volume 4 section 2.5 (a small excerpt is included here):

> Inventories can be based on direct measurements from which emissions and removals of carbon are estimated. Purely measurement-based inventories, e.g., based on repeated measurements using a national forest inventory or similar estimation methods can produce carbon stock change estimates but still rely on appropriate statistical models, such as allometric models or volume and wood density functions. Inventories using measurement-based methods also need to select appropriate statistical sampling estimators to produce a national inventory from the plot estimates.
>
> 2019 Refinement to the 2006 IPCC Guidelines Vol 4:2.5.1 page 2.57

> Model-based Tier 3 inventories are developed using empirical (e.g. forest growth curves that represent carbon stock increase with tree age.), process-based (e.g. model representation of underlying physiological, biophysical, and management processes that drive carbon dynamics in ecosystems), hybrid (e.g. the development of forest growth curves from empirical data combined with a process model calibrated from research data on dead organic matter dynamics) and/or other types of models. Just as Tier 3 measurement-based methods typically also require models to estimate carbon stock changes, Tier 3 model-based inventories require measurements to calibrate and validate the models used to estimate carbon stock changes.
>
> 2019 Refinement to the 2006 IPCC Guidelines Vol 4:2.5.2 page 2.60

1.5.6 Verification activities

For identified CDR and CCUS activities, guidance will need to be provided for inventory compilers as to how they may be able to devise appropriate **verification** activities.

For example, for CCS, activity data relates to the measurement of injected amounts of carbon dioxide into storages sites. In this case, verification activities might be suggested or recommended for the stock of carbon stored in the site, as in the 2006 Guidelines:

> 4. Determine whether each site has a suitable monitoring plan. Each site's monitoring plan should describe monitoring activities that are consistent with the leakage assessment and modelling results.
>
> Continuous monitoring of the injection pressure and periodic monitoring of the distribution of CO_2 in the subsurface would be useful as part of the monitoring plan.

2006 IPCC Guidelines Vol 2:5.7.1 page 5.15

2. A preliminary stocktake of IPCC guidance on CDR activities

In the sections that follow, the CDR pathways identified in the IPCC Sixth Assessment Report are described briefly and have been grouped by type of removal process and by storage reservoir (Table 1).

Table 1: Grouping of CDR pathways by type of technology

Group	**The IPCC WGIII AR6 Report examples of CDR methods**
Engineered carbon capture with geological storage in the lithosphere	• Direct air carbon capture and storage • Bioenergy with carbon capture and storage
Carbon capture in products	• Concrete carbonation*
Anthropogenic mineral processes with storage of inorganic carbon in minerals or as bicarbonate ions	• Enhanced weathering • Ocean alkalinity enhancement
Anthropogenic biological processes (photosynthesis) – biomass	• Afforestation/Reforestation • Agroforestry • Improved Forest Management • "Blue carbon management" in coastal wetlands
Anthropogenic biological processes (photosynthesis) – soils and waterways	• Soil carbon sequestration in croplands and grasslands • Peatland and coastal wetland restoration • Biochar

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

2.1 Removals and CCUS through engineered carbon dioxide capture

Processes for the capture of carbon dioxide may be described in two pathways: capture of removals from the atmosphere and capture of a generated gas from human activity.

Removals through engineered capture using physical-chemical technological processes

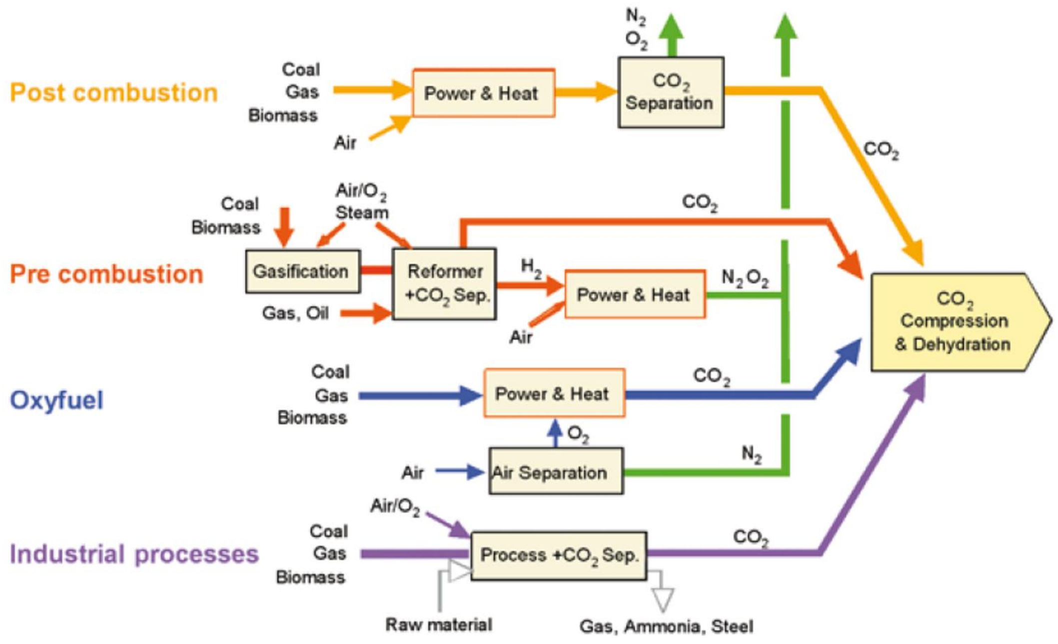
Technologies for Direct Air Capture of carbon dioxide extracted from the atmosphere use physical-chemical capture methods to directly extract carbon dioxide from the atmosphere using solid sorbents or liquid solvents (Figure 3 is relevant).

