A6.4-SB005-AA-A09

Information note

Removal activities under the Article 6.4 mechanism

Version 04.0

COVER NOTE

1. Procedural background

1. The Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA), by its decision 3/CMA.3 “Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement”,[1] requested the Supervisory Body of the mechanism established by Article 6, paragraph 4, of the Paris Agreement (the Supervisory Body) to elaborate and further develop, on the basis of the rules, modalities and procedures of the Article 6.4 mechanism (RMPs), recommendations on activities involving removals, including appropriate monitoring, reporting, accounting for removals and crediting periods, addressing reversals, avoidance of leakage, and avoidance of other negative environmental and social impacts, in addition to the activities referred to in chapter V of the RMPs (Article 6, paragraph 4, activity cycle), for consideration at its fourth session (CMA 4, November 2022).

2. The Supervisory Body, at its first meeting (25–28 July 2022),[2] requested the secretariat to prepare an information note providing technical information on the elements related to activities involving removals, as referred to in decision 3/CMA.3, paragraph 6 (c), with respect to each type of activity, and agreed that an informal working group on removals, composed of its members and alternate members and secretariat staff would work prior to the second meeting of the Supervisory Body to prepare draft recommendations for consideration by the Supervisory Body at its second meeting with a view to forwarding the recommendations to the CMA at its fourth session.

3. The Supervisory Body, at its second meeting (19–22 September 2022),[3] agreed that the informal working group on removals should continue to work on the development of the information note. It requested the secretariat to launch a call for public inputs on the information note and the draft recommendations, including the in-meeting working document.

4. At its third meeting (3–6 November 2022),[4] the Supervisory Body took note of the high-level summary of the public inputs received in response to the call for public inputs and requested the secretariat to take these inputs into account while updating the document “Information note: Activities involving removals under the Article 6.4 mechanism” for its consideration at a future meeting.

[1] See document FCCC/PA/CMA/2021/10/Add.1 available at: https://unfccc.int/documents/460950.

[2] The meeting report of the first meeting of the Article 6.4 mechanism Supervisory Body (SB 001) is available at: https://unfccc.int/sites/default/files/resource/a64-sb001.pdf.

[3] The meeting report of SB 002 is available at: https://unfccc.int/sites/default/files/resource/a64-sb002.pdf.

[4] The meeting report of SB 003 is available at: https://unfccc.int/sites/default/files/resource/a64-sb003_0.pdf.

5. At its fourth meeting (7–10 March 2023),[5] the Supervisory Body requested the secretariat to prepare an updated version of the information note, taking into account the guidance and questions contained in annex 2 to the SB 004 meeting report[6] and the views of Parties and observers submitted in response to the call for submissions pursuant to decision 7/CMA.4, paragraph 19.

2. Purpose

6. This document contains the updated version of the information note, which has been revised to include the guidance of the Supervisory Body as well as the views of Parties and observers, as referred to in the previous paragraph. The purpose of the information note is to support the work of the Supervisory Body in developing recommendations on activities involving removals, pursuant to decision 3/CMA.3, paragraph 6 (c).

3. Key issues and proposed solutions

7. The key issues are considered from a broader perspective, and options for addressing the issues have been provided in the information note.

4. Impacts

8. This document will facilitate the Supervisory Body's consideration of the recommendations on removal activities pursuant to the decision 3/CMA.3, paragraph 6 (c).

5. Subsequent work and timelines

9. Further work will be taken up as agreed by the Supervisory Body, including the following:

   (a) Conducting a future structured public consultation process to invite feedback from stakeholders, based on an assessment of information gaps identified through submissions made by Parties and observers in accordance with paragraph 5 above;

   (b) Any other related work, including updating of this information note based on the outcome of work done under (a) above.

6. Recommendations to the Supervisory Body

10. It is recommended that the Supervisory Body take this information note into account when developing the recommendations requested by the CMA and provide further guidance to the secretariat in this regard.

[5] The meeting report of SB 004 is available at: https://unfccc.int/sites/default/files/resource/a64-sb004.pdf.

[6] Annex 2 of the SB 004 meeting report titled "Information note: Guidance and questions for further work on removals (v.01.0) is available at: https://unfccc.int/sites/default/files/resource/a64-sb004-a02.pdf.

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1. Introduction

1. This note provides technical information on the elements related to activities involving removals referred to in decision 3/CMA.3, paragraph 6 (c)[1], with respect to different types of activities involving removals.

2. For brevity, the term "removal activities" has been used in this note to imply "activities involving removals".

3. Also, for reasons of brevity, the term "RMPs" has been used to imply the "Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement" as contained in the annex to decision 3/CMA.3.

1.1. Scope

4. In addition to the background scientific and technical information on removal activities, this note covers the following issues relating to removal activities in the context of the A6.4-RMP:

   (a) Monitoring;

   (b) Reporting;

   (c) Accounting for removals;

   (d) Crediting periods;

   (e) Addressing reversals;

   (f) Avoidance of leakage; and

   (g) Avoidance of other negative environmental and social impacts.

1.2. Sources of information

5. This note is based upon the following sources of information:

   (a) Reports of the Intergovernmental Panel on Climate Change (IPCC);

   (b) Rules, regulations, and standards of other market-based mechanisms;

   (c) Input provided by stakeholders in response to the public call for inputs (open from 27 September to 11 October 2022)[2]. The relevant sources referred to in the public input were also consulted;

[1] Decision 3/CMA.3, paragraph 6(c) is contained in document FCCC/PA/CMA/2021/10/Add.1 available at: https://unfccc.int/sites/default/files/resource/cma2021_10a01E.pdf.

[2] Submissions received in response to the call for input on activities involving removals under the Article 6.4 mechanism are available at: https://unfccc.int/process-and-meetings/the-paris-agreement/article-64-mechanism/calls-for-input/sb002-removals-activities.

(d) Information provided in the guidance and questions contained in annex 2 to the meeting report of SB004 as well as views of Parties and observers submitted in response to the call for submissions pursuant to decision 7/CMA.4, paragraph 19;

(e) Other published literature related to climate change science and policy.

6. The sources have been cited in the text as appropriate.

7. A consolidated list of sources cited can be found in appendix A. Search strings have been provided in the list of sources to quickly navigate to the paragraph or sentence relevant to the citation. This could be particularly useful in the case of long documents such as IPCC reports, where it can take some time to find the relevant text.

2. Definitions

8. This section contains terms that are defined specifically for the scope of this information note.

2.1. Definition of removals

9. A carefully considered definition of removals and related terms has been emphasized to be of fundamental importance in some of the public inputs received. This section analyses in detail the issues and options related to defining removals and the associated terms.

10. The term removal can be used in different ways and contexts.

Removal as a process of separation

11. As an uncountable noun, removal refers to the process of separating greenhouse gases (GHGs) from the atmosphere. Atmosphere here refers to the free atmosphere where GHGs have already been uniformly mixed with the air. The capture of GHGs at or near emission sources counts as GHG avoidance, not removal. There remains some ambiguity as to how far from the emission source the capture equipment must be located to qualify as removal from the free atmosphere. One proposal is that the capture of GHGs from the atmosphere outside the direct influence of the emission sources should count as removal (P-10:b). However, it is debatable whether the construction of a carbon dioxide (CO_2) capture facility near coal-fired power plants or a methane capture facility in the middle of rice fields would qualify as GHG capture from free atmosphere.

Removal as a quantity removed

12. Used as a countable noun, often in the plural, “removals” refers to the physical quantities of GHGs removed from the atmosphere. The quantities can be expressed in tonnes of the respective GHGs removed or in equivalent tonnes of CO_2 (i.e. tonnes of CO_2 equivalent or tCO_2eq) calculated on the basis of the 100-year global warming potential values of the respective GHGs. Tonnes removed in the case of land-based activities are also called

carbon stocks, usually expressed in units of tCO_2 or tCO_2eq, but sometimes in units of tonnes of carbon (tC).

Scope of GHGs covered

13. The terms carbon dioxide removal (CDR) and greenhouse gas removal (GGR) are used to specify the scope of the gases covered.

14. The following observations can be made in this regard:

(a) According to the IPCC, there are currently no removal methods for removal of non-CO_2 GHGs that have progressed beyond conceptual discussion (R-32:a). The term “GGR” is no longer used by the IPCC (R-32:b). The IPCC defines "anthropogenic removals" as " withdrawal of GHGs from the atmosphere as a result of deliberate human activities" (R-32:c);

(b) Some stakeholder submissions suggest that GHGs other than CO_2 should not be included in the definition of removals (P-28:b, P-03:b). Others suggest including all GHGs (P-16:a, P-22:a, P-14:a). There are also cases where the term GGR is used when the actual removal is limited to the removal of CO_2 (R-50:a, R-16:a).

2.2. Definition of removal activities

15. For the purposes of the Article 6.4 mechanism, the definition of CDR comes closest to defining removal activities. CDR is defined in three slightly different ways in the latest IPCC report (Working Group III contribution to the Sixth Assessment Report, AR6 WGIII):

(a) Definition in Annex I (Glossary): “Carbon dioxide removal (CDR) Anthropogenic activities removing carbon dioxide (CO_2) from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological or geochemical CO_2 sinks and direct air carbon dioxide capture and storage (DACCS), but excludes natural CO_2 uptake not directly caused by human activities. (R-32:e)”;

(b) Definition in the Technical Summary: “CDR refers to anthropogenic activities removing CO_2 from the atmosphere and durably storing it in geological, terrestrial, or ocean reservoirs, or in products. It includes existing and potential anthropogenic enhancement of biological, geochemical or chemical CO_2 sinks, but excludes natural CO_2 uptake not directly caused by human activities (Annex I) (R-32:f)”;

(c) Definition in Chapter 12, Cross-Chapter Box 8: “CDR refers to anthropogenic activities that remove CO_2 from the atmosphere and store it durably in geological, terrestrial, or ocean reservoirs, or in products. It includes anthropogenic enhancement of biological, geochemical or chemical CO_2 sinks, but excludes natural CO_2 uptake not directly caused by human activities. Increases in land carbon sink strength due to CO_2 fertilisation or other indirect effects of human activities are not considered CDR (see Glossary) (R-32:i)”.

16. The following can be noted about the above three definitions:

(a) Compared to the definition in the Glossary, the definitions in the Technical Summary and Chapter 12 include the words "or chemical" after the word "geochemical", and remove the words referring to DACCS. Thus, these definitions provide a technology-neutral reference to chemical sinks by avoiding the term DACCS (P-13:a);

(b) The definition in Chapter 12 differs from the other two definitions in that it uses the words “includes anthropogenic” instead of the words “includes existing and potential anthropogenic” used in the other two definitions.

17. Based on the public inputs, the following observations can be made on the IPCC definition of removal activities:

(a) Some stakeholders suggest that the IPCC definition should not be changed unless there is a demonstrated need and added value (P-25:a, P-16:b). Others suggest adapting the IPCC definition to the specific needs of the mechanism (P-07; P-03);

(b) Some of the issues raised and proposed solutions are as follows:

(i) The term "durably" is not defined in terms of minimum duration (P-07). It is suggested that a minimum storage period of 200 to 300 years be included in the definition (P-07:a);

(ii) The words "storage in products" should be deleted as most products have a shorter life than the desired durability (P-07:b);

(iii) The words "net removal" should be used to convey that activity emissions should be subtracted from the removals achieved (P-07:d, P-03:a).

(c) It is worth considering whether the requirement for "net" should be specified in the definitions or elsewhere, such as in the methodologies, as "net" may imply different accounting approaches, such as the use of life-cycle assessment (LCA) emissions, embedded emissions, or only the net of direct and indirect emissions;

(d) There is also the question of how many tonnes of removals would need to be subtracted for each tCO2eq of emissions resulting from the implementation of a removal activity. If an activity involving removals also results in emission reductions or avoidance, such that the net balance of the activity in terms of emissions is negative (i.e. the emissions avoided are greater than the emissions caused by the implementation of the activity), should the emissions from the activity still be deducted from the removals achieved?

(e) Avoiding the use of the word "net" in the definition itself may allow for a more streamlined approach to addressing these issues in their respective places.

18. If the definition were to cover non-CO_2 GHGs, the word "storage" might not be appropriate, as in the case with methane removal, for example, it may be more appropriate to burn ("destroy") the GHGs removed. If the word "destruction" is used in the definition, "climate-neutral destruction" could be specified (P-28:a), although the emissions accounting

requirements of the methodology may also cover this aspect. The IPCC no longer uses the term climate neutrality (R-32:g) because of its ambiguous meaning.

19. If the definition were to include non-CO_2 GHGs and their precursors, it would be necessary to specify the nature and extent of the precursors to be included (P-10:a), how they are physically handled, and how their mitigation value is accounted for (P-07:c).

20. It has also been suggested that the words "voluntary direct anthropogenic activities" be used (P-17:a), perhaps to exclude unintentional removals and removals resulting from policy actions that could qualify as removal activities, although the words "not directly caused by human activities" in the IPCC definition already exclude unintentional removals. There is a further suggestion that policy actions should qualify as eligible removal activities if they result in quantifiable removals (P-02:a).

Removal of CO_2 from oceans

21. A further suggestion is that the definition should use the words "removal of CO_2 from the atmosphere or ocean" (P-23:a). This allows for removal activities that stimulate growth of macroalgae in the oceans and store it on the ocean floor, thereby accelerating the CO_2 flux from the atmosphere to the oceans. It is argued that effectively addressing the climate crisis should include addressing ocean acidification and warming. Such removal activities could shift carbon to rebalance the natural carbon reservoirs by transferring carbon from the fast cycling reservoirs (i.e. the biosphere, the atmosphere, and the upper ocean) to the slow cycling reservoirs (i.e. the deep ocean and marine sediments).

22. Rebalancing of carbon reservoirs will also serve the broader goals of sustainable development, which include an equitable net-zero transition, socio-ecological sustainability, and the pursuit of broad economic opportunity (R-20:a, R-10:a). On the other hand, other sources maintain that macroalgae cultivation as an effective climate mitigation solution is not yet established (R-32:g, R-44:a, R-42:a).

Temporal boundary of removals

23. The time at which actual removals take place is a relevant consideration for an unambiguous definition of removal activities (P-10:c). In the broadest sense, even fossil fuels resulted from the removal of atmospheric CO_2 that occurred millions of years ago. Trees that have grown over the past few centuries store CO_2 that has been removed over that period. The biogenic waste that is burned today in an energy recovery facility was removed from the atmosphere at some point in the past, although we don't know exactly when. If a bioenergy with carbon capture and storage (BECCS) plant is powered by such biogenic waste, does it achieve removals? If the wood that was grown in country X over the last half century is pelletized and burned in a BECCS plant in country Y today, does that achieve removals?

24. If we do not impose any temporal boundary on when the removals occurred, then the above BECCS activities would count as removal activities, because the CO_2 injected into the geological storage facility was, over some period of time, removed from the open atmosphere by biological sinks. This creates a need for delineating a temporal boundary for removals to allow unambiguous attribution of removals to a particular removal activity.

25. For the purposes of the Article 6.4 mechanism, an option for clearly defining the temporal scope of removals would be to limit to the removals that occur after the removal activity is registered. This would avoid the problem of old or legacy removals being counted as

removals achieved by the activity. Prior consideration or prompt commencement of activities may be taken into account if so agreed under the rules of the mechanism, in which case removals occurring after notification of prior consideration would be considered removals achieved by the activity if such an activity is later successfully registered.

Ownership of removal activities

26. Since a removal activity consists of two components, separation of CO_2 from the atmospheric air and subsequent storage of the removed CO_2, the question arises as to how an activity participant is unambiguously identified when different actors are performing these two components.

27. For example, if a forest entrepreneur grows timber that is sold to another actor who produces engineered timber out of it, thus causing prolonged storage of carbon, which actor gets the credits and if both of them get credits, in what proportion? According to the definition, none of the two actors (and there could be many actors) by themselves achieves removals as defined.

28. In another example, deep geological storage is a highly specialized operation, and one such service provider can store carbon removed by a large number of actors who separate the CO_2 and ship it to the same storage service provider. Realization of actual removals depends upon investment by all actors. In such a case, how an activity is to be defined and how credits are to be awarded remains an open issue.

Removals versus avoided emissions

29. Some stakeholders have argued that BECCS activities driven by biogenic waste should be considered removal activities. However, asking the question "What would be the baseline fate of the biogenic material being used in the BECCS activity?" points to different outcomes.

30. If the biogenic material would have been stored durably in the baseline (e.g. buried), then the BECCS activity achieves nothing except the emission savings resulting from displacement of the grid electricity (if the GHG balance is favourable).

31. On the other hand, if the baseline fate of the biogenic material would have been combustion without carbon capture and storage (CCS), then the BECCS activity achieves emission reductions on two counts: preventing the emission of the carbon contained in the biogenic material, and displacing the emissions from the grid electricity (if the GHG balance is favourable).

32. In either case, the removal of the carbon from the atmosphere does not fall within the scope of the BECCS activity since removal had happened before the start of the BECCS activity. Of course, a BECCS activity driven by biomass sourced from dedicated plantations or energy crops (specifically raised for the purpose of producing fuel for the power plant) generates removals. In such a case, the raising of plantation falls within the boundary of the BECCS activity and emissions associated with the cultivation of biomass will be accounted within the activity.

33. Table 1 summarizes the suggested changes to be made in the definition of removal activities provided in the Technical Summary of the IPCC AR6 WGIII report and the pros and cons of such changes.

Table 1. Proposed changes in the definition of removal activities provided in the Technical Summary of the Intergovernmental Panel on Climate Change Working Group III contribution to the Sixth Assessment Report (IPCC AR6 WGIII)

Proposed change	Pros	Cons
Include non-CO_2 greenhouse gases (GHGs)	- A broader scope to include potential activities from ongoing innovations under greenhouse gas removal (GGR).	- Removal of other GHGs is not currently anticipated at relevant scales; - It is unclear if the removal of other GHGs has a comparable mitigation effect to the removal of CO_2; - The Intergovernmental Panel on Climate Change (IPCC) recommends that, for now as well in the foreseeable future, the effects of non-CO_2 GHGs should be balanced through additional removal of CO_2 based on 100-year global warming potential equivalence.
Specify minimum duration of storage as 200 to 300 years	- Scope of what counts as removals is unambiguously defined; - Short-term removal activities are not counted as eligible removal activities.	- It is not clear how the number of years is to be arrived at; - With this limitation, only engineering-based removal activities will qualify; - Removal activities of all durations can contribute to the mechanism goal, not just those that store carbon for 200 years or more.
Delete reference to products	- Products of shorter lifetime can be excluded from counting as durable storage.	- Products of varied lifetime can also contribute to the mechanism goal; - Products can range from biochar and other inert-carbon products to intermediate lifetime products such as timber.
Include the word "net"	- Removals are accounted for as net result of implementation of the removal activity.	- Net applies to quantification and calculation of credits, not to activity itself; - There is no single method to define net for all activities and situations; this is a methodological question and includes aspects such as whether to use life cycle assessment (LCA) accounting or activity accounting; - It is the accounting of removals that needs to be net of all emissions; these provisions belong to the methodologies.