Engineered Direct Air Capture technologies that remove carbon dioxide from the atmosphere are not mentioned in the *2006 IPCC Guidelines*.

Engineered carbon dioxide capture: from a stream of carbon dioxide generated by human activity

Processes for the capture of carbon dioxide by engineered physical-chemical means are described in the Special Report on CCS and in the *2006 IPCC Guidelines*. In this case, the stream of carbon dioxide is generated by human activity but captured before it can become an immediate emission at this facility.

Figure 3 Overview of carbon dioxide capture processes and systems



Source: IPCC 205 – IPCC SRCCS 2005 (Figure TS.3)

IPCC estimation methods for carbon dioxide capture from Energy facilities are addressed in Volume 2 Chapter 2.3.4.

In the Energy sector, the Guidelines specify that the captured carbon dioxide should be measured with the residual emissions at the facility estimated as the difference between the stream of generated carbon dioxide implied by the carbon content of the fuel and the measured amount of carbon dioxide captured.

> Under Tier 3, the CO_2 emissions are therefore estimated from the fuel consumption estimated as described in earlier sections of this chapter minus the metered amount removed.
>
> 2006 IPCC Guidelines Vol 2:2.3.4 page 2.36

The treatment of captured carbon dioxide from biomass combustion is the same as above - however, the *2006 IPCC Guidelines* go on to say this:

> 2.5.3 Negative emissions may arise from the capture and compression system if CO_2 generated by biomass combustion is captured. This is a correct procedure and negative emissions should be reported as such.
>
> 2006 IPCC Guidelines Vol 2:5.3 page 5.8

This formulation applies only to the case of biomass combustion and follows directly from the reference from page 2.36. The 'negative' emission is an artefact caused by the zero-emission reporting of tail pipe or stack emissions from biomass combustion in the Energy Sector[19].

In the IPPU sector, the *2006 IPCC Guidelines* also require higher tier measurements of capture and higher tier estimates of the residual emissions at the facility:

> Similarly, all CO_2 captured should be accounted for in the IPPU Sector.
>
> 2006 IPCC Guidelines Vol 3:3.2 page 3.11

> It is *good practice* to account for capture of emissions using detailed country specific or more suitably plant-level data. Consequently, Tier 1 methods provided in this volume are not appropriate for tracking this type of abatement. Capture should be incorporated into equations by means of an additional term that represents either a measured quantity of capture, or the efficiency of an abatement system in combination with that system's utilisation throughout the year. It is recommended not to account for capture by using a modified emission factor, as this reduces transparency and risks inconsistency in time series.
>
> Should CO_2 capture technology be installed and used at a plant, it is *good practice* to deduct the CO_2 captured in a higher tier emissions calculation.

Short term use of carbon dioxide should be treated differently to carbon dioxide captured for permanent storage.

> Quantities of CO_2 for later use and short-term storage should not be deducted from CO_2 emissions except when the CO_2 emissions are accounted for elsewhere in the inventory. The default assumption is that there is no carbon dioxide capture and storage (CCS) taking place.
>
> 2006 IPCC Guidelines Vol 3:1.2.2 page 1.7

> If a country reports capture of CO_2, it is *good practice* to ensure that CO_2 is stored in long-term geological storage sites that are monitored according to the guidance in Chapter 5, CO_2 Transport, Injection and Geological Storage, of Volume 2: Energy.
>
> 2006 IPCC Guidelines Vol 3:1.2.2 page 1.8

Short-term storage is not a term that is defined by the *IPCC Guidelines*.

IPCC estimation methods for fugitive emissions from carbon dioxide capture are addressed in Volume 2 Chapter 5.3.

[19] Biomass is treated as having zero emissions in the Energy sector to avoid double counting of the carbon loss that is estimated and reported in the AFOLU sector.