Proposed change	Pros	Cons
Include “destruction” of GHGs	- In case of a GGR activity, destruction is relevant rather than storage (e.g. in removal of methane).	- Methane could also potentially be converted into a product.
Include “precursors”	- Leads to more comprehensive accounting of the impact of removal activities.	- There are no accepted methodologies for accounting of precursors; the science may not be settled yet; - It would add complexity without adding commensurate value.
Include removal from oceans	- The large mitigation potential of oceans can be leveraged; - Removal activities under the mechanism can contribute to rebalancing of carbon reservoirs.	- Macroalgae cultivation as an effective climate solution is not yet established.

2.3. Definition of other terms

34. The following definitions used in this document have been taken from the glossary of the IPCC reports and from the RMPs contained in the annex to decision 3/CMA.3:

(a) **Carbon dioxide capture and storage (CCS)** A process in which a relatively pure stream of carbon dioxide (CO_2) from industrial and energy-related sources is separated (captured), conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere. Sometimes referred to as Carbon Capture and Storage;[3]

(b) **Carbon dioxide capture and utilisation (CCU)** A process in which CO_2 is captured and then used to produce a new product. If the CO_2 is stored in a product for a climate-relevant time horizon, this is referred to as carbon dioxide capture, utilisation and storage (CCUS). Only then, and only combined with CO_2 recently removed from the atmosphere, can CCUS lead to carbon dioxide removal. CCU is sometimes referred to as Carbon dioxide capture and use;[4]

(c) **Bioenergy and carbon dioxide capture and storage (BECCS)** Carbon dioxide capture and storage (CCS) technology applied to a bioenergy facility. Note that depending on the total emissions of the BECCS supply chain, carbon dioxide (CO_2) can be removed from the atmosphere;[5]

(d) **Biochar** Stable, carbon-rich material produced by heating biomass in an oxygen-limited environment. Biochar may be added to soils to improve soil functions and

[3] IPCC, 2018: Special Report on Global Warming of 1.5°C, Annex I: Glossary.

[4] IPCC, 2018: Special Report on Global Warming of 1.5°C, Annex I: Glossary.

[5] IPCC, 2018: Special Report on Global Warming of 1.5°C, Annex I: Glossary.

to reduce greenhouse gas emissions from biomass and soils, and for carbon sequestration;[6]

(e) **"Article 6, paragraph 4, activity"** is an activity that meets the requirements of Article 16, paragraphs 4–6, these rules, modalities and procedures, and any further relevant decisions of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA);

(f) **"Article 6, paragraph 4, emission reduction" (A6.4ER)** is issued for mitigation achieved pursuant to Article 6, paragraphs 4–6, these rules, modalities and procedures, and any further relevant decisions of the CMA. It is measured in carbon dioxide equivalent and is equal to 1 tonne of carbon dioxide equivalent calculated in accordance with the methodologies and metrics assessed by the Intergovernmental Panel on Climate Change and adopted by the CMA or in other metrics adopted by the CMA pursuant to these rules, modalities and procedures.

3. Types of removal activities

35. As can be seen from the IPCC definition of removal activities, there are two main elements of a removal activity: the process of separation of CO_2 from the atmospheric air (the removal method), and the process of durably storing the removed CO_2 (the storage method). There may be an intermediate stage of conversion (e.g. liquefaction) and transportation of CO_2 (e.g. trucking, shipping, and conveyance through pipelines). Since the transport methods are not unique to removal activities, these are not discussed further in this note.

3.1. Taxonomy of removal activities

36. The following are the broad types of removal methods (R-32:j):

(a) Biological methods: The separation of CO_2 from the atmosphere is achieved through the photosynthesis process. These methods can be further divided into:

(i) Land-based biological methods consisting of tree planting or regeneration of natural vegetation such as forests. Almost all current removals come from this category (R-50:b);

(ii) Ocean-based biological methods including stimulating growth of macroalgae or another type of marine biomass and sinking the resulting biomass to the seabed where it is expected to last over a long period. These methods are experimental and not yet proven safe or practical and have limited feasibility of implementation at scale in view of the multilateral treaties regulating the marine environment, such as the London Protocol to the London Convention (P-12:a) and the Convention on Biological Diversity (P-12:g);

(b) Geochemical or chemical methods: These methods employ geochemical or chemical reactions to separate CO_2 from the atmospheric air. Examples include direct air capture (DAC) and enhanced weathering (EW). Most of the methods are in various stages of development and are not expected to be technologically, economically, and environmentally feasible until 2030, or even until 2050 (P-12:h).

[6] IPCC, 2018: Special Report on Global Warming of 1.5°C, Annex I: Glossary.

These methods theoretically have the potential to create a large and indefinitely sustained removal capacity, even if with a large share of resource use. Hence these methods are thought to be useful in the long term, when the global economy will have been decarbonized to the extent possible, but some residual GHG emissions will continue in the hard-to-abate sectors (e.g. agriculture, aviation).

37. The following are broad categories of storage methods:

(a) Storage in ecosystem carbon pools:

(i) Land-based ecosystem reservoirs such as above-ground biomass, belowground biomass, deadwood, litter, and soil-organic matter can store carbon over durations ranging from years to centuries. These reservoirs have the limitation of becoming saturated over time and thus cannot go on accumulating carbon indefinitely unless biomass is harvested at a sustained rate and transferred to other reservoirs such as long-lasting products or geological storage;

(ii) Marine ecosystem reservoirs, such as marine biomass or seabed can store carbon over durations varying from decades to centuries. However, there is considerable uncertainty about the impacts of such storage on the marine ecosystems;

(b) Storage in geological reservoirs, or storage through mineralization of CO_2 in subsurface rocks: Currently there are a few well-tested sites of deep geological storage being mainly used for storing CO_2 removed from flue gases of industrial facilities combusting fossil fuels. These storage facilities achieve carbon recycling instead of carbon removal. The same storage sites can be used by removal activities, including biological or engineering-based removal activities, for the purpose of durable storage of removals;

(c) Storage in durable products occurs when carbon removed through biological or engineering-based methods is converted to useful products and preserved over long periods of time. The products can be made either after complex conversion and transformation processes or with minimal processing. The following are some of the product types:

(i) Durable biomass products such as massive timber, engineered timber, and other structural wood used in the construction of buildings, and biochar. Typically, these products can last from decades to centuries;

(ii) Inert carbon products such as concrete, building bricks, and other products made from CO_2 removed through engineering methods. These products can typically last for centuries.

38. Any implementation of a removal activity will consist of a combination of removal methods and storage methods described above. Table 2 below provides some examples of such implementations.

Table 2. Examples of implementations of removal activities combining different removal methods with storage methods

Storage method	Land-based biological removal	Ocean-based biological removal	Geochemical/ chemical removal
Land-based ecosystem reservoirs	- Afforestation/ reforestation and forest restoration - Revegetation - Improved forest management - Wetland restoration	Organic matter grown in oceans is added to soils	Enhanced weathering with the sequestered atmospheric carbon stored in soils
Ocean ecosystem reservoirs	-	Stimulating macroalgae growth	-
Deep ocean storage	Biomass grown on land is sunk to the ocean floor	Stimulating macroalgae growth and sinking the biomass to seabed	DACCS activity with the removed carbon stored in seabed
Deep geological storage	BECCS activities driven by sustained harvest of biomass from forests or dedicated energy plantations where the removed CO_2 is injected in deep geological formations	-	DACCS activity with the removed carbon stored in deep geological formations
Sub-surface mineralization	BECCS activities driven by sustained harvest of biomass from forests or dedicated energy plantations where the removed CO_2 is mineralized in subsurface rocks	-	DACCS activity with the removed carbon stored through subsurface mineralization in rocks
Wood-based products	Biomass grown on land with the harvested wood stored in timber, engineered timber, and wooden building construction	Stimulating macroalgae growth and using the macroalgae biomass as a feedstock for bio-based products	-

Storage method	Land-based biological removal	Ocean-based biological removal	Geochemical/ chemical removal
Carbon products from mineralization	BECCS activities driven by sustained harvest of biomass from forests or dedicated energy plantations where the removed CO_2 is mineralized to form concrete aggregates	-	DAC activities with the removed CO_2 mineralized to form concrete aggregates

3.2. Eligibility of activity types under the Article 6.4 mechanism

39. Based on the public input from stakeholders and other sources consulted, table 3 summarizes the pros and cons of the eligibility of different types of activities under the A6.4 mechanism.

Table 3. Pros and cons of the different activity types being made eligible under the mechanism

Activity type	Pros and cons
Engineering-based activities	**Pros** – Engineering-based removal activities result in permanent net removal of carbon dioxide from the atmosphere. **Cons** – Engineering-based removal activities are technologically and economically unproven, especially at scale, and pose unknown environmental and social risks (P-12, R-83:a, R-84:a, R-50:c,d). Currently these activities account for removals equivalent to 0.01 MtCO2 per year (P-15:a) compared to 2,000 MtCO2 per year removed by land-based activities. – These activities do not contribute to sustainable development, are not suitable for implementation in the developing countries and do not contribute to reducing the global mitigation costs, and therefore do not serve any of the objectives of the Article 6.4 mechanism.

Activity type	Pros and cons
Land-based activities	**Pros** – Land-based activities are proven and safe, have a long history of practice, and are backed by considerable experience under compliance and voluntary carbon market mechanisms. – Land-based activities have the potential to the deliver cost-effective CO_2 mitigation required by 2030, a third of which could be below USD 10 per tCO_2. – Land-based activities generate significant sustainable development co-benefits (P-26:b,R-80): – Economic: increased availability of wood and non-wood products including wood fuels and livestock feed; improved crop yields through soil erosion control, soil fertility improvement, groundwater recharge, water filtration, water quality); sustainable and equitable local employment and livelihoods. – Environmental: biodiversity conservation, reduced air pollution, reduced pressure on natural forests, flood control, and enhanced climate resilience. – Socio-cultural: space for socio-cultural events, nature contemplation, aesthetic appreciation, creativity and learning, recreation, and ecotourism. **Cons** – Removals stored in ecosystem reservoirs can be released back into the atmosphere, thus limiting their mitigation value.

40. Table 4 summarizes the mitigation potential of different activity types, which may also be a relevant factor while considering the eligibility of activity types.

Table 4. Mitigation potential of some removal activity implementations ($GtCO_2.yr^{-1}$ to 2050)

			Mitigation potential ($GtCO_2$ per year)		
Activity type	Status (TRL)	Cost (USD tCO_2^{-1})	IPCC AR6 WGIII (R-32)	Roe et al. (R-81)	Fuss et al. (R-85:a)
Land–based activities					
Afforestation/reforestation	8–9	0–240	0.5–10.1	0.5–10	0.5–3.6
Agroforestry	8–9	–	0.3–9.4	0.11–5.68	0.8–2.0
Improved forest management	8–9	–	0.1–2.1	0.44–2.1	0.1–1.5
Soil carbon sequestration	8–9	-45–100	0.6–9.4	0.38–9.5	2.0–5.0
Wetland restoration	8–9		0.5–2.1	0.35–1.6	0.6–2.2
Biochar	6–7	10–345	0.3–6.6	0.03–4.9	0.5–2.0
Engineering–based activities					
Direct air capture (DACCS)	6	100–300	5.0–40.0		0.5–5
Bioenergy with CCS (BECCS)	5–6	15–400	0.5–11.0	0.4–11	0.5–5
Enhanced weathering	3–4	50–200	2.0–4.0		2.0–4.0

41. The following observations can be made from Table 4:

(a) The IPCC and Roe et al. estimates of mitigation potential for land-based activities are similar. These estimates represent the technical potential, which is greater than the economic and sustainable (feasible) potentials. The sum of the mid-ranges of the two estimates is 21 and 18 GtCO2 per year respectively, while the sum of the first terciles (one-thirds) is 14 and 12 GtCO_2 per year respectively.

(b) The estimates of Fuss et al. represent the sustainable potential and the sum of the lower and the upper bounds yields 4.5 and 16.3 GtCO2 per year respectively.

(c) In comparison, a calculation based on an available land area of 500 Mha to 760 Mha (R-85) and a conservative sequestration rate of 10 tCO2/ha/year (R-86:a, R-46:b) gives estimated annual removals of 5.0 to 7.6 GtCO2 per year from afforestation/reforestation activities alone.

4. Quantification of mitigation value of removal activities

42. The mitigation value of a climate action can be defined in various ways with respect to different climate goals or climate policy objectives.

43. While removals cannot serve as a substitute for deep emissions reductions, these can still play multiple complementary roles in the mitigation strategies at global or national levels (R-32:h):

(a) Removals can further reduce net CO_2 or GHG emission levels in the near-term;

(b) Removals can counterbalance residual emissions from hard-to-transition sectors, such as CO_2 from industrial activities and long-distance transport (e.g., aviation, shipping), or methane and nitrous oxide from agriculture, and thus help reach net zero CO_2 or GHG emissions in the mid-term;

(c) Removals can achieve and sustain net-negative CO_2 or GHG emissions in the long-term, by deploying removal activities at levels exceeding annual residual CO_2 or GHG emissions.

4.1. Basic considerations

44. Limiting the global warming so as to stay below a temperature target (e.g. 1.5 ^{o}C) is the most commonly stated mitigation goal. This goal as stated says nothing about the time by when we will know that the goal has been achieved. However, in terms of practical value, reaching a warming of 1.5 ^{o}C within 20 years is different from reaching the same in 50 years. The performance in the first case will be worse than that in the second. In the second case, the rate of warming is slower and therefore some unknown tipping points may have been avoided, and more time may be available for adaptation of human and natural systems, and more cost-effective opportunities and technologies for decarbonization may have become available.

45. The role of removals in reducing near-term warming mentioned in paragraph 43(a) above helps delay the adverse effects of climate change by decreasing the rate of warming (R-37:b).

46. An emission pulse of CO_2 into the atmosphere causes marginal atmospheric warming over time. The time rate of marginal warming, at any point in time, is proportional to the fraction of CO_2 remaining in the atmosphere which declines over time in an exponential manner (as a sum of three exponential functions with different half-life periods). The fraction reduces to 0.38 over the first 100 years and thereafter declines slowly with an ever declining rate so that a fraction of 0.20 remains even after a thousand years (R-28:a).

47. To neutralize the effect of 1 tCO_2 emission, a removal of 1 tCO_2 must happen at the same time as the occurrence of the pulse of emission and the removed CO_2 must stay outside of the atmosphere indefinitely.

48. If ‘indefinitely’ is understood as an infinite period of time, delaying emissions will have no impact. In other words, the impact of 1 tCO_2 emitted today and that of 1 tCO_2 emitted 100 years from now will be the same. Conversely, emitting 1 tCO_2 today and removing the same 20 years later could be considered an activity without any atmospheric impact. But we know that this is not so. Although the net emission over the entire period is zero, clearly some damage has been done to the atmosphere (R-26:b).

49. Because we care for the time period, or the temporal space of our relevance, delaying emissions has the effect of pushing the emission impact partly out of our temporal space (apart from helping us gain strategic or manoeuvring space). That temporal space within which we aim to address the climate crisis is our time horizon for the purpose of climate policy and climate action. A time horizon of 100 years has been widely recognized and adopted under various policy instruments, standards, and regulations relating to climate policy, including carbon accounting (see paragraphs 73ff below).

4.2. Permanent versus temporary removals

50. Within the accounting framework based on a finite time horizon, removals have the value of cancelling emissions if they are permanent and of delaying emissions if they are temporary. Note that permanence here does not refer to the physical permanence of removals; rather, permanent means that the carbon removed is stored for as long as or longer than the time horizon.

51. The permanence of being chemically fixed (e.g. in rocks or in geological storage) is physical permanence (or physical irreversibility) and has no economic value beyond the time horizon. If we were to value carbon storage independently of any time horizon of interest, 1 tCO_2 removed and stored through carbon mineralization could be considered to have a value 100, 1000 or 10,000 times greater than the value of 1 tCO_2 removed and stored for 100 years. This leads us to an absurd conclusion that we know is not true.

52. The value of removals, and indeed of emissions reductions or any climate action, is relative to our climate goals and our time horizon. If our goal was to tackle the next ice age, we might have set a time horizon of 25,000 years. But given the situation we are in, a time horizon of 100 years might be more appropriate. Of course, one could argue that it should be 200 or even 300 years.

53. Some of the sources consulted suggest that, assessed on a physical science basis, temporary carbon removals do not provide any reduction in atmospheric warming (R-34:a). These arguments are however countered by other sources (R-22:a, R-15:a, R-31:a,).

54. Yet others suggest that temporary carbon storage may cause temporary reduction in warming, but these do not mitigate the atmospheric concentration of CO_2 over the long term. Since carbon removed is eventually re-emitted into the atmosphere, the final effect on the total carbon budget, considered over long term, is zero. (P-24:a; P-07:f; P-27:a).

55. Others use the economic rationale and conclude that value of temporary removals can be nearly equivalent to permanent sequestration if marginal damages remain constant or if there is a backstop technology that caps the abatement cost in the future (R-25:c). Others show that based on climate economics, periodically monitored temporary removals can provide the same value as permanent removals (R-05:a).

56. Others suggest that the cooling effectiveness of negative CO_2 emissions decreases if applied at higher atmospheric CO_2 concentrations (R-56:a). This seems to imply that the maximum of the available capacity of removals should be deployed now rather later from the perspective of physical effectiveness and consequently economic efficiency.

57. Additional research finds that successful carbon sequestration through nature-based climate solutions can have climate benefit even in the case where the carbon storage is temporary and the stored carbon is returned to the atmosphere later this century (R-39:a). Temporary removals can also help decrease the peak warming if implemented alongside reductions in fossil fuel emissions (R-39:b).

58. In addition to the mitigation value of temporary removals in terms of slowed atmospheric warming, temporary carbon removal provides multiple other benefits. In short, deployment of temporary carbon removals:

    (a) Moderates adverse impacts on biodiversity and allows ecosystems and human socioeconomic systems to adapt over a longer time;

    (b) Buys time for technological developments and economic capacity to address climate mitigation more effectively, and for economic opportunities including capital turnover;

    (c) Reduces risk of reaching tipping points such as release of carbon from permafrost or icesheet collapse by smoothing out the path of emissions and avoiding peaks;

    (d) Reduces long-term cumulative climate impacts;

    (e) Reduces costs of meeting temperature targets relative to late mitigation as a slower increase of the damage level lowers the present value of costs;

    (f) Bridges the progress toward the long-term climate target through achievement of near-term benefits.