Carbon dioxide transport

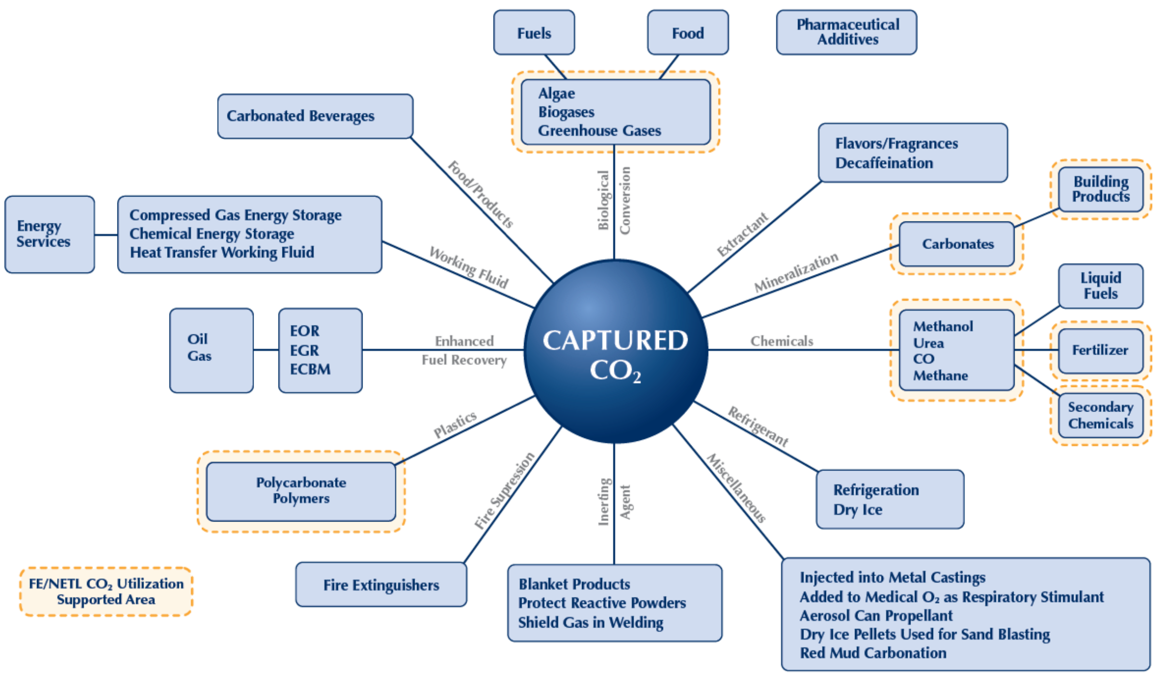
Once captured, carbon dioxide (regardless of its origin) may be used directly at the facilities or transported to a site of subsequent utilisation or storage (i.e. a long-term geological storage). Pipelines and ships provide large-scale carbon dioxide transport.

IPCC estimation methods for fugitive emissions from the transport of carbon dioxide capture are addressed in Volume 2 Chapter 5.4: emissions from transport by pipeline are addressed in 2.5.4.1 and transport by ship in 2.5.4.2.

Carbon dioxide utilisation

Utilization of captured carbon dioxide (regardless of its origin) includes enhanced oil/gas/coal recovery, production of construction materials, fuels, chemicals and plastics and other uses (see Figure 4). Some uses – eg building products – represent a stable form of storage, while for some uses -eg soft drinks – the ultimate point of emission is transferred to a different industry and delayed only briefly.

Figure 4: Possible pathways of carbon dioxide utilization



Source: National Energy Technology Laboratory www.netl.doe.gov

BOX: Example from the 2006 IPCC Guidelines of capture, utilisation and storage

The production of ammonia represents a significant non-energy industrial source of CO_2 emissions.

Should CO_2 capture technology be installed and used at a plant, it is good practice to deduct the CO_2 captured in a higher tier emissions calculation. The default assumption is that there is no CO_2 capture and storage. In most cases, methodologies that account for CO_2 capture should consider that CO_2 emissions captured in the process may be both combustion and process-related. However, in the case of ammonia production no distinction is made between fuel and feedstock emissions with all emissions accounted for in the Industrial Processes and Product Use (IPPU) Sector.

Urea production is a downstream process associated with ammonia production plants. The process uses the by-product CO_2 stream from an ammonia synthesis plant along with ammonia.

Emissions of CO_2 from urea use should be accounted for in the corresponding sectors. In particular, emissions from urea use as fertiliser should be included in the Agriculture Forestry and Other Land Use (AFOLU) Sector. Emissions from urea use in automobile catalytic converters should be accounted for in the Energy Sector.

If captured CO_2 was not transformed for another use, but instead was sent to geological storage sites, the emissions from transport and storage should be accounted in the category 1C. Carbon Dioxide Capture and Storage in the Energy Sector.

IPCC estimation methods for emissions from the utilisation of carbon dioxide are spread through Volume 2 and 3. There may be room to review the consistency of the treatment of the estimation of the amounts of carbon dioxide captured for use across various sectors.

> In certain IPPU categories, particularly large point sources of emissions, there could be capture of emissions for recovery and use, or destruction. .... Tier 1 methods provided in this volume are not appropriate for tracking this type of abatement. Capture should be incorporated into equations by means of an additional term that represents either a measured quantity of capture, or the efficiency of an abatement system in combination with that system's utilisation throughout the year. It is recommended not to account for capture by using a modified emission factor, as this reduces transparency and risks inconsistency in time series.
>
> 2006 IPCC Guidelines Vol 3:1.2 page 1.7

In the oil and gas sector the Guidelines say this:

> Fugitive greenhouse gas emissions from oil and gas related CO_2 capture and injection activities (e.g., acid gas injection and EOR projects involving CO_2 floods) will normally be small compared to the amount of CO_2 being injected (e.g., less than 1 percent of the injection volumes). At the Tier 1 or 2 methodology levels they are indistinguishable from fugitive greenhouse gas emissions by the associated oil and gas activities. The emission contributions from CO_2 capture and injection were included in the original data from which the presented Tier 1 factors were developed (i.e., through the inclusion of acid gas injection and EOR activities, along with conventional oil and gas activities, with consideration of CO_2 concentrations in the leaked, vented and flared natural gases, vapours and acid gases).
>
> 2019 Refinement to the 2006 IPCC Guidelines Vol 4:2.2 page 4.43

An additional issue not considered in the *IPCC Guidelines* relates to the international trade of carbon dioxide or products containing captured carbon dioxide.

Carbon dioxide injection for storage

Captured carbon dioxide through engineering processes and not utilised for commercial purposes (regardless of its origin) may be injected into geological forms for storage. The injection system comprises surface facilities at the injection site, e.g. storage facilities, distribution manifold at end of transport pipeline, distribution pipelines to wells, additional compression facilities, measurement and control systems, wellhead(s) and the injection wells.

This group includes technologies designed to capture carbon dioxide and store it underground in geological formations – including the activities listed by IPCC WGIII, Direct Air Carbon Capture and Storage and Bioenergy with Carbon Capture and Storage, as well as engineered carbon capture from human generated streams of carbon dioxide (CCS).

IPCC estimation methods for fugitive emissions from carbon dioxide injection are addressed in Volume 2 Chapter 5.5. IPCC estimation methods for fugitive emissions from carbon dioxide geological storage are addressed in Volume 2 Chapter 5.6.

Discussion

All aspects of existing guidance for carbon capture, utilisation and storage may be reviewed. A new treatment of direct air capture technology could be considered.

Currently, the IPCC reporting framework allows all issues related to removals/capture of carbon dioxide to be addressed. The capture of carbon dioxide in energy and industrial sectors is covered by the Reporting tables Categories 1.A-1.B of the Energy Sector and 2.A-2.H of the IPPU Sector.

The subsequent transport, injection and geological storage of captured carbon dioxide in energy and industry are covered by the category 1.C Carbon Dioxide Transport, Injection and Storage of the Energy Sector.

Direct Air Capture may not be covered explicitly by the existing reporting framework, but there is a category 'Other' in both Energy and IPPU sectors (1.B.3, 1.C.3 and 2.H) and in a general 'Other Sector' (5.B).

See examples of the current reporting framework in Annex 1.

Nevertheless, existing reporting structures could be clarified with respect to direct air capture and other CDR and CCUS activities.

One option would be to introduce new explicit categories for CDR methods in respective sectors Energy, IPPU, AFOLU and Waste.

A second option would be to expand the category 1.C in the Energy Sector.

A third option would be to specify the distinctive category in the category 5.B Other or create a new category/sector dedicated to CDR methods (e.g., category 6 CDR and CCS) and to move there 1.C from the Energy sector, taking into account that removal/capture of carbon dioxide can be covered in respective sectors (Energy, IPPU, AFOLU and Waste).

2.2 Removals through direct capture by products

In some cases, carbon dioxide may be directly removed from the atmosphere and stored in products as a function of the product's attributes.

Concrete carbonation may be considered to be an example of a carbon dioxide removal process as it effectively captures carbon dioxide from the atmosphere and stores it in a solid form within a concrete structure. While this process was not listed by IPCC WGIII as a strategy for large-scale carbon dioxide removal, there may be elements in the specification of concrete or in the design of settlement structures that may influence uptake. This CDR process is modelled by IPCC WGI in their analyses of the global carbon balance.

The process was previously listed as an area for future work in the *IPCC Guidelines*.

> Free lime (CaO not part of the formulae of the clinker minerals mentioned above) released during the curing of concrete (i.e., from the hydration of the clinker minerals) can potentially re-absorb atmospheric CO_2 - a process called carbonation. However, the rate of carbonation is very slow (years to centuries) and, as a practical matter, should not be considered for good practice. This is an area for future work before inclusion into national inventories.
>
> 2006 IPCC Guidelines Vol 3:2.2.1.4 page 2.15

Currently, reporting would be possible under 'Other' categories and has occurred in at least one instance.

Discussion

The IPCC Guidelines do not provide estimation methods that could be elaborated. The Meeting could consider whether this is a new area for emission and removal estimation methods.

There may be other processes to be considered.

The Meeting could consider new reporting structures: noting that concrete carbonation occurs in structures within the existing Settlement lands category.

2.3 Removals through anthropogenic enhancement of mineral processes

This group comprises technologies or processes that leverage geochemical or physical processes to capture carbon dioxide and store it as minerals or as bicarbonate ions. Enhanced Rock Weathering and Ocean Alkalinization are WGIII listed CDR activities in this grouping.

Enhanced Rock Weathering may be likely to involve spreading crushed silicate rocks on land or ocean, where carbon dioxide is absorbed through the accelerated dissolution of rock minerals that release cations and convert atmospheric CO_2 into bicarbonate ions (HCO_3^-). This process leads to the formation of stable store of carbonate minerals in rocks, within soils and dissolved in waterways.

Ocean Alkalinization may be likely to entail adding alkaline materials, such as silicate or carbonate rocks, to the ocean to increase its alkalinity. This prompts a reaction with dissolved CO_2 which converts into bicarbonate and carbonate ions and which is then stored within the ocean.

This type of process was previously listed as an area for possible future work in the *IPCC Guidelines*.

> No emissions estimation methods are provided for any other type of storage option such as ....conversion of CO_2 into inert inorganic carbonates. If and when they reach later stages of development, guidance for compiling inventories of emissions from these technologies may be given in future revisions of the Guidelines.
>
> 2006 IPCC Guidelines Vol 2:5:7 page 5.5

The IPCC Guidelines do not currently provide methods for estimating changes in inorganic carbon held within soils. While IPCC recognizes its relevance (*Equation 2.24, Volume 4*), only the possibility of Tier 3 country-specific methods are referenced, so deferring to inventory compilers the need to produce a complete, consistent and accurate methodology.