4.3. Time preference and discounting

59. Another consideration in valuing temporary removals is based on the fact that early climate action is preferable to later climate action. This is called the time rate of preference, or time discount rate, and is commonly considered in economic decision making.

60. Using a discount rate of zero implies that a mitigation activity can be postponed indefinitely without any effect on the overall objective of mitigation.

61. To appreciate this, consider three hypothetical removal activities: activity participant A removes 1 tCO_2 today and promises to store it for 500 years; activity participant B removes 5 tCO_2 today and promises to store it for 100 years; and activity participant C removes 25 tCO_2 today and promises to store it for 20 years. Which offer has more value? We can intuitively appreciate that offer C perhaps provides the best value, but how do we calculate that? In the case of the 500-year offer, our intuitive response would be “Who has seen 500 years?”, and this is a time horizon question. Between 25 tonnes for 20 years and 5 tonnes for 100 years, we tend to think that the near-term offer of 25 tonnes is more attractive as it offers more value early on and has more certainty in time. The 100 years offer is long way into the future, and there are many more uncertainties over a 100-year period than over a 20-year period. And this is the issue of time preference that is used commonly as a basis of decision making, both by economists and by policy makers as well as by private individuals.

62. Based on the above considerations, there are two parameters involved in valuation of mitigation produced by removals: time horizon and time discount rate. The first is question of relevance of valuation, and the second is a question of economics of valuation. Mitigation, or avoided climate damage, is fundamentally an economic value, otherwise we would not care for this just as we do not care for the scientific fact that the Sun is gradually running out of hydrogen and will collapse in a few billion years, making the Earth uninhabitable.

63. Although the two parameters of time horizon and discount rate have different rationales, and both should be used in any decision making, the quantitative effect of the two can also be simulated with either of these: a time horizon with a zero discount rate and a discount rate applied over an indefinitely long time such as 1000 years can produce quantitatively similar, though not the same, results (P-18:a; P-21:a ; R-25:b). For example, using the formulation of discount rate only, a method called the social value of offsets method yields an estimate that 2.5 offsets each sequestering 1 tCO_2 for 50 years are equivalent to 1 tCO_2 of permanent removal (P-18:b).

64. The relationship between the effects of the two parameters can be seen from table 5 below. The numbers in the table represent tonnes of CO_2 needed to be removed in order to produce mitigation equivalent to 1 tCO_2 of permanent removal when the removals are stored over different periods of time. Note that here ‘permanent removal’ means removals that are stored over the time horizon. Note that apart from time discounting, the non-linearity of the decay of a CO_2 pulse over time has been taken into account while calculating these factors.

Table 5. Tonnes of CO_2 needed to produce mitigation equivalent to 1 tCO_2 permanent removal stored over different periods of time

		Discount rate									
Time horizon (years)	Storage period (years)	0%	1.00%	1.25%	1.50%	1.75%	2.00%	2.25%	2.50%	2.75%	3.00%
100	10	13.04	7.42	6.65	6.01	5.47	5.02	4.63	4.3	4.02	3.77
	20	6.43	3.88	3.52	3.22	2.96	2.75	2.57	2.41	2.28	2.16
	50	2.44	1.75	1.65	1.56	1.48	1.42	1.37	1.32	1.28	1.24
	75	1.52	1.27	1.23	1.2	1.17	1.14	1.12	1.1	1.08	1.07
	100	1	1	1	1	1	1	1	1	1	1
500	10	68.01	10.51	8.55	7.22	6.27	5.56	5.01	4.57	4.2	3.9
	20	33.94	5.52	4.54	3.88	3.41	3.05	2.78	2.56	2.38	2.24
	50	13.49	2.54	2.15	1.9	1.72	1.59	1.48	1.41	1.34	1.29
	75	8.94	1.89	1.64	1.48	1.37	1.29	1.23	1.18	1.15	1.12
	100	6.66	1.58	1.4	1.29	1.21	1.16	1.12	1.09	1.07	1.05
1000	10	123.27	10.55	8.56	7.22	6.27	5.56	5.01	4.57	4.2	3.9
	20	61.63	5.54	4.54	3.88	3.41	3.05	2.78	2.56	2.38	2.24
	50	24.64	2.55	2.16	1.9	1.72	1.59	1.48	1.41	1.34	1.29
	75	16.42	1.9	1.64	1.48	1.37	1.29	1.23	1.18	1.15	1.12
	100	12.31	1.58	1.4	1.29	1.21	1.16	1.12	1.09	1.07	1.05

65. Table 5 shows that using a discount rate of 1.75 per cent with a 100-year time horizon produces similar, though not the same, number of tonnes as using a discount rate of 2.0 per cent with an indefinite time horizon.

66. Conversely, a time horizon of 100 years can be considered to be equivalent to an implicit discount rate of 3.3 per cent applied to an indefinite time horizon (R-47:a)

67. However, explicit consideration and adoption of both the parameters would be a more rational, transparent, and scientific approach, and will result in more accurate values of the number of tonnes required to be stored at different durations (R-38:a).

68. Some sources have noted that time horizon is an important consideration independent of any discounting decision (R-23:a; R-36:a).

69. Some sources argue that discounting of physical quantities (e.g. the marginal warming or number of storms) located in the future is not justified (P-11:a). Others have argued that the discounting applies to these effects since these effects represent utility or disutility. These quantities are not something to which today's decision makers can be indifferent (R-36:b).

70. The terms time horizon, equivalence period (also called permanence period) and storage period have their precise meanings. Time horizon is the span of time over which assessment is conducted and it is the relevant temporal space for assessment. The equivalence period is the period of storage of removals such that the 1 tCO_2 of removal over this period produces mitigation value that is equivalent to the mitigation value of 1 tCO_2 of emission reduction, noting that this equivalence is not physical but an economic equivalence. Storage period is the actual storage period for given tonnes of removals. The equivalence period differs from the time horizon only if a non-zero discount rate is applied; with a zero rate of discount, the equivalence period is equal to the time horizon.

71. The word ‘permanence’ is also used in the sense of physical/chemical irreversibility of a mass of removals. The term permanence period in this context would imply the time of storage after which the necessary chemical reactions have occurred, and the mass of removals has become irreversible. This is a completely different meaning of the term permanence period from the meaning whereby permanence period is synonymous with equivalence period.

72. In this document the term permanence period has been used to imply the equivalence period.

4.4. Choice of time horizon

73. The time horizon of 100 years is a commonly accepted normative choice and is used in different climate policy instruments, such as follows:

    (a) Some of the carbon offset standards, in compliance as well as voluntary carbon markets, use 100 years as the permanence period for accounting and crediting of removals, notably: Canadian Greenhouse Gas Offset Credit System Regulations (R-09:a); Climate Action Reserve (R-40:a); Regulation for the California Cap on Greenhouse Gas Emissions and Market-Based Compliance Mechanisms (R-08:a); and Australian Government’s Carbon Credits (Carbon Farming Initiative) Act (R-04:a).

    (b) In some GHG LCA standards and bioenergy systems studies, a distinction is made between temporary carbon storage and permanent carbon storage based on the threshold storage period of 100 years, notably in the British Standards Institution's publicly available specification PAS 2050 (R-07:a); European Commission's Product Environmental Footprint (PEF) Guide (R-19:a) and I the International Life Cycle Data (ILCD) Handbook General guide for Life Cycle Assessment (R-18:a);

    (c) The IPCC methodologies for biochar in the 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories use the 100-years permanence threshold (R-29:a);

    (d) Other sources listed in this note also suggest using 100-year threshold to distinguish between permanent and temporary removals (P-22:b; P-06:a; P-01:a; R-44:b; R-25:a; R-55; R-21; R-47).

74. There are others who argue that a longer time horizon such as 200 or 300 years should be used. Proponents of geological storage argue that assuming a time horizon of 100 years is not fair to removals that are physically permanent. Since geological or geochemical storage of removals is very expensive to achieve, and provides mitigation beyond 100 years, these should be valued more.

75. However, as seen above, economic valuation means applying a non-zero discount rate which takes time value into consideration. Under this valuation, mitigation resulting from 300 years storage and 100 years storage turns out to be comparable.

76. The argument of expensive production of credits is an issue that needs perhaps to be posed elsewhere and not in the context of a market mechanism, since a market mechanism by its very nature is about leveraging low-cost mitigation opportunities and not about guaranteeing a price that is commensurate with the cost of production.

4.5. Choice of discount rate

77. A survey of climate policy literature reveals that an appropriate value of discount rate for assessment of climate action alternatives should be between 1.75 per cent and 2.25 per cent (P-19; R-15, R-16, R-17, R-18, R-19). Further details about choice of a discount rate are given in appendix D.

78. It might be useful to consider the practical impact of using different discount rates in the quantification of the mitigation value of temporary storage in real-life implementations of removal activities, as illustrated by the following examples.

Example 1. Existing compliance and voluntary carbon market mechanisms require a storage period varying from 30 years to 100 years in order to issue removal credits that are used for offsetting 1 tCO_2 of emissions. When assessed under a time horizon of 100 years, the different storage periods correspond to implicit discount rates as shown in the table 6 below.

Table 6. Implicit discount rate for different storage periods under a 100-year time horizon

Required storage period (years)	Implicit discount rate under a 100-year time horizon
30	11%
40	8%
50	6.25%
60	5%
80	3.25%
100	0%

79. It is seen from table 6 (extended version not shown here) that storage periods of 92 and 88 years correspond to discount rates of 1.75 per cent and 2.25 per cent respectively. Thus, the standards that require storage periods of less than 92 years are issuing credits that overestimate mitigation value assessed on a 100-year time horizon. Since guaranteeing or monitoring storage over a duration of 90 years is impractical, the only feasible approach to achieving this level of environmental integrity is to require multiple tonnes of removals for issuing a credit. For example, under a discount rate of 1.75 per cent, 5.48 tCO_2 and 2.14 tCO_2 should be required to earn a credit when removals are stored for 10 years and 30 years respectively.

Example 2. To assess the impact of the discount rate on real-life implementations of removal project activities, the table 7 below provides the average annual yield of credits per hectare that can be earned by medium-growth mixed-species watershed reforestation activity over a crediting period of 45 years (the maximum allowed under the Article 6.4 mechanism (see appendix E for the details).

Table 7. Average annual credits per hectare earned by a reforestation activity (A6.4ERs per hectare per year, averaged over the crediting period)

	Crediting period		
Discount rate	15 years	30 years	45 years
0%	0.54	1.46	2.14
1%	0.96	2.45	3.35
2%	1.43	3.50	4.51
3%	1.92	4.51	5.54
4%	2.40	5.43	6.40
5%	2.86	6.26	7.09

80. Table 7 shows that the use of discount rate of 2 per cent, which falls within the range of the most-recommended rates, results in 4.51 credits per hectare per year over the period of 45 years. The relevance of carbon credits in terms of financial incentive is significant if credits can be sold at a price of USD 20 to USD 50 (the upper limit will enable a larger number of activities than the lower one).

81. It is thus seen that not only are the discount rates between 1.75 per cent and 2.25 per cent justified by experts, the use of these discount rates with a 100-year time horizon also results in practically feasible carbon incentives. Explicit consideration of appropriate discount rate helps make a rational choice of the equivalence period while avoiding arbitrary choices. For example, if tonne-based credits are issued for a storage period of 45 years, this corresponds to an implicit discount rate of 7 per cent which is by far too high to be justified on sound economic rationales. Without using an assessment framework of time horizon and discount rate, we would have no way of judging whether a storage period of 45 years justified a tonne-based credit or not, and if not, how much could be the extent of overcrediting or undercrediting resulting therefrom.

4.6. Short-term versus long-term removals

82. In the case of temporary removals (i.e. removals that are stored for a shorter time than the permanence period), sometimes a further distinction is made between short-term and long-term removals.

83. As a general term, one can speak of shorter-term removals relative to longer-term removals in a given context, but what does the term ‘short-term’ mean by itself? Just as in the case of making a distinction between temporary and permanent removals based on a threshold value of storage period, a threshold value of the storage period (e.g. 10 years) has to be agreed upon to unambiguously differentiate between short-term removals and long-term removals.

84. However, there is no generally agreed threshold storage period that delineates short-term removals from long-term removals. It is also not clear on what basis, scientific or economic, can such a threshold be determined.

85. Even if such a threshold were to be agreed, for example by consensus, there needs to be a significance for such a threshold.

86. In general, shorter-term removals have less mitigation value than longer term removals. This is self-evident on a tonne-to-tonne comparison. However, the mitigation value of 2 tCO_2 of shorter-term removals could be equal to or greater than the mitigation value of 1 tCO_2 of longer-term removals (R-49:a) depending upon the precise storage period of each.

87. In terms of science, the mitigation value of different tonnes stored over different years can simply be represented by the product of the tonnes and the years. Such a two-dimensional measure has been called tonne-year (R-011:a) and can be seen as the basic unit of mitigation produced by removals because of its proportionality to the amount of marginal atmospheric warming avoided.

88. In the case of removals that are stored indefinitely, (e.g. fixed geochemically through mineralization), the storage period is undefined, but it is a common denominator across any such removals, and therefore cancels out. This makes a tonne-to-tonne comparison across such removals possible.

89. As far as physical science and economic science are concerned there is no unique threshold of storage period where any qualitative change, or a quantitative discontinuity, occurs in the value of temporary removals as the storage period changes. The value of a one-year removal is as valid as (though not equal to) the value of a 100-year removal. The only difference is the quantitative difference in the value of mitigation produced, which is best quantified through the atmospheric warming avoided.

90. However, there may be other considerations for distinguishing between short-term and long-term removal activities, such as follows:

(a) Minimum activity periods are desirable for delivering significant co-benefits associated with land-based activities, such as prevention of erosion and salinization, or protection of biodiversity. Such co-benefits are associated with long-term restoration of vegetation cover;

(b) Minimum (and maximum) activity periods are also relevant for the purpose of baseline setting, additionality demonstration and leakage potential in the context of a market mechanism (R-51:a,b; R-55:a-f; P-29:a).

91. These considerations of minimum period sometimes apply to the removal activities rather than to the period of storage which can be independent of the activity itself (e.g. a tree-planting activity in which the harvested biomass is used for production of biochar).

92. The duration over which removals are stored also depends upon the scale of aggregation or boundary of assessment. A series of short-term removals that are implemented sequentially, thus always storing an average amount of carbon over a longer period, can be categorized as short-term individually but long-term collectively.

93. For example, if a 10-year threshold for storage period is adopted to delineate short-term removals from long-term removals, in the case of a pulpwood plantation that has a harvesting cycle of 7 years and is managed over a multi-rotation period of 45 years, the average stock of removals across multiple harvest cycles can be categorized as long-term storage, even though the individual rotation cycle is short.

94. The same applies to the collective impact of a large number of removal activities registered under a mechanism. If activities are registering in and dropping out constantly, at any given point of time there always is a certain amount of carbon stored that is attributable to the mechanism. This would be a case of collective long-term storage caused by individual short-term activities.

4.7. Choice of a minimum activity period

95. In view of the above considerations, it might be desirable to adopt a minimum activity period to exclude activities with too short periods from being eligible under the mechanism. The rationales for such a choice would be as described in paragraph 90 above.

96. A period of 10 years has been commonly adopted as the minimum period for the purpose of accounting of removals (R-55:ai; R-01:a).

97. Other sources suggest that a minimum activity period ranging from 5 to 30 years should be adopted while recognizing that many of the co-benefits are generated only by multi decade land-based removal activities (R-55:aj; R-51:i).

5. Crediting removal activities under the mechanism

98. In the case of removals that are stored in physically irreversible reservoirs (e.g. through sub-surface rock mineralization) quantified net removals can be credited on the basis of 1 credit per tonne. The storage period is indefinite and hence common across all tonnes of such removals.

99. In case of removals that are stored in leaky reservoirs, such as the ecosystem carbon pools or durable wood carbon products, the storage by its very nature is temporary and hence crediting methods must take this aspect into account.

100. Different approaches to crediting temporary removals are described in the sub-sections 5.1 to 5.3 below.

5.1. Temporary crediting

101. Under this method, credits are issued that are temporary in nature and expire after a certain period of time from the date they are retired (i.e. are used for offsetting purposes). These credits do not offset emissions; rather, they offset temporary exceedances of the permitted emission limits. These credits are issued based on tonnes of removals, but the storage period of these tonnes must be at least equal to the number of years during which the emission limit is exceeded. This is best illustrated by the following example.

Example. Entity X is subject to an emissions cap of 100 tCO_2 for each five-year accounting period. At the end of the first accounting period, the entity's emissions are found to be 110 tCO_2, which is 10 tCO_2 above the cap. The entity has the option to purchase 10 temporary credits from a removal activity. These removals must have been be stored for at least five years. At the end of the second accounting period, the entity's emissions are found to be 100 tCO_2, equal to the cap for the second accounting period. However, they do not compensate for the 10 tCO_2 of excess emissions that had occurred during in the previous accounting period. The entity must purchase a further 10 temporary credits to cover the emissions exceedance during the second accounting period. In the third accounting period, the entity's emissions are found to be 90 tCO_2. At this point, the temporary exceedance has been covered by permanent emission reductions and the entity is no longer required to purchase temporary credits. For the removal activity, the possibility of obtaining further temporary credits remains open as long as the same removals continue to be stored.

102. This arrangement is similar to the temporary certified emission reductions (tCERs) issued under the clean development mechanism (CDM). There are, however, some important differences:

(a) In tCERs quantification, the actual storage period is not taken into account. If 100 tCO_2 of removals were achieved, irrespective of whether these were stored for 5 years or 10 years, the number of credits issued would be the same. From the atmospheric impact perspective, the period of storage matters as much as the number of tonnes. Thus, the environmental integrity is not the same across the different tCERs;

(b) The tCERs issued were not allowed to be carried forward across emission accounting periods (called commitment periods under the Kyoto Protocol). This restriction diminished the marketability of the credits since these could only be used within a narrow window of time.

5.2. Tonne-year crediting

103. As discussed in the previous section, the quantification of credits earned by a removal activity is carried out based on an agreed permanence period and the actual storage period of each tonne of removal.

104. In terms of issuance of the credits, however, the following two methods can be considered.

5.2.1. Ex post tonne-year crediting

105. Under this method, credits are issued based on the verified tonnes and the verified storage period of the tonnes. Since the tonnes as well as the storage period have been verified, ex post crediting eliminates the need for continued monitoring, reversal risk management, liability agreement and its enforcement. On the other hand, fewer credits get issued early in the crediting period. In the case of land-based removal activities, however, the annual rate of crediting accelerates over time since both the tonnes and the storage period increase with time (see figure E.1(b) in appendix E). The following example illustrates this method:

Example. A verification occurs in year 5 of an activity having a crediting period of 15 years. The number of credits is calculated based on the verified tonnes and the verified storage period applicable to each tonne, which results in 150 credits. Potentially, each tonne could have been stored for a different period and this is accounted for. As long as the tonnes are stored during the coming years, annual issuance of credits is possible since for a given number of tonnes, the years increase with time. If the crediting period gets successfully renewed, the annual credits stream continues to flow. Whenever additional tonnes are verified, the rate of annual crediting will increase accordingly.

5.2.2. Advance tonne-year crediting

106. Under this method, credits are issued based on the verified tonnes and a nominal (expected) storage period such as the period up to the end of the crediting period. Since

the credits are issued in expectation of achieving a certain storage period, there remains a need for continued monitoring, reversal risk management, liability agreement and its enforcement until the required storage period has been verified. The advantage of this method is that more credits get issued early in the crediting period. The following example illustrates this method:

Example. A verification occurs in year 5 of an activity having a crediting period of 15 years. The number of credits is calculated based on the verified tonnes and the expected storage period of 10 years, which results in 280 credits. If the crediting period is successfully renewed, the credits can be re-calculated for the same tonnes, based on a storage period of 25 years. The difference between the re-calculated number of credits and the previously issued credits is issued upon successful renewal. Whenever additional tonnes are verified, the number of credits can be recalculated, and the difference issued accordingly.

107. This crediting methods brings forward in time the availability of credits. On the other hand, the credits face the risk of reversal. To address the risk of reversals, the activity participants, and potentially the host Party, must enter into contractual agreement to ensure the continued storage of the verified tonnes of removals until the end of the required storage period. The mechanism for enforcing the contractual agreement and managing the risks of reversals can include a pooled buffer of credits backed up by host Party guarantee, or a pooled buffer of credits backed up by commercial insurance. The details of such a mechanism and its limitations are discussed in appendix G.

5.3. Tonne-based crediting

108. Under this method, credits are issued equal to the verified tonnes of removals in expectation of achieving the storage period equal to the permanence period. Under this method ex post crediting is not feasible since the credits issued at the end of the storage period would get issued too far into the future. For this reason, only advance crediting is feasible. This method has the advantage of issuing a large number of credits upfront. However, since the credits are issued in expectation of achieving a certain storage period, there remains a need for continued monitoring, reversal risk management, liability agreement and its enforcement until the required storage period has been verified. The mechanism for enforcing the contractual agreement and managing the risks of reversals can include pooled a buffer of credits backed up by host Party guarantee, or a pooled buffer of credits backed up by commercial insurance. The details of such a mechanism and its limitations are discussed in appendix G. The following example illustrates this method:

Example. A verification occurs in year 5 of an activity having a crediting period of 15 years. The number of credits is calculated to be equal to the verified tonnes which results in 12,500 credits. The storage of these tonnes will be periodically monitored until the year 105 (assuming a permanence period of 100 years). Activity participants can get additional tonnes verified when they wish, but the monitoring liability at each issuance will extend 100 years beyond the date of issuance. If the crediting period is renewed twice, and issuance happens in year 45, then the monitoring liability will extend to year 145.

5.4. Concerns raised about use of tonne-year accounting

109. From the preceding analysis it appears that tonne-year accounting, including tonne-year crediting, has several advantages over other methods of accounting and crediting. However, some of the inputs received from stakeholders have questioned the method of

tonne-year accounting whereas others have recommended the use of tonne-year accounting. Yet others have suggested that further consultation should be held on this issue before deciding about the use of tonne-year accounting.

110. Tables 8 and table 9 analyse the arguments and responses regarding the use of tonne-year accounting methods. Based on this analysis, Table 10 summarises the advantages and disadvantages of the different accounting methods discussed above. Table B.2 in appendix B provides a timeline of the consideration and adoption of tonne-year accounting in compliance and voluntary carbon markets and other climate change instruments.

Table 8. Arguments against use of tonne-year accounting and their response

Arguments against use of tonne-year accounting	Response to the arguments
(1) Temporary storage of carbon cannot provide the same benefits as emission reductions and therefore cannot be used to offset CO_2 emissions for the following reasons: a. The consequences of CO_2 emissions beyond an arbitrary time horizon are ignored which makes the approach physically inconsistent with the Paris Agreement's goal of temperature stabilization (P-11:e, P-24b, P-11:b; P-29:d); b. The tonne-year accounting approach is not compatible with the reality of a limited remaining global carbon budget. From a carbon budget perspective storing carbon for 1 year makes no difference whatsoever (R-55:y; P-07:f; P-11:c; R-55:ac); c. Temporarily storing carbon reduces the cumulative amount of energy trapped by the Earth's atmosphere, but that does not make it identical to either avoiding emissions or permanently storing CO_2 (R-11:a; P-07:g); d. Creating this equivalence will open the door to creative accounting in carbon markets (P-07:h); e. The tonne-year approach is myopic because all the benefits will accrue in the short term while the costs will materialize in the long term (R-55:aa);	(1) Most of these objections relate to temporary carbon storage in general and not to the specific case of tonne-year accounting. For example, argument (a) notes that the consequences of CO_2 emissions beyond an arbitrary time horizon are ignored. In a tonne-based accounting method applying a fixed permanence period, the consequences beyond the adopted permanence period are also ignored. (2) The following responses to the arguments can be found in other sources: a. Use of a time horizon provides a framework to quantify the value of climate-relevant policies and actions. It is not just the physical effects that matter but their economic impact in a given policy context should guide decision making. Temporary removals are a strategic tool that can be leveraged to navigate the path to the goal of CO_2 stabilization while minimizing the damages and risks along the way. The benefits generally agreed to be accruing from temporary removals are listed under paragraph 58; b. Temporary removals help in staying within the carbon budget longer, even if these do not help to indefinitely postpone the event of using up the budget. The assertion that "storing carbon for 1 year makes no difference whatsoever" is not logical, as can be seen from the following scenario: An entity emits on 1 tCO_2 on 1 January every year and removes on 1 tCO_2 on 31 December of the year for ever. Will they have no effect on the atmosphere whatsoever? Evidently their activity will have as much impact on the atmosphere as 1 tCO_2 of permanent emission; c. The question, in unambiguous terms, is this: Can N tCO_2 of removals stored for 10 years produce the benefit to counteract the impact of 1 tCO_2 emission? The answer evidently is yes. Only the number N needs to be determined on some scientific and economic basis. That is what tonne-year accounting does; d. On the contrary, the explicit approach of tonne-year accounting based on science and economics helps keep away from creative accounting such as assuming that 1 tCO_2 of 30-year or 40-year removals can offset 1 tCO_2 of emissions. When

Arguments against use of tonne-year accounting	Response to the arguments
f. Actors will benefit financially today (from not having to reduce the tonne that is being offset, and from selling a carbon credit and society will benefit from lower climate impacts today. It is society in the future that will suffer from increased climate impacts. (R-55:ab).	assessed under the tonne-year method with a rational choice of parameters, one concludes that any fixed storage shorter than 80 to 100 years does not have the required environmental integrity to justify offsetting of emissions (see paragraph 79); e. Taking out a financial loan can appear to be myopic. Consumption in the short term is preferred in lieu of repayment liabilities in the long term. Yet a financial loan is not a zero-sum game, it has a value: it helps navigate an urgency. By the logic suggested, all form of financing would be myopic, but we know that that is not the case; f. It is not about enjoying benefits; it is about taking urgent action to save a house from collapsing so that future generations can still have the house intact or at least minimally damaged. Present generation should recruit all means available, even temporary removals, to safely navigate the path so that a relatively safer planet can be handed over to the future generations.
(2) Equivalence of removals to emission reductions is based on arbitrary choices: a. The tonne-year concept measures climate impacts over a predetermined time horizon, the choice of which remains largely a policy decision rather than a scientific one (R-52:b); b. The arguments for choosing a time horizon are conceptually flawed. Suggesting that the time horizon could be linked to expectations about how long it will take to decarbonize the global economy is far too simplistic. If we expect the world to decarbonize by 2060, it does not follow that we no longer need to be concerned about reversals of stored carbon after that date (P-24:c);	(3) The equivalences are based on scientific and economic principles: a. Relevant policy choices have to be made in any decision-making context except the most trivial ones. A fixed period temporary removal such as 30-year or 50-year removals under tonne-based accounting also assumes a predetermined horizon that is normatively adopted; b. It is not that we are not concerned about emissions after 2060; it is that emission reduction after 2060 will cost less than today. Secondly, the reversals will not happen all together after 2060; rather there will be a statistical distribution of activities that will gradually trail off as the carbon price declines. Many of the land-use changes will get locked in economically and will never be reversed. However, the objection being raised does not relate to tonne-year accounting alone; it also relates to the case of tonne-based crediting where the required storage period does not extend beyond 2060;

Arguments against use of tonne-year accounting	Response to the arguments
c. The tonne-year method rests on enormous assumptions about the atmospheric lifetime of carbon dioxide (R-55:v); d. The conversion rate is highly sensitive to policy choices. The validity of the tonne-year approach is highly dependent upon the specific assessment method and assumptions therein (e.g., equivalence timeframes, discount rates, asymptotic decay of CO_2, etc.). These concerns are not trivial, as recent work shows that the choice of these variables can affect the crediting outcomes by as much as 10-fold. (P-29b).	c. The CO_2 diffusion model (the Bern-CC model) has been in use for a very long time by now. Different versions of the Bern-CC model only lead to a marginal change in the equivalence period or in the intermediate conversion rates. The IPCC has been using these models in all of its the IAM assessments. Also, the model does not make a key difference since if we do not know how removals decay, we also do not know how emissions decay. d. The Lashoff method is a widely used approach to equivalence time calculation. The parameter choices of time horizon and discount rate are objectively determined on the considerations of policy relevance and economic valuation of alternatives. There is no ambiguity or leeway beyond the choice of these parameters. As indicated in paragraph 79, the equivalence time comes out to be between 80 and 100 years. This does not support the observation that there could be a 10-fold difference in outcomes.
(3) Tonne-year accounting incentivizes short-term storage: a. Under tonne-year accounting the payments per tonne would in decline over time, reducing the incentive to avoid reversals (P-24:h); b. Tonne-year approaches inherently fail to internalize maintenance costs since reservoir owners can essentially “walk away” from a mitigation activity at any time, without any penalty for ensuing reversals (P-24:j); **c.** As it can generate a significant amount of credits on large areas during a period of one or two years after which the reservoirs are destroyed, tonne-year credits should only be issued after a minimum period of five years (R-55:a-g).	(3) Tonne-year accounting does not require short-term activities; it allows flexibility in the duration of activities. Adopting tonne-year accounting or tonne-year crediting does not preclude the prescription of a minimum activity period. a. Reversals cannot occur under tonne-year crediting if ex post (i.e. incremental) crediting is followed. Where credits are issued in advance of verified storage, the number of annual credits issued increases over time because the two variables, tonnes and years, grow together in most tree-planting activities (see figure E.1(b) in appendix E). Because of this, the activity participants have a strong incentive to continue the activity; b. The risk of “walking away” applies to advance tonne-year crediting and tonne-based crediting. Ex post tonne-year crediting does not have this risk since both the tonnes and the storage are verified before issuance of credits. Where advance tonne-year crediting happens, the activity participants are required to enter into contractual agreement to contribute to the buffer and to assume the liability for compensation for reversals not covered by the buffer;

Arguments against use of tonne-year accounting	Response to the arguments
	c. Generation of a significant amount of credits on large areas during a period of one or two years is not possible where credits are issued on an ex post basis, since in two years no significant tonnes of removals can be achieved and the number of credits would be a small fraction of those tonnes. Where ex-ante issuance happens, the activity participants have to enter into contractual agreements for the liability of compensation for reversals and also contribute to the buffer. Nevertheless, it is also possible to enforce a minimum period of time before ex-ante credits can be issued.
(4) Using tonne-year accounting will lead to too many credits: Under tonne-year accounting there is a risk that a large number of temporary credits could suddenly enter the market, lowering prices for existing developers who have committed to traditional long-term commitments (R-51:f; R-55:ag).	(4) There is certainly no justification to suggest that using tonne-year accounting will lead to too many credits in the market. On the contrary, the main concern commonly expressed about the use of tonne-year accounting is that there will be too few credits to incentivize sufficient number of activities. (R-35:b ; R-54:a). Tonne-year accounting based on an 80 to 100-year permanence period and ex post crediting has the highest stringent environmental integrity. Since there is trade-off between the stringency of environmental integrity and number of credits produced, the logical expectation would be to have fewer credits issued. On the other hand, it is the tonne-based accounting method that leads to a huge number of credits (R-49:b).
(5) Alternative discount-based methods are better suited: We are very sceptical of the tonne-year approach which generates equivalence of permanent and temporary emissions reductions in a manner that ignores a) the latest climate science; b) the welfare economic aspects of the problem of temporary reductions; and c) the risks associated with temporary projects. In the attached paper we offer a useful alternative that addresses these shortcomings. While it could be said that our approach introduces controversial issues concerning discount rates, the previous contributions which focus on the physical	(5) The alternative proposed called social value of offsets is based on a temporary carbon valuation using discounting only. As noted in paragraph 63, an indefinite time horizon can be assumed if non-zero discount is used, and still quantitively similar valuation of temporary carbon can be arrived at. According to this alternative proposal based on the social cost of carbon, 125-tonne-years of removal is considered equivalent to 1 tCO_2eq of emission reduction. Quantitively it is similar to the tonne-year method based on 100-year time horizon and zero discount rate which finds that 134 to 100 tonne-years of removals is equivalent to 1 tCO_2eq of emission reduction. On practical application, the outcomes are comparable. However, this proposal incorporates uncertainties in additionality and leakage into the model used, which under the Article 6.4 mechanism

Arguments against use of tonne-year accounting	Response to the arguments
measures of carbon make implicit discounting assumptions and assumptions about damages (P-18:c).	will be addressed separately and explicitly based on activity design and the methodology applied.
(6) The alternative method of tonne-based accounting is better: a. Rather than coming up with overly sophisticated discounting techniques (tonne-year or tonne-based crediting options), we believe that buffers have worked well in other programmes and initiatives dealing with permanence of removals (P-02:b); b. The tonne-based crediting approach in that context would be more straightforward where credits issued are equal to the tonnes of verified removals. It is more in line with the current practices in the voluntary markets (P-20:d); c. The alternative tonne-based methods are not premised on the idea of equating arbitrarily short carbon storage periods with permanent mitigation. Instead, credits are issued only if there are credible guarantees to compensate for reversals if they occur at any point during the permanence period (P-24:i).	(6) The basis of the observation that tonne-based crediting has performed well is not clear. If fungible credits are issued on the basis of a storage period of 30 or 40 years, the environmental integrity is certainly not the same as when the credits are issued on the basis of a storage period of 80 to 100 years. In the case of mechanisms issuing tonne-based credits based on a 100-year permanence period, there remains considerable uncertainty about the reality of these credits since their future is fraught with so many uncertainties (see below). There already is wide criticism of the existing voluntary carbon market mechanisms, including those using a 100-year permanence period, questioning the environmental value of the credits generated (B-05, B-19, R-49). To illustrate this, consider the following example: Imagine that 1 MtCO2 of removals are verified today, which will be issued as ex post credits after their storage period of 100 years has been verified. The activity participants are looking for forward contracts to sell their credits. Will there be enough market participants willing to enter into such forward contracts, even at a small fraction of the current credit price? Most likely not. The buyers, who want to use credits to offset their emissions, face complete uncertainty as to whether they will need any credits in 100 years' time or not, and whether their business will still exist by then. Given this, it is clear that the market will not value credits that will be realized far into the future. Should a regulator issue credits in advance based on a storage period to be verified 100 years later? Some sources suggest that regulatory offset programmes should not allow forward credits, although they may allow forward sales [R-60:a]. Others recommend that all credits should be issued with ex post verification, including verification of the storage period [R-51:l]. While some argue that advance crediting helps to provide up-front funding to activity participants, others suggest that switching to up-front crediting to facilitate funding is not recommended [R-61:a]. It is not the role of the regulator to play

Arguments against use of tonne-year accounting	Response to the arguments
	the market maker. The role of the regulator is to ensure the environmental integrity of the credits and operate the mechanism without unnecessary barriers and transaction costs. If tonne-based crediting is to be used under the Article 6.4 mechanism, the following scenario emerges: Assuming a permanence period of 80 to 100 years and a maximum crediting period length of 45 years (which is already decided under the RMPs), the period over which liabilities for compensation of reversals will have to be enforced will be from 125 to 145 years. Over such a long period, the credibility and robustness of environmental integrity of the credits faces numerous challenges for the following reasons: (i) In an international setting, entities may be unwilling or unable to enter into contractual obligations for such long durations; (ii) Entities, including activity participants, emitting entities that retire credits, and the regulating governance institutions, may not last that long; in such a case, the required compensation of reversals will never happen; (iii) Buffers may be ineffective against intentional reversals, which are inherently difficult to model at a system level; (iv) The intentional reversal penalties, if used, would implicitly recognize that real-world factors may induce project attrition during the 145-year monitoring period, raising questions about the validity of baselines, and increasing landowners’ costs of participation; (v) Predicting the growth and timber harvests over a 100-year period is highly uncertain, compromising the robustness of the baseline; (vi) It is difficult to distinguish between a project that would have happened without the offset programme from one that is motivated; (vii) Commercial insurance is not well-suited to cover against these intentional actions, and a system-wide buffer could put the entire system at risk if the prevalence of intentional reversals is high relative to the size of the buffer.

Arguments against use of tonne-year accounting	Response to the arguments
	In a sovereign jurisdiction it is easier to enforce legal contracts. In an international setting it is not clear how legal contracts, which impact successive generations, can be enforced and under which laws.