> No Tier 1 or 2 methods are provided for estimating the change in soil inorganic C stocks due to limited scientific data for derivation of stock change factors; thus the net flux for inorganic C stocks is assumed to be zero. Tier 3 methods can be used to refined estimates of the C stock changes in mineral and organic soils and for soil inorganic C pools.
>
> 2006 IPCC Guidelines Vol 4:2.3.3.1 page 2.29

Similarly, no methods are provided for estimating changes in carbon storage in waterways.

> No emissions estimation methods are provided for any other type of storage option such as ocean storage.
>
> 2006 IPCC Guidelines Vol 2:5:7 page 5.5

Currently, reporting would be possible under 'Other' categories, but this is not known to have occurred.

Discussion

The IPCC Guidelines do not provide estimation methods that could be elaborated. The Meeting could consider whether this is a new area for emission and removal estimation methods. This is a process not directly associated with soil organic matter, and thus an estimation method has not been specified by the IPCC methodological approaches. The Meeting could consider whether the Methodology Report could specify new methods for the estimation of changes in stocks of inorganic soil carbon for various carbon pools.

Currently, reporting would be possible, but this is not known to have occurred. Note that these processes occur on rocks ('other land' [reflecting lack of vegetation]) or held within soils ('grassland' and 'cropland') or in coastal waterways.

2.4 Removals through anthropogenic biological processes– biomass

This grouping of WGIII listed CDR activities includes afforestation/reforestation, agroforestry, improved forest management, and coastal wetlands management (Blue Carbon).

Extraction through photosynthesis results always in the production of biomass. The principal focus of these activities is to enhance the reservoir of organic carbon in forests, especially related to above ground biomass in forests, although other carbon pools in forests may be important (dead organic matter, soil organic carbon (especially for mangroves)). The distinction between the accumulation of biomass in forests and biomass in other ‘land categories’ has not been important since the end of the Kyoto Protocol first commitment period.

IPCC Guidelines already provide methods and the reporting framework to be applied to estimate carbon dioxide removals and any subsequent reversal in categories on Land and HWP (categories 3.B and 3.D). Afforestation/ Reforestation, Agroforestry, improved forest management methods are provided in volume 4, chapters 2, 3 and 4.

Currently, reporting occurs mainly under 3.B.1 ‘Forest land’.

Discussion

Methods for the estimation of emissions and removals from forest lands are specified in the *2019 Refinement to the 2006 IPCC Guidelines* Volume 4 chapters 2, 3 and 4.

Current methods for the estimation of emissions and removals are considered to be mature.

Current reporting structures are considered to be mature.

2.5 Removal through anthropogenic biological processes– soils and waterways

The group of activities that aim to increase the biological uptake of carbon with storage principally in soils include the WGIII listed CDR activities of soil carbon sequestration in cropland and grassland, biochar application and peatlands/wetlands restoration.

Capture occurs through biological processes and is affected by agricultural practices that enhance (or diminish) inputs, the application of biochar, or rewetting and revegetation of peatlands and wetlands. Carbon is then stored principally in soil organic matter.

Ocean fertilisation is also listed by WGIII as a CDR activity and refers to activities to promote the production and storage of organic carbon in coastal waters/oceans.

Methods for the estimation of emissions and removals from organic carbon in soils in grassland and cropland are principally specified in Volume 4 chapters 2, 3, 5, 6.

Soils

IPCC considers among the reservoirs of GHG precursors soil organic matter (SOM), and accordingly provides good practice methodologies to estimate anthropogenic emissions and removals of CO_2 associated to C stock gains and loss from such C reservoir.

Given the diversity of processes that determine the SOC level and its dynamic, IPCC provides two alternative methodological approaches to deal with carbon net removal in soils:

- ✓ <u>A stock-change approach for mineral soils</u> (*Section 2.3.3, Volume 4*), that estimates annual SOC changes by comparing 2 long-term equilibrium SOC stocks (*under initial conditions vs changed conditions*), which thus requires to calculate such a long-term equilibrium.

Also Biochar additions to mineral soils are counted in an NGHGI for the impact of those on the long-term[20] equilibrium SOC, although IPCC does not provide Tier 1 EF and parameter[21].

- ✓ An EF-based approach for organic soils (*Sections 3.2.1 and 4.2.3.3 Wetlands Supplement*) that estimates annual rate of CO_2 removal associated with the accumulation of carbon in organic soils (*peatlands, mangroves, tidal marshes*).

IPCC also provides a Tier 2 steady-state model that on the basis on annual C stock gains calculates annual C stock losses, which application is limited to agricultural mineral soils (Section 5.2.3.1, Volume 4, *2019 Refinement to the 2006 IPCC Guidelines*).

Alternative country-specific methods to estimate SOC net accumulation can of course be implemented based on, for example, a process modelling of the annual SOC level according to relevant variables, so far as those methods produce a complete, consistent and unbiased estimate of the anthropogenic SOC net gain/ SOM CO_2 net removal.

Accordingly, a techniques/technology that determine an increase in the SOC (soil organic carbon) stored in the SOM (soil organic matter) is reported within a national GHG Inventory (NGHGI) and consequently counted as a net CO_2 removal in the national total net GHG emission.

Other technologies that although may determine an increase of C stored in the land, e.g. fossilization of carbon in Solid Waste Disposal Sites (SWDS) or even a burial of organic matter in the soil, which are not counted as an increase in the SOC stored in the SOM do not consequently count as a net CO_2 removal in the national total net GHG emission and are thus excluded from this exercise.