Table 9. Arguments for use of tonne-year accounting and its framing

Advantages of using tonne-year accounting	Conditions and limitations
Tonne-year accounting has the following advantages: a. Avoids the risk of carbon credits being issued before their storage period has been verified (P-21:b); b. Credits the climate benefit that has already occurred on an annual basis and is therefore irreversible (R-55:p); c. Ensures the environmental integrity of the credits relative to the adopted permanence period, whether it is 100 years or 300 years; d. Allows for flexibility in activities, thereby broadening potential stakeholder participation (P-21:b); e. Pays for climate action today, rather than paying for carbon removal decades from now (P-21:b); f. Adds transparency to credits of different durations and time horizons observed under different standards and different activities under a given standard; (R-55:t);	No sources contradict the benefits of tonne-year accounting listed in the first column. However, see Table 8 for objections to the use of tonne-year accounting, including the scientific validity of the value of temporary carbon storage. Regarding the details and design of a tonne-year crediting system, the following views are found in the sources: (i) Only ex post crediting should be used (R-35:a); (ii) A minimum storage period should be made mandatory; suggested minimum periods range from 5 to 30 years; (iii) Interpolation of the conversion ratio should be based on cumulative radiative forcing rather than linear proportionality to the storage period; (iv) A time horizon of 100 years should be used without applying discounting; this implies a permanence period of 100 years. However, others suggest that a conversion ratio of 50:1 would be more pragmatic and economically viable. Elsewhere it is suggested that the issue of economic viability should not be addressed by weakening the environmental integrity of offsets (R-49:c). Instead, it should be addressed from the perspective of the price of credits. If the price of credits is too low for certain types of activities, this means that the carbon market is not yet ready to take advantage of these types of activities.

Advantages of using tonne-year accounting	**Conditions and limitations**
g. Avoids the need to commit land to particular land uses for long periods, providing flexibility that is valuable, especially for small-scale landowners (R-14:a); h. Avoids long-term commitments as a means of justifying loans granted in advance (i.e. before the required storage period has been verified); i. Allows credits to be issued as the project progresses, rather than waiting until the end of the project or crediting in advance against outstanding liabilities (R-21:a); j. Provides a means of avoiding sovereignty concerns in the countries hosting the projects; k. Is the most consistent method of accounting for temporary carbon storage activities across all project timelines, project type, and project configurations [R-23:b]. l. Can bring larger areas under the mechanism by enabling greater participation by local communities, thus increasing overall mitigation as well as the proportion of benefits accruing to local communities [R-14:b]. **m.** Encourages long term carbon storage by rewarding landholders for each year of carbon storage [R-63:a, R-49:d].	(v) Due consideration should be given to the implications of tonne-year accounting for baseline, additionality, and leakage provisions in the respective methodologies. Others suggest that further details should be provided and further public consultation on tonne-year accounting should take place before a decision is taken to adopt this approach: (P:51:c; P-29:g): (i) Policy choices such as time horizon, discount rate, calculation models (linear vs. radiative forcing based) and minimum storage period should be carefully decided; (ii) Compatibility of tonne-year crediting with nationally determined contribution (NDC) accounting and related adjustments should be considered (P-13:b, P-20:c); (iii) Review, comment, and "road-testing" should be undertaken before the tonne-year approach is prescribed as an approved method under Article 6.4 (P-29:c); (iv) Practical implementation details, such as how to apply this approach over multiple verifications where each subsequent verification extends the permanence period of the removals achieved, should be worked out (P-20:b).

Table 10. Summary of crediting methods and their pros and cons

Description of crediting method	Pros and cons
Temporary crediting Credits are issued that are temporary in nature and expire after a certain period of time from the date of retirement. These credits do not offset emissions but compensate for temporary exceedances of permitted emission levels. These credits are issued based on tonnes of removals, but the storage period of these tonnes must be at least equal to the number of years during which the emission limit is exceeded (see paragraph 101).	**Pros** – Provides a consistent way to address the non-permanence risk that follows the stock-change approach used in GHG inventories. – Eliminates the need to create mechanisms to address non-permanence risk. – Provides flexibility and options for host countries that do not wish to commit to maintaining areas under fixed land use in perpetuity. **Cons** – The credits are not fungible with A6.4ERs and are not generally tradable on the market. They can only be used by countries or entities to cover their shortfall in meeting emissions targets in a specific accounting period. – When the credits expire, the buyers must replace them with other (usually permanent) credits. This obligation makes the credits less attractive to buyers. With insufficient demand for credits, participation in the mechanism may be limited. – Expiring credits may be priced too low by the market relative to the transaction costs, making the credits unattractive to activity participants. – Special provisions for issuance, tracking, cancellation, and replacement of the credits add complexity to the regulatory rules and registry operation without adding commensurate value.
Ex post tonne-year crediting Credits are issued based on the verified tonnes and the verified storage period of the tonnes (see paragraph 105).	**Pros** – Credits are issued after verification of tonnes and their storage period and are therefore based on actual mitigation. – Credits are only issued for mitigation achieved within the crediting period. – Credits represent the net present value of the mitigation achieved.

	– As both the tonnes and their storage period have been verified, there is no need for ongoing monitoring, reversal risk management, and liability agreements for compensation of reversals. – Encourages long term carbon storage by rewarding landholders for each year of carbon storage. – Broad participation in the mechanism can be ensured because of the flexibility in the types of activities, their duration, scale, and participants. – Provides flexibility and options for host countries that do not wish to commit to maintaining land areas under fixed land– use for very long periods of time **Cons** – Fewer credits get issued early in the crediting period. – Allows short-term land-based activities that do not provide the same co-benefits as long-term activities (e.g. preventing erosion and salinisation or protecting biodiversity).
Tonne-based crediting Credits are issued for the verified tonnes of removals with the expectation that the storage period of these tonnes will be equal to the permanence period (e.g. 100 years). Under this method, ex post crediting is not feasible because ex post credits can only be issued 100 years after the verification of the tonnes. For this reason, only advance crediting is feasible (see paragraph 108).	**Pros** – More credits get issued early in the crediting period. **Cons** – The credits issued are provisional, not real, as the storage period for which the credits are issued remains to be verified. – Much of the storage period for which credits are issued is not within the crediting period. For example, if tonnes are verified in year 45, credits are issued for the storage period from year 45 to year 145, all of which is outside the crediting period. – As credits are issued in advance of verified storage, the future uncertainty of storage, as well as the present value of storage occurring far in the future, makes the value of the credits questionable (for details, see table 8, row 6). – The environmental integrity of these credits is unlikely to be robust as both baseline and additionality are difficult to assess over such a long period of time.

	– Activity participants are required to monitor the storage of removals over an unsustainably long period of time. For individuals, this represents an intergenerational liability. For companies, there is a risk of going out of business or going bankrupt over the period of 100 years. – In an international setting, entities may be unwilling or unable to enter into contractual obligations for such long periods. This can limit participation in the mechanism. – Entities, including activity participants, emitting entities that retire credits, and the regulatory governance institutions, may not last that long. – The liability for compensation for reversals must be assumed by the host Party. If fewer host Parties are willing or able to do so, participation in the mechanism may be limited. – The alternative to host party liability is commercial insurance, which is not well suited to cover risks of intentional reversals. It is not clear whether such insurance is available in most host Parties and whether insurance companies can operate for 100 years without going out of business. – The credits deposited in the buffer are not real, but provisional, and the loss of the underlying tonnes simultaneously invalidates the credits retired and the credits in the buffer. Credits that are not real cannot be used as an effective collateral to cover the risk of reversals. – In a sovereign jurisdiction, it may be easier to enforce legally binding contracts. In an international setting, it is not clear how such contracts can be enforced and under which laws.

6. Methodological issues related to land-based removal activities

111. Land-based activities currently account for most removals and are expected to be the main driver of removals in the short term (i.e. up to 2030) and possibly even up to 2050.

112. Table 11 lists examples of common implementations of land-based removal activities that are currently in place. The categorization of implementations is based on two facets: the biophysical characteristics of the vegetation and the underlying dominant management objective types. It should be noted that a conservation activity may also result in some economic products, and a production activity may also provide environmental and conservation services, but the main objective of an activity is different from its co-benefits.

Table 11. Categorization with examples of land-based removal activities

Activity type based on the biophysical characteristics of vegetation	Activity type by dominant management objective: Conservation	Activity type by dominant management objective: Production
Afforestation/reforestation	– Reforestation of watersheds – Restoration of protected/ designated forests – Restoration of biodiversity areas/protected areas	– Timber plantations – Pulpwood plantations – Horticultural plantations – Energy plantations
Revegetation	– Sand dune stabilization – Reclamation of saline/alkaline soils – Revegetation of watersheds	– Energy plantations (perennial non-tree vegetation) – Cultivation of perennial crops – Cultivation of medicinal plants
Tree planting	– Urban forestry – Agroforestry – Shelterbelts	– Agrisilvipastoral systems – Fuelwood woodlots – Small timber woodlots
Improved forest management	– Restocking native species by planting – Assisted natural regeneration	– Rotation age management – Reduced impact logging – Cleaning/pruning/thinning treatments
Wetland management	– Rewetting wetlands – Restoring mangrove habitats	-
Soil organic carbon enhancement	– Conservation tillage – Fallows	– Soil productivity improvement

113. The following sections provide information on the various issues listed in paragraph 4 that need to be addressed for land-based activities. The types of activities based on engineering methods are dealt with in section 7.

6.1. Monitoring

114. Monitoring of all removal activities is based on the quantification of removal stocks. All stocks are expressed in units of tCO_2eq.

6.1.1. Quantification of carbon stocks

115. For land-based removals, quantification of removals is based on an inventory of carbon stocks using sampling, field measurements and modelling. Remote sensing data can be used in combination with field measurements for cost-effective monitoring. Estimates at successive points in time are used to calculate changes in carbon stocks.

116. Estimates of carbon stocks are based on measurements of vegetation combined with biomass allometry models that enable the conversion of measurements, such as tree diameter and height, to biomass.

117. Remote sensing data can be used in combination with field measurements to reduce the cost of monitoring.

118. Conservative default factors can be used if activity participants do not wish to measure some carbon pools to reduce monitoring costs.

119. The accuracy of measurements can be ensured by establishing specifications for data collection methods in advance, such as appropriate sampling methods, calibration of equipment, validation of models and specifications for the use of remote sensing data.

120. Estimates of carbon stocks should include the associated uncertainties and the uncertainties should remain within the prescribed limits. Where uncertainties exceed the prescribed limits, the estimates should be adjusted to make them conservative, unless the activity participants wish to undertake additional measurements to reduce the uncertainties.

121. Where appropriate, use of digital tools should be encouraged to improve the accuracy and reduce the cost of monitoring.

6.1.2. Frequency of monitoring

122. First inventory of the carbon stocks is carried out when sufficient carbon stocks have been accumulated to justify the cost of inventory.

123. Subsequent inventories are carried out as follows:

    (a) If the ex post crediting method is used, incremental carbon stocks should justify the cost of inventory;

    (b) If advance crediting is used, the interval between the two successive inventories should not exceed the prescribed maximum period.

6.2. Reporting

124. Verified monitoring reports form the basis for issuance of credits.

125. Monitoring reports summarize the results of monitoring. Monitoring reports are submitted to a designated operational entity (DOE), which verifies the accuracy of the monitoring results.

126. Monitoring reports should be submitted as soon as possible after the inventorying of the carbon stocks to allow the DOE to carry out on-site spot checks if necessary.

127. Monitoring reports should include all relevant data. If the data is too voluminous, a summary of the data may be included and a link to the full data set should be provided, except for any confidential data.

128. In addition to carbon inventory data, monitoring reports should include records of events and incidents, such as fires, pest outbreaks, harvests, leaks and seepage, that may have had a significant impact on the carbon stocks during the period covered by the report.

129. Simplified monitoring and reporting may be allowed where the purpose of reporting is to demonstrate the continued storage of the removals rather than to verify additional tonnes of removals.[1]

130. Monitoring reports should include information on:

(a) How the negative environmental and socio-economic impacts have been assessed and addressed;[2]

(b) How the activity contributes to sustainable development in the host Party.[3]

131. In the case of advance crediting, periodic monitoring reports should be submitted even after the end of the crediting period until the required storage of all the tonnes for which credits have been issued has been verified.

6.3. Accounting of removals

132. Net removals achieved by a removal activity are equal to the total removals minus the baseline removals, minus the activity emissions, minus the leakage emissions.

133. In the case of tonne-year accounting, activity emissions and leakage emissions cannot be subtracted directly from the tonnes of removals; instead, these must be accounted for on a tonne-year basis. For example, if 1 tCO_2 emission occurred during a monitoring period, 100 tonne-years should be deducted from the tonne-years of removals achieved during that monitoring period (assuming a permanence period of 100 years).

134. The cost of accounting for emissions and removals can be reduced by avoiding the need to account for emissions that are only a theoretical possibility and can only be insignificant (P-20). Instead of specifying a quantitative threshold for defining insignificant emissions, it is possible to allow sources to be excluded from accounting on this basis. This is in addition to excluding GHG sources where the impact of such exclusion is likely to be in favour of the atmosphere (the conservative exclusion of carbon pools). However, where there are no monitoring costs and a conservative estimate of the emissions can be made, such emissions should not be excluded just because these are small.

135. If GHG emissions occur in the baseline of the activity and the implementation of the activity results in a reduction of those emissions, the emission reductions are not accounted for as credits under the removal activity. Such emission reductions may be

[1] For example, see section 6.4 Demonstration of “no-decrease” in the CDM AR-TOOL14 “Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities”.

[2] See RMPs, paragraph 24(x).

[3] See, RMPs, paragraph 24(xi).

claimed as credits under an emission reduction activity registered under the mechanism according to the applicable rules.

136. Comprehensive accounting of removals and emissions from activities requires the use of LCA, where appropriate (P-25; P-07; P-16; P-22; P-14; P-05). The accounting burden can be reduced by using known standardized emission factors for the products used (e.g. the LCA emissions associated with the production of one tonne of a particular type of fertilizer may be known) (P-16). In addition, if a piece of equipment or machinery is purchased exclusively for the implementation of the activity (e.g. a tractor), the LCA emissions, including embodied emissions, should be included. If the equipment was already in use in the baseline, this cancels out and this fact needs to be taken into consideration.

6.3.1. Baselines

137. Baseline scenarios are the business-as-usual (BAU) scenarios against which changes in carbon stocks and removals are measured.

138. Three types of business-as-usual (BAU) scenarios are possible (see Figure 1):

(a) The BAU scenario in which there are significant carbon stocks that are increasing over time. In this case, both the initial carbon stocks and the BAU removals are non-zero;

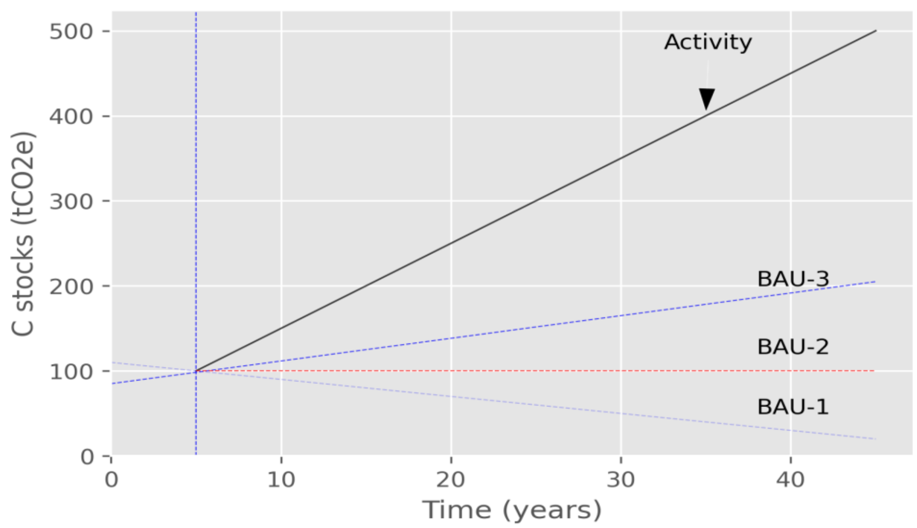
(b) The BAU scenario where there are significant carbon stocks that are decreasing over time. In this case, the initial carbon stocks are not zero, but the BAU removals are zero;

(c) The BAU scenario where there are no significant carbon stocks. In this case, both the initial carbon stocks and the BAU removals are zero.

6.3.1.1. Determining the baseline scenario

139. The baseline scenario of a removal activity should be determined by applying one of the three approaches provided in paragraph 36 of the RMPs.

Figure 1. Types of business-as-usual scenarios in a removal activity



140. The host Party may, at its discretion, set a more ambitious level.

141. Baseline scenarios must be consistent with applicable legal and regulatory requirements.

142. Baselines may be established at the national, regional or activity level. National or regional baselines, also known as standardized baselines or jurisdictional baselines, should be developed from analyses of national and/or regional trends and practices and could be based on a combination of measurements of control scenarios, models, and published data sets.

143. Activity-specific baseline takes into account the specificities of carbon stocks as well as other local conditions and is likely to result in a more accurate prediction of changes in carbon stocks.

144. On the other hand, activity-specific baselines run the risk of the activity participants choosing scenarios that maximize their perceived benefits.

145. Within a crediting period, baselines could be set to be fixed or updated periodically. In the case of a renewable crediting period, baselines are assessed at the beginning of each renewal period and updated as appropriate.

6.3.1.2. Quantification of baselines

146. Baselines are quantified as ex-ante estimates of carbon stocks and changes in carbon stocks over time. These estimates remain valid throughout the crediting period. Methods for estimating baselines could be the same as those used for monitoring (see section 4.1.1 above). Simplified conservative default-based methods can be used if the baseline carbon stocks are relatively small (e.g. less than 10 per cent of the carbon stocks expected to be generated by the activity).[4]

147. Where significant removals are likely to occur under the baseline scenario, baselines may also be estimated ex post using control areas where the baseline activities are expected to continue, unaffected by the removal activity.

148. The quantitative estimation of baselines should consider factors that are likely to affect the carbon stocks or changes in carbon stocks, including factors such as changes in legislation, changes in market prices, and changes in environmental awareness, etc.

6.3.1.3. Periodic re-validation of the baseline

149. The baseline is set at the time of validation and registration of the activity and reassessed at the time of renewal of the crediting period.

[4] Baselines for some of the land-based removal activities are not as large as in emission reduction (ER) projects. In an ER project, e.g. a renewable energy activity, more than 90 per cent of emissions could be in the baseline; in an afforestation and reforestation (A/R) project, the baseline typically has less than 10% as much carbon stocks as are expected to be achieved by the activity. An uncertainty of 10 per cent in the baseline estimation actually corresponds to 1 per cent uncertainty in the estimation of credits. Exceptions to this pattern are improved forest management and soil carbon sequestration activities, wherein the baseline stocks could be comparable to the activity stocks.

6.3.2. Activity boundary

150. The activity boundary for the purpose of accounting of net removals achieved by a removal activity consists of the physical boundary (e.g. carbon pools, equipment and materials, emission sources associated with the activity) and the GHG boundary.

151. The activity boundary may be optionally simplified by excluding certain sources, sinks and GHGs if such exclusion leads to conservative estimation of the net removals.

6.3.3. Additionality

152. The removals achieved by an activity must be additional to the removals that would occur in the baseline.

6.3.3.1. Types of additionality

153. Financial additionality means that the removal activity or its result would not have been realised without the income from the carbon credits earned by it.

154. Regulatory additionality means that the mandatory requirements, such as laws, regulations, industry standards and/or enforced policies, and unconditional NDC commitments, would by themselves not be sufficient to ensure the realisation of the activity or its results. The activity must achieve a GHG performance that is above and beyond these mandatory requirements.

155. Common practice additionality implies that the activity goes beyond what is commonly practiced in similar socio-economic, environmental, and technological environments.

156. Performance additionality means that the activity exceeds the average GHG efficiency of the best performing comparable activities providing similar outputs and services in similar social, economic, environmental, and technological circumstances.

6.3.3.2. Demonstration of additionality

157. The additionality requirement set out in paragraph 152 is demonstrated by proving that the baseline has been established independently of the activity and that the difference between the removals occurring in the activity and the removals occurring in the baseline is a positive quantity.

158. Financial additionality is demonstrated by a financial analysis showing that the activity would not be financially viable without the potential revenue from the carbon credits.

159. Under most existing carbon market standards, including the CDM, financial additionality is not a mandatory requirement for removal activities, but an optional additionality test.

160. A removal activity may be economically attractive but still be additional because it faces non-financial barriers that prevent it from being realized if it is not registered under the mechanism, and its registration under the mechanism contributes to overcoming these barriers. Types of barriers could include adverse environmental conditions, unavailability or high cost of investment capital, inadequate infrastructure, lack of technological or entrepreneurial capacity or skills, cultural barriers, institutional barriers, organizational barriers, customary barriers, property rights barriers, social barriers, and barriers related to entrenched traditions.

161. Activities can also be screened for additionality based on approved positive lists. Positive lists reflect pre-defined criteria, which, if met by an activity, are sufficient evidence that the activity is unlikely to be implemented without being registered under the mechanism.[5]

162. Regulatory additionality, common practice additionality and performance additionality are demonstrated by providing a justification, supported by data and analysis where appropriate, of why and how the removal activity meets these types of additionality.

163. A removal activity does not have to demonstrate all types of additionality. It must pass the tests that are most relevant to its design. The specific procedure for demonstration of additionality of an activity are often provided in the applicable methodology.

6.3.4. Double counting

164. The validation of activities should reliably rule out the possibility of double counting, double issuance, and double claiming of credits, in the context of the various international cooperation instruments, mechanisms and registries.

165. Double counting occurs when more than one credit is issued for the same removals, either under the same mechanism or under two or more different mechanisms.

166. Double use occurs when the same issued credit is used twice (e.g. sold or retired twice when inter-registry tracking is not possible).

167. Double claiming occurs when the same removals are counted twice by both the buyer and the seller.

168. Safeguards to avoid double counting could include the following:

(a) Integrity checking at the registry level and transaction processing through linking of registries. Transparency of transactions can be made robust by creating a single global registry that is open to public scrutiny. Such a registry can be implemented efficiently and comprehensively by using the open-source distributed ledger technologies often known as blockchain technologies.

(b) The host Party may be required to provide the necessary assurances at the time of the issuance of the authorization letter to exclude the possibility of double counting of any kind.

169. For example, a Party to the Paris Agreement that intends to host an activity under jurisdictional approaches to enhance forest carbon stocks must state in its letter of approval and authorization of the activity that it agrees to the implementation of the land-based removal activity under Article 6.4 in the area and must demonstrate that:

(a) Where monitoring is conducted across the jurisdiction, the purpose is to ensure that project leakage and any reversals within the jurisdiction are accounted for and that environmental integrity is maintained at the jurisdictional level, but no credit is issued by jurisdictional program unless the activity is a nested activity, although a baseline may be established at the jurisdictional level;

[5] For example, see A/R CDM standardized baseline AR-ASB0001 "Afforestation and reforestation project activities in Namibia" which provides for automatic additionality. Available at https://bit.ly/3KOpCM8.

(b) The activity area credited under a jurisdictional program for enhancing forest carbon stocks is not an activity area for Article 6.4 removal activities, unless the activity is a nested activity.

170. An analysis of the various possible configurations of jurisdictional activities and individual activities is necessary in order to assess the benefits and limitations arising from the eligibility of such configurations under the mechanism.

171. The provision of the exact geolocation of a removal activity in the activity design document should be made mandatory.

172. Further analysis of the relationship between activities under forest carbon enhancement approaches and land-based removal activities under the Article 6.4 mechanism would be required to fully address potential issues, including the relationship with the requirements under Article 5 of the Paris Agreement.

6.4. Crediting period

173. The crediting period for a removal activity is the period during which the activity is eligible to generate credits.

174. The RMPs contained in the annex to decision 3/CMA.3 require that a crediting period for removal activities shall not exceed 15 years and shall be renewable a maximum of twice.

175. A host Party may require a shorter crediting period for activities hosted under its jurisdiction.

176. The crediting period of a removal activity may be renewed in accordance with the relevant provisions, if the host Party has agreed to such a renewal and a technical assessment by a DOE based on updates to the baseline and the ex-ante estimates of emission reductions concludes that the renewal of the crediting period meets all the relevant requirements.

177. At the time of renewal of a crediting period, the activity participants must apply the latest version of the relevant approved methodologies.

178. The end of the crediting period of a removal activity does not relieve the activity participants of the obligation to continue the periodic monitoring of the storage of removals for which credits were issued in advance of the verification of the required storage.

179. Activities that create a carbon debt in an earlier phase and then recover it in subsequent years (e.g. rewetting of wetlands) should not be eligible if recovery cannot be ensured within the crediting period. Note that each tCO_2 emitted requires a deduction of N tonne-years from the tonne-years achieved, where N is the permanence period in years.

180. This also applies to a situation where, for example, soil organic carbon (SOC) cannot be claimed on the basis of the IPCC default transition factors if the crediting period is shorter than the time required for the transition (e.g. 20 years). However, SOC gains demonstrated through measurement-based monitoring can be included in removals.

6.5. Addressing reversals

181. Reversals occur in the case of advance issuance of credits when the verified tonnes for which credits were issued are released back into the atmosphere before the end of the required storage period. Causes of release may include natural events such as occurrence of fire and pests (unintentional reversal) or a decision by the activity participants (intentional reversal).

182. Not all fluctuations in stocks of removals lead to a reversal. Fluctuations, whether due to natural hazards or intentional actions, that do not reduce the stocks below the level required by the issued credits do not count as reversals.

183. Reversals are addressed through periodic monitoring and a compensation agreement signed by the activity participants and backed up by a liability agreement by the host Party in case activity participants are unable or unwilling to fully compensate the reversals. Details and limitations of such agreements are provided in annex G to this note.

184. Reversals cannot occur in the case of ex post crediting, as credits are issued on the basis of the actual storage period already verified at the time of issuance. Crediting methods are described in section 5 of this note.

6.6. Avoidance of leakage

185. Leakage is defined as the net change of GHG emissions that occurs outside the accounting boundary of the removal activity and which is measurable and attributable to the activity.

186. Leakage can be caused by a number of factors, as described in the following sections.

6.6.1. Leakage caused by shifting of baseline activities

187. If the implementation of a removal activity prevents an economic activity that was taking place in the baseline, it is likely that the baseline activity will be shifted to another land area. The emissions caused by the relocated activity in excess of the emissions caused at the original location must be accounted for as leakage emissions [R-62:a].

Example. An area of land is used for grazing and firewood collection activities, resulting in emissions of 100 tCO_2 from vegetation degradation. A reforestation activity is implemented in this area. The grazing and firewood collection activities are shifted to a new area of land, where they result in emissions of 110 tCO_2 per year from vegetation degradation.

Interpretation (a): The leakage caused is 10 tCO_2 as this is the net change in emissions resulting from the shifting of activities. The 100 tCO_2 emissions at the original site no longer occur because the area is now managed under the removal activity and any changes in carbon stocks are accounted for under the removal activity.

Interpretation (b): All of the 110 tCO_2 is accounted for as leakage, as this is the net change in emissions that occurs 'outside' the accounting boundary of the activity.

188. This type of leakage is unlikely to occur in the case of removal activities carried out in areas where there is no competing land use (e.g. wasteland reclamation, reforestation of watersheds and nature reserves where no economic activities take place, tree planting on private lands, tree planting in urban areas).

189. Leakage due to activity shifting can be addressed by designing the removal activity so that the baseline level of services continues to be provided within the activity. For example, in the case of fuelwood collection and livestock grazing in the baseline of a reforestation activity, the demand for these services can initially be met by staggering the closure of areas over several years and eventually allowing local communities to collect fuelwood and fodder from the activity areas under managed access. Alternatively, activity participants may decide to set aside some of the land area available to them to continue to meet the needs of baseline users [R-57:a]. These design considerations are particularly appropriate in the case of removal activities undertaken by communities who are also customary users of the land.

190. To prevent an economic activity from shifting across multiple land areas under the control of the activity participants, the activity participants may be required to include all land areas within the activity boundary or monitor carbon stocks on all land areas under their control [R-58:a]. This consideration is particularly appropriate in the case of removal activities undertaken by commercial forestry enterprises.

191. To prevent an economic activity from shifting across multiple land areas under the control of different land owners in a jurisdiction, the entire jurisdiction (e.g. state, province, county) in which the removal activity is located can be required to monitor and report carbon stocks against a jurisdictional baseline. If, during a monitoring period, the actual changes in carbon stocks at both the jurisdictional and activity levels are found to be positive, then no leakage can be assumed. If the carbon stocks at the jurisdictional level have decreased compared to the jurisdictional baseline, the following possibilities would need to be examined and addressed:

(a) The activity increased its own carbon stocks but caused a decrease somewhere else in the jurisdiction level. In this case, there is a leakage, which can be debited to the activity based on an agreed adjustment factor;

(b) The activity increased its own carbon stocks, but the rest of the jurisdiction did not perform well, or the jurisdictional baseline was set too high compared to the actual carbon stocks and the decrease reflects this. In this case, the activity should not be subject to any leakage deduction.

192. A disadvantage of linking jurisdictional performance to the performance of individual actors is that it is difficult to determine ex post whether the scenario (a) or scenario (b) described in paragraph 191 above actually occurred. In absence of this, one cannot design suitable incentives to encourage private participation of local communities and other progressive climate actors in the context of apathetic and non-performing jurisdictions [R-51:j]. This may restrict the participation of private actors in the mechanism, and despite the avoidance of potential leakage the net result may be less mitigation at the mechanism level.

193. A solution often proposed to address the above limitation is to require the jurisdiction to register the removal activity as a jurisdictional activity. The jurisdiction supervises the performance of the individual private actors within the jurisdiction and allocates the baselines and credits earned at the jurisdiction level among the actors (nested jurisdictional crediting).

194. However, a disadvantage of restricting mechanism participation to jurisdictions only, or to mandatory nesting of activities, is that this can limit the participation of enterprising climate actors in the mechanism, as most jurisdictions in developing countries lack the

capacity ad governance structures to design and operate a baseline and crediting mechanism.

195. If a solution through appropriate activity design is not possible, leakage can be estimated by collecting monitoring data on the baseline activities (e.g. how many households no longer collect fuelwood from the area). The receiving land areas of the shifted activities can be identified, and a conservative estimate of the carbon stocks lost due to the shifted activity can be made [R-62:a]. The net removals achieved by the removal activity are then reduced by the amount of carbon stocks estimated to have been lost as a result of the shifted activities.

6.6.2. Leakage caused by market effects

196. Market leakage (sometimes called economic leakage) is caused by a shift in the balance of supply and demand for a product. If the removal activity increases or decreases the supply of a marketable product, the market prices of the product may be driven up or down, which may induce market actors other than those involved in the activity to increase, decrease or shift their production. Higher prices may lead to increased demand for the product, which will be met from other areas. Lower prices may induce other producers of the same or a similar product to switch to other, potentially more GHG-intensive, activities. The magnitude of such changes will depend on the size of the removal activity relative to the size of the accessible market.

197. Because market leakage is indirect and diffuse, its effects cannot be isolated and measured directly. One possible solution is to use leakage adjustment factors that reflect the likelihood and potential magnitude of market effects [R-58:b].

198. Market leakage can also occur across national boundaries due to international trade in commodities. International leakage is not currently accounted for in any of the carbon market standards, either compliance or voluntary [R-51: k]. According to the latest IPCC report, there is no consistent evidence to date that emissions trading schemes have led to significant emissions leakage [R-32: k].

6.6.3. Leakage caused by indirect ecological changes

199. Ecological effects triggered or accelerated by land-based removal activities may result in the loss of carbon stocks outside their boundaries. For example, a forest management or afforestation activity using exotic species could introduce pathogens, or compete for water resources, increasing tree mortality in neighbouring forests [R-58:c]. Similarly, changes in the hydrology of the area of a wetland restoration activity may trigger or exacerbate hydrological changes outside its boundary that result in GHG emissions or tree mortality [R-59:a].

200. Ecological leakage can be addressed through:

(a) Activity eligibility criteria: Activity participants could be required to demonstrate safeguards to avoid negative impact on carbon pools in neighbouring ecosystems [R-58:d];

(b) Activity design: If the likely impact is expected to be confined to the vicinity of the activity area, the activity participants may include the establishment of a leakage management zone within the project boundary [R-57:a];

(c) Measurement and discounting of ecological leakage [R-58:e].

6.7. Avoidance of other negative environmental and social impacts

201. The implementation of land-based removal activities may have an impact on other environmental and social objectives. The side effects may be either positive co-benefits or negative side effects.

202. The impacts, risks and co-benefits of land-based removal activities on ecosystems, biodiversity and local communities will depend on the type of activity, the site-specific context, the implementation and the scale.

203. This section describes negative environmental and social impacts and safeguards to avoid them.

6.7.1. Impacts on land, biodiversity, and water

204. Afforestation, reforestation, forest restoration and improved forest management can have negative impacts on biodiversity if these activities result in the replacement of native species with exotic species.

205. Large-scale afforestation and reforestation can lead to competition for land, with negative impacts on biodiversity conservation and food production.

206. Agroforestry and soil organic carbon enhancement activities can adversely affect crop productivity if not carefully designed for synergy with crop production.

207. In general, any land-based carbon removal activity implemented outside the context of sustainable development (i.e. an activity with the sole objective of maximizing the amount of carbon removed) is likely to have some negative environmental and social impacts.

208. A removal activity that is designed to be implemented in the context of other activities providing economic or environmental services, where removal is realized as a co-benefit rather than the main benefit, is less likely to result in adverse environmental and social impacts.

209. For example, a removal activity, including a BECCS power plant, that is driven by the sole objective of maximizing the cumulative carbon stocks may lead to competition for land and displace other higher-priority needs, such as food security and fuelwood for cooking. Such an activity may also compete for land that supports biodiversity conservation. On the other hand, a BECCS-supported removal activity that is driven by the objective of unblocking the saturation of the bio-sequestration sink in a vegetation system that provides economic or ecological services is complementary and synergistic with the underlying objective of meeting human needs or providing ecological services, and is therefore less likely to cause adverse environmental and social impacts.

6.7.2. Impacts on food security and local livelihoods

210. Negative social impacts can occur if removal activities are implemented on land for which communities have alternative priorities, such as agricultural production, and if communities are not effectively involved in all stages of the design and implementation of the activities.

211. These negative impacts can be mitigated by ensuring that the removal activity is consistent with the long-term regional land-use plans and that community development

priorities are effectively incorporated into the design, development, and implementation of the activity.

212. Afforestation or biomass crop production for BECCS or biochar, if poorly implemented, can have negative impacts on local livelihoods and indigenous peoples' rights, especially when implemented at large scale and where land tenure is not clearly defined.

213. Adverse impacts are less likely to occur if the free, prior and informed consent of the relevant stakeholders has been obtained before the removal activity is registered and stakeholder consultations are systematically followed.

214. Social and environmental impact assessments should be a prerequisite for the registration of a removal activity.

215. The scope of the assessments must include human well-being and the conservation of biodiversity and other natural resources.

216. Periodic consultation with the community during the crediting period should be held where relevant to the nature of the removal activity being implemented.

217. Feedback and dispute resolution mechanisms should be established to address issues related to adverse environmental and social impacts, allowing for feedback from employees, local communities and relevant regional or national authorities.

218. Feedback and dispute resolution mechanisms should be adequately publicised and should be easily accessible to the concerned stakeholders.

7. Methodological issues related to engineering-based removal activities

219. This section provides information on removal activities based on engineering approaches and technologies. In the absence of experience with the implementation of these types of removal activities under existing market mechanisms, the information below is largely based on the IPCC reports and other published scientific literature.

220. The following types of engineering-based removal activities are considered:

(a) Direct air carbon capture and storage (DACCS);

(b) Enhanced rock weathering (EW);

(c) Ocean alkalinization (OA);

(d) Ocean fertilization (OF).

221. A summary description of each of these activity types is provided in appendix I.

222. IPCC guidance on quantifying removals is available for land-based removal activities (IPCC, 2006 and 2019), but has yet to be developed for engineering-based removal activities.

223. International governance considerations include global technology transfer around implementation of engineering-based removal activities and land-use changes that could affect food production and land conditions or lead to conflicts over land tenure

and access. Efforts are required to create sustainable and equitable supply chains for engineering-based removal activities, such as resources used for BECCS, EW and/or OA.

224. International governance would be particularly important for processes that pose transboundary risks, especially ocean-based processes. Specific rules have so far only been developed in the context of the London Protocol, an international treaty that explicitly regulates OF and allows Parties to regulate other types of activities such as OA.

225. Enhanced rock weathering and ocean-related activities have no known method of monitoring, while there is considerable uncertainty about their environmental and social impacts. These types of activities are therefore not discussed in the following sections.

7.1. Monitoring

226. Monitoring of all removal activities should be based on the quantification of cumulative stocks of removals.

227. For most engineering-based removal activities, the quantities of carbon stocks are known through physical measurements, such as the total mass of CO_2 removed.

228. Monitoring of removal activities using geological formations for storage should be carried out in accordance with the relevant provisions of the annex to decision 10/CMP.7 "Modalities and procedures for carbon dioxide capture and storage in geological formations as project activities under the clean development mechanism".

229. For removal activities that occur across Party boundaries (e.g. in a BECCS activity where biomass is grown in Party A, pellets are made in Party B and transported to Party C where electricity is generated, and the CO_2 captured is sent to Party D for geological storage), such complexities need to be addressed.

7.1.1. Frequency of monitoring

230. The frequency of monitoring will depend on the rate of accumulation of removal stocks to justify the cost of monitoring. There must be sufficient accumulation of carbon stocks before the first verification of the removals by an activity takes place.

231. As will be seen later, the timing of the first verification and the frequency of subsequent verifications, as well as the length of time over which mandatory periodic verification is required, will depend on the type of storage and whether credits are issued in advance of verification of the required storage period.