SOC in mineral soils can be increased in a number of ways, although all associated with:

- ✓ an increase of the organic matter inputs in the soil -*e.g. organic fertilizers, green manure, biochar*- or
- ✓ a decrease of the SOC losses -*e.g. no-tillage, sod-seeding*-

and a number of options can-occur/usually-occurs at same time.

Coastal waters

> No emissions estimation methods are provided for any other type of storage option such as ocean storage.
>
> 2006 IPCC Guidelines Vol 2:5:7 page 5.5

Currently, reporting of changes in soil organic carbon stocks principally occurs under 3.B.2 'grassland' and 3.B.3 'cropland' and in 3.B.4 wetlands. Reporting of changes in carbon stocks in seagrass has occurred in the UNFCCC CRTs as category 4.D.1.c.i "Coastal wetlands", which is a subcategory of Other Wetlands remaining Other wetlands.

---

[20] Here set at 100 years

[21] This implies that inventory compiler shall provide their own data and provide for information on the verification of those data.

Discussion

For SOC in both mineral and organic soils, IPCC guidance provides default EFs and parameters at a global or regional level and not necessarily for those specific activities that a country wishes to apply for CDR. In particular:

- ✓ IPCC defaults allow the inventory compiler to estimate net carbon dioxide removal for rewetting[22] of organic soils in previously drained wetlands by climate zone and N content of peat, but with no further level of disaggregation to promote accuracy of removal estimates.
- ✓ No IPCC tier 1 default values are provided for Biochar. Only countries with capacity to undertake direct measurements and to model those *-given that a 100-year time frame is required-* can estimate net removals.
- ✓ IPCC stock-change factors are not provided for all possible activities for SOC increase in mineral soils: for instance Cover cropping, Agroforestry, Grazing intensity, Legumes on pasture; although these encompass the activities at an aggregated level as carbon-stock-change factor for land-use, tillage, C input (altogether), improved pasture; stratified by climate zone + moisture regime.

On the other hand, IPCC default methods are to be built on easily available activity data, which may prevent the production of more detailed methods/stratified EF and parameters.

It is worth noting that the current methodological approach applied to biochar (see equation 2.25A, Volume 4, *2019 Refinement to the 2006 IPCC Guidelines*), where the activity data –i.e the amount of biochar applied to soil is multiplied by a factor to quantify the fraction permanently (i.e. over a 100-year period) stored in the soil - may be useful in the specification of a method for the enhanced weathering of rocks.

In the case of enhanced weathering of rocks, given the amount of rock applied to soil as activity data, the variables to assess over the year are: the fraction of cations released, the fraction of cations released that react with atmospheric CO_2 to produce HCO_{3-}, the fraction of HCO_{3-} permanently stored –i.e. over a 100-year period– in the soil/water-basin/ocean.

[22] Including for coastal wetlands that are instead stratified by ecosystem only.

References

IPCC 2022 - *IPCC Sixth Assessment Report: Working Group III: The Mitigation of Climate Change, Technical Summary (Table TS.7)* IPCC_AR6_WGIII_TechnicalSummary.pdf

IPCC 2021 - *IPCC Sixth Assessment Report: Working Group I: The Physical Science Basis* Chapter 5: Global Carbon and other Biogeochemical Cycles and Feedbacks | Climate Change 2021: The Physical Science Basis (ipcc.ch)

IPCC 2019 - Calvo Buendia, E., Tanabe, K., Kranjc, A., Baasansuren, J., Fukuda, M., Ngarize, S., Osako, A., Pyrozhenko, Y., Shermanau, P. and Federici, S. (eds), *2019 Refinement to the 2006 IPCC Guidelines*. IPCC - TFI (iges.or.jp)

IPCC 2013 - Takahiko Hiraishi, Thelma Krug, Kiyoto Tanabe, Nalin Srivastava, Baasansuren Jamsranjav, Maya Fukuda and Tiffany Troxler (eds), *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. IPCC - TFI (iges.or.jp)

IPCC 2006 - Simon Eggleston, Leandro Buendia, Kyoko Miwa, Todd Ngawa, and Kyoto Tanabe (eds), *2006 IPCC Guidelines for the preparation of national greenhouse gas inventories*. IPCC - TFI (iges.or.jp)

IPCC 2005 - Metz et al (eds), IPCC Special Report *Carbon Dioxide Capture and Storage* Carbon Dioxide Capture and Storage — IPCC

UNFCCC 1992 - UN Framework Convention on Climate Change conveng.pdf (unfccc.int)

Annex 1. Current reporting of CDR technologies and CCUS in IPCC Reporting Tables

Excerpt – Energy 1A1-1A2

Table 1.1 Energy Background Table: 1A1-1A2 (1 of 2)