232. Periodic monitoring will also be required after the end of the crediting period where credits are issued in advance of verification of the required storage period.

7.2. Reporting

233. Verified monitoring reports form the basis for issuance of credits.

234. Monitoring reports summarize the results of monitoring. Monitoring reports are submitted to a DOE, which verifies the accuracy of the monitoring results.

235. Reporting must take place as soon as possible after the end of the monitoring operations to allow the DOE to visit the site and carry out spot checks of the measurements made during the monitoring operations.

236. The monitoring report should include all relevant data, or, if such data are too extensive, a summary of such data. In any case, the complete data set, except for any confidential data, should be made available to the DOE at the time of verification.

237. In addition to the data on removals stored in geological formations, reporting should include records of events and incidents, such as seepage from previously verified and stored removals.

238. Simplified reporting may be allowed in certain circumstances, for example where the purpose of reporting is to demonstrate the continued storage of verified removals, rather than to verify additional tonnes of removals.

239. Reporting should be required to include information on how environmental and socio-economic impacts have been assessed and addressed.[6]

240. Reporting should include information on how the activity contributes to sustainable development in the host Party.[7]

7.3. Accounting of removals

241. Net removals achieved by a removal activity are equal to the total tonnes of removals achieved by the activity minus baseline tonnes of removals, minus emissions attributable to the implementation of the activity, minus leakage emissions.

242. For removal activities with an activity boundary spanning multiple Parties (e.g. in a BECCS activity where biomass is grown in Party A, pellets are made in Party B, transported to Party C where electricity is generated, and the CCS capture is sent to Party D for geological storage), such complexities need to be addressed.

243. As the current format of national GHG inventories does not provide space for accounting for engineering-based removals, the CMA/COP will need to address this issue with the assistance of the IPCC (P-22).

7.3.1. Baselines

244. Baselines are the reference scenarios against which changes in stocks of removals are calculated.

[6] See, A6.4M-RMP, paragraph 24(x).

[7] See, A6.4M-RMP, paragraph 24(xi).

245. In the case of engineering-based removals with a newly installed facility, the baseline is zero.

246. If the capacity of an existing facility is increased, the baseline removals would be equal to the removals that occurred prior to the activity.

7.3.1.1. Periodic re-validation of the baseline

247. The baseline is set at the time of validation and registration of the activity and is reassessed at the time of renewal of the crediting period.

7.3.2. Activity boundaries

248. The accounting of net removals achieved through an activity should be based on the boundaries defined in terms of physical boundaries (e.g. plant, equipment and materials, sources of emissions associated with the activity) and, in the case of geological storage of carbon stocks achieved, should meet the requirements set out in the annex to decision 10/CMP.7 "Modalities and procedures for carbon dioxide capture and storage in geological formations as a clean development mechanism project activity".

7.3.3. Additionality

249. A removal activity must demonstrate that the removals associated with it are additional to the removals that would occur in the baseline.

250. If an activity uses the removal stocks for economically useful products, financial additionality must also be demonstrated.

251. Regulatory additionality should be demonstrated by proving that, in absence of its registration under the mechanism, the activity would not be undertaken solely due to mandatory requirements such as laws, regulations, industry standards and enforced policies.

7.3.4. Double counting

252. The validation of activities should take into account the possibility of double counting, double issuance and double claiming in the context of the various international cooperation instruments, mechanisms and registries.

253. Double counting occurs when more than one credit is issued for the same removals, either under the same mechanism or under two or more different mechanisms.

254. Double use occurs when the same issued credit is used twice (e.g. sold twice if inter-registry tracking is not fully assured).

255. Double claiming occurs when the same removals are counted twice by both the buyer and the seller.

256. Two methods could be used to avoid double counting:

   (a) Integrity checking at the registry level and transaction processing and linking of registries;

(b) The host Party may be required to provide the necessary assurances at the time of the issuance of the authorization letter to exclude the possibility of double counting of any kind.

257. The provision of the exact geolocation of a removal activity in the activity design document should be made mandatory.

7.4. Crediting period

258. The crediting period for a removal activity is the period during which the activity is eligible to receive credits.

259. The RMPs require that a crediting period for removal activities shall not exceed 15 years (renewable a maximum of twice).

260. The host Party may require a shorter crediting period for activities hosted under its jurisdiction.

261. The crediting period of a removal activity may be extended in accordance with the relevant provisions, if the host Party has agreed to such an extension following a technical assessment by a DOE to determine the necessary updates to the baseline and the ex-ante estimates of emission reductions.

262. The end of the crediting period of a removal activity shall not necessarily be the end of the obligations of the proponents of the activity to continue periodic monitoring of the carbon stocks for which credits were issued until such carbon stocks have been sequestered from the atmosphere for a period equivalent to that for which the credits were issued.

7.5. Addressing reversals

263. The provisions for addressing reversals applicable to land-based activities described under section 6.5 also apply to engineering-based removals.

7.6. Avoidance of leakage

264. Leakage is defined as the indirect decrease or increase in carbon stocks that occurs outside the boundary of the activity.

7.6.1. Leakage caused by resource competition

265. If the implementation of an engineered abatement activity uses resources (e.g. energy, water, photovoltaic panels, windmills) that would have been used by another activity in the baseline scenario, the latter is likely to shift to a different resource (e.g. using less clean energy). The emissions caused by the shifted resource should be accounted for as leakage.

266. This type of leakage can be addressed through the design of the removal activity such that the activity uses only the resources that have no competing use.

267. If a solution through appropriate activity design is not possible or only partially possible, leakage can be estimated by collecting monitoring data on the baseline activities (e.g. how much resource displacement has occurred). A conservative estimate of the resulting emissions can be made. The net removals achieved by the removal activity

are then reduced by the amount of emissions estimated to have been caused by the resource shift.

7.6.2. Leakage caused by market effects

268. Market leakage is caused by a shift in the balance of supply and demand for resources such as energy and water. If the abatement activity reduces the availability of energy or water by competing for the resources, the market prices of the resources may be driven up or down. The magnitude of the price changes will depend on the amount of resources used by the activity relative to the amount of resources available in the accessible market. Higher prices may lead to the resources (e.g. energy, water) being obtained from more polluting sources and technologies.

269. As market leakage is indirect and diffuse, its effects cannot be isolated and measured directly. A possible solution is to use leakage adjustment factors based on the likelihood of leakage and the relative size of the abatement activity.

7.6.3. Addressing seepage in geological storage

270. Seepage from geological storage should be addressed in accordance with the relevant provisions of the annex to decision 10/CMP.7 "Modalities and procedures for carbon dioxide capture and storage in geological formations as clean development mechanism project activities".

7.7. Avoidance of other negative environmental and social impacts

271. The implementation of removal activities may have an impact on other environmental and social objectives. The side effects can be either positive co-benefits or negative side effects.

272. The impacts, risks and co-benefits of the implementation of removal activities on ecosystems, biodiversity and people will be highly variable, depending on the type of activity, the site-specific context, the implementation and the scale.

273. This section addresses the negative environmental and social impacts and their avoidance associated with engineered removal activities.

7.7.1. Impacts on land, biodiversity, and water

274. Large-scale engineered removal activities such as DACCS can lead to competition for resources such as clean energy and water. This can affect energy security and access to water in areas immediately surrounding the activity site.

275. If the waste products of the activity, such as used chemicals and waste water, are not managed safely, they can cause toxicity and other damage to land, biodiversity and water resources.

7.7.2. Impacts on food security and local livelihoods

276. Negative social impacts may occur if the removal activities undertaken compete for resources used by vulnerable local populations.

277. These negative impacts can be reduced by ensuring that the removal activity is appropriately sited and uses resources that have no opportunity cost.

278. Social and environmental impact assessments should be a prerequisite for the registration of a removal activity.

279. The scope of the assessments must include human well-being and the conservation of biodiversity, water and other natural resources.

280. Feedback and dispute resolution mechanisms may be established to address issues related to adverse environmental and social impacts, allowing for feedback from employees, local communities and relevant regional or national authorities.

281. Feedback and dispute resolution mechanisms should be easily accessible to the public and adequately publicized.

Appendix A. List of sources

The tables A.1 and A.2 contain the list of sources used in this information note. There are two types of sources: public inputs received from stakeholders (P-series) and other references including the Intergovernmental Panel on Climate Change (IPCC) reports and published papers (R-series).

Table A.1. List of sources: public inputs

Source ID	Source with search strings
P-01	Aircapture. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/40Dfv4v a:100 years
P-02	ALLCOT. Call for input 2022 - Activities involving removals under the Article 6.4 https://bit.ly/3xbZcxS a:passing a law a:passing a law, b:worked well
P-03	Bellona. Call for input 2022 - Activities involving removals under the Article 6.4 https://bit.ly/3Xl8hPz a: balance of a removal process, b:only focus on a:balance of a removal process, b:only focus on, c:land and geological
P-04	Carbon Business Council. Activities involving removals under the Article 6.4 https://bit.ly/3x5DD27 a: range of solutions a:range of solutions, b:two distinct
P-05	Carbon Engineering. Activities involving removals under the Article 6.4 https://bit.ly/3YCZzNZ a: fundamental limitations a:fundamental limitations
P-06	Carbon Finance Labs. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/3HI8yq5 a:activity over a 100-year
P-07	Carbon Market Watch (2021). Respecting the laws of physics. Principles for carbon dioxide removal accounting http://bitly.ws/zHsJ a:new proposed option, b:majority of all products, c:unclear what, d:in a net removal, e:sb to focus, f:budget perspective, g:a quantitative manner. h:creative accounting
P-08	Carbon Market Watch (May 2022). Carbon Market Watch recommendations to Article 6 negotiators on removals https://bit.ly/3lDBpo8 a:offsetting or to meet
P-09	Carbon Market Watch (Sept. 2022). Carbon Market Watch inputs on grievances, methodologies, and removals prior to the Article 6.4 Supervisory Body 2nd meeting https://bit.ly/3IbwlyY a:fungible
P-10	Carbon Recycling - Activities involving removals under the Article 6.4 https://bit.ly/3IgnITE a:consider defining, b: influence of the sources, c: recentness of the carbon a:consider defining, b:influence of the sources, c:recentness of the carbon
P-11	CarbonPlan. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/3RMVcNV a:undermines, b:inconsistent with the Paris, c:on cumulative emissions, d:are used to justify, e:ignore the climate, f:employ discounting , g:recently reached
P-12	Center for International Environmental Law - Activities involving removals under the Article 6.4 https://bit.ly/3ljtzjA a:present significant risks, b:are speculative, c:serves to prolong, d:highest-cost mitigation, e:courts have, f:capture targets set, g:has engaged with a:present significant risks, b:are speculative, c:serves to prolong, d:highest-cost mitigation, e:courts have, f:capture targets set, g:has engaged with, h:do not exist, i:on their own
P-13	Clean Air Task Force. Call for input 2022 - Activities involving removals under the Article 6.4 https://bit.ly/3JVyAsH a:technology-neutral a:technology-neutral, b:greater clarity
P-14	Climeworks. Call for input 2022 - Activities involving removals under the Article 6.4 https://bit.ly/40CC4Gp a:more inclusive a:more inclusive

Source ID	Source with search strings
P-15	DAC Coalition. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/3RKAs9E a:0.01 mt, b:risk of detracting
P-16	Evident C-capsule. Activities involving removals under the Article 6.4 https://bit.ly/3lh4aa6 a:replaced with GHG, b:why a departure a:replaced with GHG, b:why a departure
P-17	Global CCS Institute. Activities involving removals under the Article 6.4 https://bit.ly/3x5deRV a: voluntary direct a:voluntary direct
P-18	Groom, B. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/3lh7DWa a:equivalent to 1 ton, b:offsets each, c:sceptical
P-19	International Emissions Trading Associatio. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/40GSsG8 a:limited adoption, b:been rejected, c:further public
P-20	MDB Article 6 Working Group. MDB Working Group comments on the annotated agenda of the third meeting of the Supervisory Body A6.4-SB003-AA-A03 Draft recommendation: Removal activities under the Article 6.4 mechanism (couldn't find on the website for submissions) a:details on the factors, b:practical implementation, c:corresponding adjustments, d:current practices
P-21	Natural Capital Exchange. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/3DRubTW a:for early action, b:numerous benefits
P-22	Perspectives GmbH. Call for input 2022 - Activities involving removals under the Article 6.4 https://bit.ly/3DSjYXr a:all greenhouse gases a:all greenhouse gases, b:period of 100 years
P-23	Running Tide. Activities involving removals under the Article 6.4 https://bit.ly/40yUYy5 a:atmosphere or ocean a:atmosphere or ocean
P-24	Stockholm Environment Institute. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/3Ys9kP2 a:fails to, b:ignores any effects, c:to be concerned, d:a problematic, e:context of reversible, f:far enough, g:future generations, h:decline over time, i:are not premised, j:at any time
P-25	Stockholm-Exergi. Activities involving removals under the Article 6.4 https://bit.ly/3Ia9zsk a:why that is necessary b:involved in defining a:why that is necessary, b:involved in defining
P-26	The Nature Conservancy (2022) Recommendations to the Article 6.4 Supervisory Body on activities involving removals https://bit.ly/3HTVmzF a:all options b: key co-benefits
P-27	Verdane. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/3x4BoMw a:carbon budget
P-28	Wetlands International. Activities involving removals under the Article 6.4 https://bit.ly/3YC8lMe a: climate-neutral, b:instead of GGR a:climate-neutral, b:instead of ggr
P-29	Winrock-ACR & ART. Call for input 2022 - activities involving removals under the Article 6.4 Mechanism of the Paris Agreement https://bit.ly/3K9v0vp a:absence of a minimum, b:highly dependent, c:further review, d:promote permanence, e:opinion was, f:shows choice, g:further public

Table A.2. List of sources: publications

Source ID	Source with search strings
R-01	Achieving NRT Permanence. (n.d.) Nori. https://nori.com/achieving-permanence a:carbon retention term
R-02	Allen M.R., Friedlingstein P. (2022) Net Zero: Science, Origins, and Implications. Annual Review of Environment and Resources. Vol. 47:849-887 https://bit.ly/40mmOgN a:compensating for fossil
R-03	Amanullah, Professor. (2019). Measuring and modelling soil carbon stocks and stock changes in livestock production systems A scoping analysis for the Livestock Environmental Assessment and Performance (LEAP) Partnership work stream on soil carbon stock changes. https://bit.ly/3YAUaGW a:and carbon storage, b: a sound basis, c: very appropriate
R-04	Australian Government (2022). Carbon Credits (Carbon Farming Initiative) Act 2011 https://bit.ly/3KgF2KX a:100-year permanence
R-05	Balmford A. et al. (2023). The value of impermanent carbon credits. Cambridge Open engage. https://bit.ly/3KsGbzj a:many impermanent credits
R-06	Baral, A., Malins, C. (2014). Comprehensive Carbon Accounting for Identification of Sustainable Biomass Feedstocks.The International Council on Clean Transportation https://bit.ly/3Yku4Iy a:savings in earlier years
R-07	British Standards Institution (2011). The Guide to PAS 2050:2011. How to carbon footprint your products, identify hotspots and reduce emissions in your supply chain. UK. https://bit.ly/3jOLZrV a:100 year time
R-08	California Air Resources Board (CARB) (2019). Unofficial electronic version of the Regulation for the California Cap on Greenhouse Gas Emissions and Market-Based Compliance Mechanisms https://bit.ly/3EjrMBu a:at least 100 years
R-09	Canada Gazette (2022.06.08) Canadian Greenhouse Gas Offset Credit System Regulations: SOR/2022-111. Part II, Volume 156, Number 12 https://bit.ly/3wQfTim a:at least 100 years
R-10	Carbon Market Watch (2021), Respecting the laws of physics. Principles for carbon dioxide removal accounting. https://bit.ly/3lmQSsR a:back into the slow
R-11	Carbonplan. (2022.01.31) Unpacking ton-year accounting. https://bit.ly/3wNAmo7 a:identical to either
R-12	Carton, W., Lund, J. F. & Dooley, K. (o. D.). Undoing Equivalence: Rethinking Carbon Accounting for Just Carbon Removal. https://www.frontiersin.org/articles/10.3389/fclim.2021.664130/full a:are hypothetical, b:distinguish between removals, c:a sectoral basis, d:fungible
R-13	Carvalho, M., Meneses, M., et al. (2022). Offset approaches in existing compliance mechanisms Adding value and upholding environmental integrity?. German Environment Agency. https://bit.ly/3jJx7uW a:nbs to be eligible
R-14	CIFOR (2000) Capturing the value of forest carbon for local livelihoods: opportunities under the clean development mechanisms of the Kyoto protocol https://bit.ly/3HuR4xy a:flexibility is particularly, b: thus increasing overall
R-15	Dornburg, V., Marland, G. (2008). Temporary storage of carbon in the biosphere does have value for climate change mitigation: a response to the paper by Miko Kirschbaum. Mitig Adapt Strateg Glob Change 13, 211-217 https://bit.ly/3HQ3Oi7 a:is an artifact
R-16	Element Energy, E4tech and Cambridge Econometrics for the UK Department for Business, Energy and Industrial Strategy (BEIS). (2022). Policy Mechanisms for First of a Kind Direct Air Carbon Capture and Storage (DACCS) and other Engineered Greenhouse Gas Removals. https://bit.ly/3XyrUUN a:primarily CO_2