Categories	Activity (TJ)						Emissions (Gg)																				Information item[2] (Gg)	
							Solid			Liquid			Gas			Other fossil fuel			Peat[1]			Biomass		Total			CO_2 amount captured[3]	Biomass
	Solid	Liquid	Gas	Other fossil fuel	Peat	Bio-mass	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CH_4	N_2O	CH_4	N_2O	CO_2	CH_4	N_2O	CO_2	CO_2 emitted
1A Fuel Combustion Activities																												
1A1 Energy Industries																												
1A1a Main Activity Electricity and Heat Production																												
1A1ai Electricity Generation																												
1A1aii Combined Heat and Power Generation (CHP)																												
1A1aiii Heat Plants																												
1A1b Petroleum Refining																												
1A1c Manufacture of Solid Fuels and Other Energy Industries																												
1A1ci Manufacture of Solid Fuels																												
1A1cii Other Energy Industries																												
1A2 Manufacturing Industries and Construction																												
1A2a Iron and Steel																												
1A2b Non-Ferrous Metals																												
1A2c Chemicals																												
1A2d Pulp, Paper and Print																												
1A2e Food Processing, Beverages and Tobacco																												
1A2f Non-Metallic Minerals																												
1A2g Transport Equipment																												

Excerpt – Energy 1.B.1-1.B.3 Fugitive Emissions

Table 1.3 Energy Background Table: 1B

Category	Activity Data			Emissions (Gg)			Information item: Amount captured [2] (Gg)
	Description	Unit [1]	Value	CO_2	CH_4	N_2O	CO_2
1B Fugitive Emissions from Fuels							
1B1 Solid Fuel							
1B1a Coal Mining and Handling							
1B1ai Underground Mines	coal produced	ktonnes					
1B1ai1 Mining	coal produced	ktonnes					
1B1ai2 Post mining Seam Gas Emissions	coal produced	ktonnes					
1B1ai3 Abandoned Underground Mines	number of mines	number					
1B1ai4 Flaring of Drained Methane or Conversion of CH_4 to CO_2	gas flared	10^6 Sm^3					
1B1aii Surface Mines							
1B1aii1 Mining	coal produced	ktonnes					
1B1aii2 Post-mining Seam Gas Emissions	coal produced	ktonnes					
1B1b Uncontrolled Combustion, and Burning Coal Dumps	solid fuel combusted	ktonnes					
1B1c Solid fuel Transformation	solid fuel transformed	ktonnes					
1B2 Oil and Natural Gas							
1B2a Oil							
1B2ai Venting	total gas vented from oil production	10^6 Sm^3					
1B2aii Flaring	gas flared from oil production	10^6 Sm^3					
1B2aiii All other							
1B2aiii1 Exploration	wells drilled	number					
1B2aiii2 Production and Upgrading	oil produced	10^3 m^3					
1B2aiii3 Transport	crude oil transported	10^3 m^3					
1B2aiii4 Refining	refinery crude oil throughput	10^3 m^3					
1B2aiii5 Distribution of Oil Products	amount distributed	10^3 m^3					
1B2biii6 Others							
1B2b Natural Gas							
1B2bi Venting	Total gas vented from natural gas production	10^6 Sm^3					
1B2bii Flaring	gas flared from natural gas production	10^6 Sm^3					
1B2biii All Other							
1B2biii1 Exploration	number wells drilled	number					
1B2biii2 Production	Gas produced	10^6 Sm^3					
1B2biii3 Processing	Amount of gas processed at facilities	10^6 Sm^3					
1B2biii4 Transmission and Storage	Amount transported and stored	10^6 Sm^3					
1B2biii5 Distribution	Amount of gas distributed	10^3 m^3					
1B2biii6 Others							
1B3 Other Emissions from Energy Production							

Excerpt – Energy 1.C CO2 Transport, Injection and Storage

Table 1.4a Energy Background Table: 1C CO_2 Transport, Injection and Storage

Category	Activity (Gg)		Annual mass of fugitive CO_2 emissions to the atmosphere or sea bed (Gg) [2]
	Annual mass of CO_2 transported	Annual mass of CO_2 injected [1]	
1C1 Transport of CO_2			
1C1a Pipelines			
1C1b Ships			
1C1c Other (please specify)			
1C2 Injection and Storage [3]			
1C2a Injection			
1C2b Storage			
1C3 Other			

Table 1.4b Energy Background Table: 1C CO_2 Transport, Injection and Storage - Overview

Category [1]	CO_2 (Gg)
Total amount captured for storage (A)	
Total amount of import for storage (B)	
Total amount of export for storage (C)	
Total amount of CO_2 injected at storage sites (D)	
Total amount of leakage during transport (E1) category 1C1	
Total amount of leakage during injection (E2) category 1C2a	
Total amount of leakage from storage sites (E3) category 1C2b	
Total leakage (E4 = E1 + E2 + E3))	
Capture + imports (F = A + B)	
Injection + leakage + exports (G = D + E4 + C)	
Discrepancy (F – G)	

Excerpt – IPPU 2.A Mineral Industry and 2.B Chemical Industry

Table 2.1 IPPU Background Table: 2A Mineral Industry, 2B (2B1-2B8, 2B10) Chemical Industry - CO_2, CH_4 and N_2O

Categories	Activity data			Emissions						
	Production/Consumption quantity			CO_2 (Gg)			CH_4 (Gg)		N_2O (Gg)	
	Description (1)	Quantity	Unit (2)	Emissions (3)	Information Item Captured and Stored (4)	(memo) Other Reduction (5)	Emissions (3)	Information Item Reduction (6)	Emissions (3)	Information Item Reduction (6)
2A Mineral Industry										
2A1 Cement production										
2A2 Lime production										
2A3 Glass Production										
2A4 Other Process Uses of Carbonates (7)										
2A4a Ceramics										
2A4b Other Uses of Soda Ash										
2A4c Non Metallurgical Magnesia Production										
2A4d Other										
2A5 Other (please specify) (8)										
2B Chemical Industry										
2B1 Ammonia Production										
2B2 Nitric Acid Production										
2B3 Adipic Acid Production										
2B4 Caprolactam, Glyoxal and Glyoxylic Acid Production										
2B5 Carbide Production										
2B6 Titanium Dioxide Production										
2B7 Soda Ash Production										
2B8 Petrochemical and Carbon Black Production										
2B8a Methanol										
2B8b Ethylene										
2B8c Ethylene Dichloride and Vinyl Chloride Monomer										
2B8d Ethylene Oxide										
2B8e Acrylonitrile										
2B8f Carbon Black										
2B10 Other (please specify) (8)										

Excerpt – IPPU 2.H Other

Table 2.10 IPPU Background Table: 2H Other

Categories	Activity Data		CO_2 (Gg)	
	Quantity	Unit	Emissions (1)	(information) Reduction (2)
2H Other				
2H1 Pulp and Paper Industry				
2H2 Food and Beverages Industry				
2H3 Other (please specify) (3)				

(1) Enter the reported emissions (adjusted with captured and/or reduced amount).
(2) Enter the quantities of reduction of generated gas (emission recovery, destruction, etc.).
(3) Insert additional rows if necessary.

Excerpt – AFOLU – 3.B Carbon Stock Changes

Table 3.2 AFOLU Background Table: 3B Carbon stock changes in FOLU (1 of 2)

Categories	Activity data		Net carbon stock change and CO_2 emissions									Net CO_2 emissions
			Biomass				Dead organic matter			Soils		
	Total area	Thereof: Area of organic soils	Increase	Decrease	Carbon emitted as CH_4 and CO from fires [1]	Net carbon stock change	Net carbon stock change	Carbon emitted as CH_4 and CO from fires [1]	Net carbon stock change	Net carbon stock change in mineral soils [2]	Carbon loss from drained organic soils	
	(ha)		(Gg C)									(Gg CO_2)
3B Land												
3B1 Forest Land												
3B1a Forest Land Remaining Forest Land												
3B1b Land Converted to Forest Land												
3B1bi Cropland Converted to Forest Land												
3B1bii Grassland Converted to Forest Land												
3B1biii Wetlands Converted to Forest Land												
3B1biv Settlements Converted to Forest Land												
3B1bv Other Land Converted to Forest Land												
3B2 Cropland												
3B2a Cropland Remaining Cropland												
3B2b Land Converted to Cropland												
3B2bi Forest Land Converted to Cropland												
3B2bii Grassland Converted to Cropland												
3B2biii Wetlands Converted to Cropland												
3B2biv Settlements Converted to Cropland												
3B2bv Other Land Converted to Cropland												
3B3 Grassland												
3B3a Grassland Remaining Grassland												
3B3b Land Converted to Grassland												
3B3bi Forest Land Converted to Grassland												
3B3bii Cropland Converted to Grassland												
3B3biii Wetlands Converted to Grassland												
3B3biv Settlements Converted to Grassland												
3B3bv Other Land Converted to Grassland												
3B4 Wetlands [3]												
3B5 Settlements												

Excerpt – Table B. Short Summary Table

Table B Short Summary Table (1 of 2)

Categories	Net CO_2 (1) (2)	CH_4	N_2O	HFCs	PFCs	SF_6	Other halogenated gases with CO_2 equivalent conversion factors (3)	Other halogenated gases without CO_2 equivalent conversion factors (4)
	(Gg)			CO_2 equivalents (Gg)				(Gg)
Total National Emissions and Removals								
1 ENERGY								
1A Fuel Combustion Activities								
1B Fugitive Emissions from Fuels								
1C Carbon Dioxide Transport and Storage								
2 INDUSTRIAL PROCESSES AND PRODUCT USE								
2A Mineral Industry								
2B Chemical Industry								
2C Metal Industry								
2D Non-Energy Products from Fuels and Solvent Use								
2E Electronics Industry								
2F Product Uses as Substitutes for Ozone Depleting Substances								
2G Other Product Manufacture and Use								
2H Other								
3 AGRICULTURE, FORESTRY AND OTHER LAND USE								
3A Livestock								
3B Land								
3C Aggregate Sources and Non-CO_2 Emissions Sources on Land								
3D Other								
4 WASTE								
4A Solid Waste Disposal								
4B Biological Treatment of Solid Waste								

Table B Short Summary Table (2 of 2)

Categories	Net CO_2 (1)(2)	CH_4	N_2O	HFCs	PFCs	SF_6	Other halogenated gases with CO_2 equivalent conversion factors (3)	Other halogenated gases without CO_2 equivalent conversion factors (4)
	(Gg)			CO_2 equivalents (Gg)				(Gg)
4C Incineration and Open Burning of Waste								
4D Wastewater Treatment and Discharge								
4E Other (please specify)								
5 OTHER								
5A Indirect N_2O emissions from the Atmospheric Deposition of Nitrogen in NO_x and NH_3								
5B Other (please specify)								
Memo items (5)								
International Bunkers								
International Aviation (International Bunkers)								
International Water-borne Transport (International Bunkers)								
Multilateral Operations								

(1) CO_2 net emissions (emissions minus removals)

(2) Total amount of CO_2 captured for long-term storage is to be reported separately for domestic storage and for export in the documentation box.