Source ID	Source with search strings
R-17	European Biochar Industry Consortium (2022)-Position Paper-Certification of carbon removals EU rules https://bit.ly/416Dn0u a:separation of sink
R-18	European Commission - Joint Research Centre - Institute for Environment and Sustainability (2010). International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance. First edition. Luxembourg. Publications Office of the European Union https://bit.ly/3Yy3R99 a:longer than 100 years
R-19	European Commission - Joint Research Centre Institute for Environment and Sustainability (2012). Product Environmental Footprint (PEF) Guide. https://bit.ly/3DTgN1r a:100 year period
R-20	Fankhauser, S., Smith, S.M., Allen, M. et al. The meaning of net zero and how to get it right. Nat. Clim. Chang. 12, 21 (2022). https://doi.org/10.1038/s41558-021-01245-w a:broader sustainable
R-21	Fearnside, P.M. Why a 100-Year Time Horizon should be used for Global Warming Mitigation Calculations. Mitigation and Adaptation Strategies for Global Change 7, 19-30 (2002). https://bit.ly/3DS8uTP a:has advantages, b:on day one, c:sovereignty concerns
R-22	Fearnside, P.M.(2008). On the value of temporary carbon: A comment on Kirschbaum. Mitigation and Adaptation Stategies for Global Change https://bit.ly/3lqNay4 a:given equal weight
R-23	Galik CS, Baker JS, Daigneault A and Latta G (2022) Crediting temporary forest carbon: Retrospective and empirical perspectives on accounting options. Front. For. Glob. Change 5:933020. doi: 10.3389/ffgc.2022.933020 https://bit.ly/3YyKi0i a:independent of any, b: most consistent
R-24	Griscom B. W., Adams J. (2017) Natural climate solutions. PNAS https://bit.ly/3JDXBZb a:cost-effective climate mitigation, b:largely a, c:not outweigh
R-25	Herzog, H., Caldeira, K. & Reilly, J. (2003). An Issue of Permanence: Assessing the Effectiveness of Temporary Carbon Storage. Climatic Change 59, 293-310. https://bit.ly/3x7UYaK a:is permanent, b:valuing temporary storage, c:nearly equivalent to
R-26	IPCC (2000). IPCC Special Report on Land use, Land-use Change and Forestry https://bit.ly/2KimF9e a:two-dimensional, b:there clearly has, c:reduce the uncertainty
R-27	IPCC (2005). IPCC Special Report on Carbon Dioxide Capture and Storage. https://bit.ly/3REXEpU a:may no longer
R-28	IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report https://bit.ly/3HXNc9E a:based on the revised
R-29	IPCC (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories http://bitly.ws/zHAH a:a permanence time frame
R-30	IPCC (2019). Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems https://www.ipcc.ch/srccl/ a:not yet deployable, b:ambitious investments, c:promise of future cdr
R-31	IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report http://bitly.ws/zHiW a:cooling or avoided warming
R-32	IPCC (2022). Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the Sixth Assessment Report http://bitly.ws/zHzZ a:progressed beyond conceptual, b:are known as CDR, c:deliberate human activities, d:refers to anthropogenic activities removing, e:(CDR) Anthropogenic, f:geochemical or chemical CO_2, g:climate neutrality is not used, g:unknown how long, h:levels in the near-term, i:the main cdr methods, j:categorised based on removal, k:no consistent evidence

Source ID	Source with search strings
R-33	ISO (2022). Net Zero Guidelines: International Workshop Agreement https://bit.ly/3xJZcFY a:exclusively use
R-34	Kirschbaum, M.U.F. (2006) Temporary Carbon Sequestration Cannot Prevent Climate Change. Mitig Adapt Strat Glob Change 11, 1151-1164 https://bit.ly/3kSrYAP a:outcome is that
R-35	Locatelli, B., Pedroni, L. (2004). Accounting methods for carbon credits: Impacts on the minimum area of forestry projects under the Clean Development Mechanism. Climate Policy. 4. 193-204. https://bit.ly/3jI6OoY a:awarded ex post, b:credits very slowly
R-36	Lueddeckens, S., Saling, P., Guenther, E (2022). Discounting and life cycle assessment: a distorting measure in assessments, a reasonable instrument for decisions. Int. J. Environ. Sci. Technol. 19, 2961-2972 https://bit.ly/3YoELtJ a:are not equivalent, b:even without the
R-37	Mackey, B., & Prentice, I. et al. (2013). Untangling the confusion around land carbon science and climate change mitigation policy. https://go.nature.com/3Xgmg9m a:the right kinds, b:slow the rate
R-38	Marshall L and Kelly A (2010) The Time Value of Carbon and Carbon Storage: Clarifying the terms and the policy implications of the debate. World Resources Institute https://bit.ly/3HvWCb0 a:to select two
R-39	Matthews, H.D., Zickfeld, K., Dickau, M. et al. (2022) Temporary nature-based carbon removal can lower peak warming in a well-below 2°C scenario. Commun Earth Environ 3, 65 https://go.nature.com/3HGuwKh a:even in, b:the peak temperature increase
R-40	Climate Action Reserve (2022). Mexico Forest Protocol. https://bit.ly/3DSLeoo a:make a 100-year, b:with the minimum
R-41	Murray, B.C., Galik, C.S.; Mitchell, St. (2012). Alternative approaches to addressing the risk of non-permanence in afforestation and reforestation projects under the clean development mechanism (English). Washington, D.C.: World Bank Group. https://bit.ly/3DQZWwf a:lack of economic viability
R-42	Ricart, A. et al. Environmental Research Letters. (2022, August 12). Sinking seaweed in the deep ocean for carbon neutrality is ahead of science and beyond the ethics. https://bit.ly/3ImRR50 a:unintended environmental
R-43	Robertson, B. et al.(2022) The Carbon Capture Crux: Lessons Learned. Institute for Energy Economics and Financial Analysis (IEEFA) https://bit.ly/3KcWqQP a:extrapolated in
R-44	Rose, D.J.; Hemery, L.G. (2023).Methods for Measuring Carbon Dioxide Uptake and Permanence: Review and Implications for Macroalgae Aquaculture. J. Mar. Sci.Eng https://bit.ly/3DUL001 a:wishful thinking, b:typically defined as
R-45	Ruseva T. et al. Additionality and permanence standards in California's Forest Offset Protocol: A review of project and program level implications, Journal of Environmental Management, Volume 198, Part 1, 2017, Pages 277-288 https://bit.ly/3I7eDOb a:harvests over, b:opportunity costs related
R-46	Salinas, Z. et al. (2011). BioCarbon fund experience : insights from afforestation and reforestation clean development mechanism projects (English). Washington, D.C. : World Bank Group. https://bit.ly/3Xdzt2P a:not fungible b: ranges widely
R-47	Sarofim M. C. et al. (2018) A quantitative approach to evaluating the GWP timescale through implicit discount rates. Earth Syst. Dynam., 9, 1013â€“1024 https://bit.ly/3l5x9h1 a:calculating an equivalent
R-48	Sierra, C.A. et al. (2021). The climate benefit of carbon sequestration. Biogeosciences, 18, 1029-1048 https://bit.ly/3YBSgG7 a:resemble our

Source ID	Source with search strings
R-49	Smith, J. (2019). California Compliance Offsets: Problematic Protocols and Buyer Behavior. Mossavar-Rahmani Center for Business & Government Weil Hall Harvard Kennedy School www.hks.harvard.edu/mrcbg. https://bit.ly/3jIT0um a:ratio that captures, b:and wow, c:no reason to avoid, d:later years, e:one option
R-50	Smith, M., Geden, O., et al (2023). The State of Carbon Dioxide Removal - 1st Edition https://bit.ly/3YBTSzU a:to include potential removal, b:primarily via, c:currently occurring on, d: encounter uncertainty
R-51	The Integrity Council for the Voluntary Carbon Markets. Public consultation on its draft Core Carbon Principles, Assessment Framework and Assessment Procedure. https://bit.ly/40ulMPP a:require a minimum, b:has to be a minimum, c:excessively long, d:credited truly, e:arbitrary minimum, f:flood, g:a minimum storage, h:should me a minimum, i:term is 5-10, j:penalized if it, k:leakage is not currently accounted, l:true ex post
R-52	The Oxford Institute for Energy Studies (2022) The Evolution of Carbon Markets and Their Role in Climate Mitigation and Sustainable Development https://bit.ly/3RwBC8p a:not always accurately
R-53	UNFCCC. (2022, September 20). Structured expert dialogue on the second periodic review ofÂ the long-term global goal under the Convention (2020-2022) Synthesis report by the co-facilitators of the structured expert dialogue. https://bit.ly/3jUFcNo a:feasibility of most
R-54	VCS (2022). Additional Background Information on Tonne-Year Accounting https://bit.ly/3DQtOca a:small volume
R-55	VCS V4 Public Consultation Summary of Comments: Q2 2022. Verified Carbon Standard. https://bit.ly/3JOUyxC a:is paired with careful, b:would support a minimum, c:issued after a minimum, d:credible minimum, e:mandate a minimum, f:required to use the minimum, g:a minimum period, h:simplicity in accounting , i:sacrifices accuracy, j:accurate representation, k:happen ex post, l:flat and linear, m:discounting prohibited, n:that substantiates, o:rate depends, p:strongly support, q:should not be applied, r:explicitly prohibited, s:supportive of tonne-year, t:no concerns, u:low volumes, v:enormous assumptions, w:beneficial flexibility, x:assumes that balancing, y:limited remaining, z:will create, aa:is myopic, ab:financially today, ac:on cumulative emissions, ad:that the short-term, ae:from optionality, af:more warming, ag:gigantic flow, ah:clear differentiation, ai:urgent action, aj:minimum acceptable
R-56	Zickfeld, K., MacDougall, H. & Matthews, H. (o. D.). On the proportionality between global temperature change and cumulative CO_2 emissions during periods of net negative CO_2 emissions. https://iopscience.iop.org/article/10.1088/1748-9326/11/5/055006 a:effectiveness of negative
R-57	SocialCarbon Standard V6.0 https://bit.ly/40BLtOn a:leakage management zones
R-58	Climate Change Task Force of the Canadian Council of Forest Ministers. A framework for forest management offset protocols https://bit.ly/3YyrL4A a:all controlled, b:simple 2%, c:introducing pathogens, d:mitigate ecological, e:discount ecological
R-59	American Carbon Registry (2020). Requirements and specifications for the quantification, monitoring, reporting, verification, and registration of project-based GHG emissions reductions and removals. Version 7.0 https://bit.ly/40pDS5C a:changes in hydrologic
R-60	Offset Quality Initiative (2008). Ensuring offset quality https://bit.ly/41Xohdw a:exclude forward contracts
R-61	European Commission (2021). Technical Guidance Handbook: Setting up and implementing result-based carbon farming mechanisms in the EU https://bit.ly/3AInvVX a: ex-ante crediting to raise
R-62	UNFCCC (2013). AR Methodological tool-Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity https://bit.ly/2AHDTXH a: emissions relative

Source ID	Source with search strings
R-63	The Institute of Foresters of Australia. (2021). Inquiry into the Long – Term Sustainability and Future of the Timber and Forest Products Industry. Submission to the New South Wales Legislative council. https://bit.ly/3jJTxMs a: encourages long term
R-64	Earth Negotiations Bulletin (2000). Highlights from LULUCF Workshop Wednesday, 12 July 2000. https://bit.ly/40Hz23S
R-65	Earth Negotiations Bulletin (2002). UNFCCC COP-8 Highlights Thursday, 24 October 2002. https://bit.ly/3XQVAg0
R-66	UNFCCC (2014). Options for possible additional land use, land-use change and forestry activities and alternative approaches to addressing the risk of non-permanence under the clean development mechanism. Technical paper. https://bit.ly/3jG3QBg
R-67	The Institute of Foresters of Australia (2021). Inquiry into the Long – Term Sustainability and Future of the Timber and Forest Products Industry. https://bit.ly/3jJTxMs a:too complex, b: now timely
R-68	Quebec Government (2022). Regulation respecting afforestation and reforestation projects eligible for the issuance of offset credits on privately-owned land. https://bit.ly/44PuEBS a:equation 15
R-69	UNFCCC (2000). Methodological issues: Land use, land-use change and forestry. Miscellaneous document for consideration by the SBTA. https://bit.ly/3DYyBbx
R-70	Brandão, M., Levasseur, A. (2011). Assessing Temporary Carbon Storage in Life Cycle Assessment and Carbon Footprinting: Outcomes of an expert workshop. https://bit.ly/3ll8ghx a: british carbon footprinting
R-71	European Commission, Directorate-General Joint Research Centre (2011). Action 22005 - Environmental Assessment and the Sustainable Use of Resources (ENSURE), European Platform on Life Cycle Assessment, Ispra, Italy. https://bit.ly/3ll8ghx
R-72	Climate Action Reserve (2022). Soil Enrichment Protocol: Reducing emissions and enhancing soil carbon sequestration on agricultural lands, Version 1.1 https://bit.ly/3x6Rllp
R-73	Matthews D. H., Zickfeld K, et al. (2022) Reimagining tonne-year accounting to capture the climate benefit of temporary carbon storage PREPRINT (Version 1) https://bit.ly/3DzBNdl
R-74	Meyer, M (2022). What is tonne-year accounting and how it is used. https://bit.ly/42Jbuf5
R-75	Parisa, Z. Marland, E. et al. (2022). The time value of carbon storage. Forest Policy and Economics Volume 144, November 2022. https://bit.ly/42vpjOG
R-76	Balmford A., Keshav S, et al. Realising the social value of impermanent carbon credits. https://bit.ly/3pvPdTE
R-77	GHG Protocol (2022). Land sector and removals guidance - Draft for pilot testing. https://bit.ly/42sakVA
R-78	Climate Action Reserve(2019). Canada Grassland Protocol Version 1.0. https://bit.ly/3I1A6HT
R-79	Wenger S. et al.(2022). Maximizing Global Cooling Potential in Carbon Dioxide Removal (CDR) Procurements-A Proposal for Tonne-Year Pricing https://bit.ly/3pucB3S
R-80	UNFCCC (2013). Afforestation and Reforestation Projects under the Clean Development Mechanism-A Reference Manual. https://bit.ly/2Xd4PZ3
R-81	Roe, S. et al. (2019) Contribution of the land sector to a 1.5 °C world. Nature Climate Change, 2019. https://bit.ly/3O5cKoP
R-82	Brack, D. and King, R. (2021). Managing Land-based CDR: BECCS, Forests and Carbon Sequestration https://bit.ly/3HIGjHP

Source ID	Source with search strings
R-83	Günther, P. and Ekardt, F. (2022). Human Rights and Large-Scale Carbon Dioxide Removal: Potential Limits to BECCS and DACCS Deployment https://bit.ly/3OcsUg2 a: enormous risks
R-84	IPCC, 2018: IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. https://bit.ly/40ustS2 a: risky technologies
R-85	Fuss, S. et al. (2018). Negative emissions—Part 2: Costs, potentials and side effects. Env. Res. Lett. https://bit.ly/3X2XdXa a:table 2
R-86	National Academy of Sciences (2015). Climate Intervention: Carbon Dioxide Removal and Reliable Sequestration. https://bit.ly/40Q1MHM a: net uptake rates

Appendix B. Equivalence of cumulative radiative forcing and tonne-year accounting

1. To analyse the equivalence between emission reductions and removals, the following hypothetical example is used for illustrative purposes, where a pulse emission is offset by a pulse removal over an assumed time horizon of 100 years.

1. Equivalence without discounting

2. A pulse emission of 1 tCO_2 into the atmosphere results in a marginal change in the atmospheric concentration of CO_2 and causes a marginal radiative forcing. The amount of CO_2 remaining in the atmosphere decreases over time as the CO_2 is absorbed by the ocean, the biosphere, and other terrestrial sinks. Figure B.1(a) shows the decay profile of CO_2 remaining in the atmosphere. The decay continues beyond the time horizon, but the part beyond the time horizon is not considered.[1]

3. Figure B.1(b) shows a removal of 1 tCO_2 occurring at the same time as the emission pulse. As long as this removal is in effect and not released back into the atmosphere, the net change in the atmospheric CO_2 concentration is zero, and hence the marginal cumulative radiative forcing is zero. If the removal is released before the end of the time horizon, say in year 60, then the area under the decay curve of the new pulse emission represents the atmospheric damage (i.e. cumulative radiative forcing) caused by that release.

4. Calculation of the areas under the two curves in figure B.1(a) and figure B.1(b) shows that at the end of the time horizon, the marginal cumulative radiative forcing in the baseline scenario is 48.14 tonne-years, while the marginal cumulative radiative forcing in the removal activity scenario is 23.96 tonne-years. The removal activity, which consists of removing 1 tCO_2 in year 0 and re-emitting 1 tCO_2 in year 60, effectively reduces the marginal cumulative radiative forcing by 50.22 per cent. The removal activity is therefore equivalent to a permanent emission reduction of 0.5022 tCO_2.

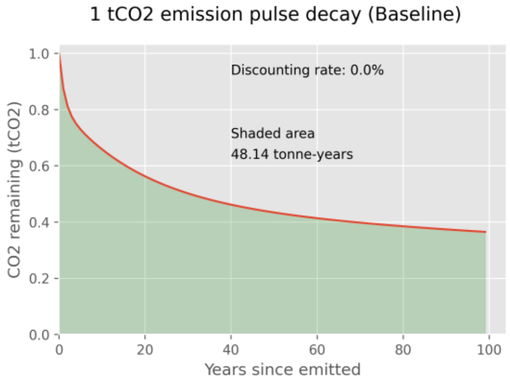
5. The factor, such as 0.5022 in this case, has been referred to in this note as the crediting factor, because multiplying the net tonnes of removals achieved and continuously retained outside the atmosphere for a specified period of time (hereinafter referred to as the storage period) by this factor gives the number of credits achieved by the removal activity.

6. It is clear from the above that 1 tCO_2 of removal can only be equated to 1 tCO_2 of emissions if the removed carbon stock is kept out of the atmosphere for the duration of the time horizon, i.e. up to 100 years. Thus, in the absence of discounting, the permanence period of removals is equal to the length of the time horizon.

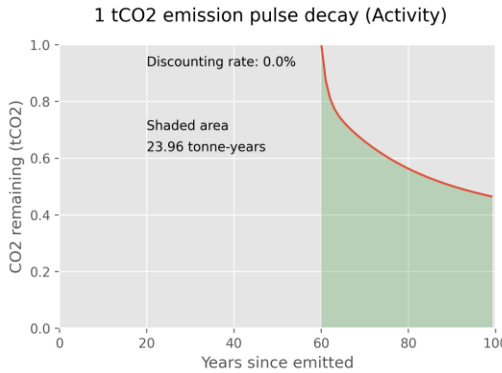
7. However, given that the marginal cumulative radiative forcing is equal to the product of the tonnes of CO_2 removed and the number of years that the removed tonnes are kept out of the atmosphere, the mitigation value equivalent to 1 tCO_2 of permanent removal can be achieved within 60 years if the quantity of removals is 1/0.5022 or 1.99 tCO_2 instead of 1 tCO_2. In other words, the removal of 1.99 tCO_2 with a storage period of 60 years results in a mitigation value equivalent to 1 tCO_2 of a 100-year removal.

[1] The time horizon defines the temporal boundary for the purpose of accounting of radiative forcing and its mitigation.

Figure B.1. Effect of 1 tCO_2 emission in year 0 compared to 1 tCO_2 removal followed by release in year 60, assuming a time horizon of 100 years and no discounting



(a) Carbon dioxide remaining in the atmosphere after a pulse emission of 1 tCO_2 in year 0 of the time horizon. The area under the curve is 48.14 tonne-years. The area is proportional to the marginal cumulative radiative forcing.



(b) Carbon dioxide remaining in the atmosphere after a pulse emission of 1 tCO_2 in year 60 of the time horizon. The area under the curve is 23.96 tonne-years.

2. Equivalence with discounting

8. When discounting is used, current mitigation is valued more than future mitigation. Similarly, current damage (cost) is valued more than future damage.

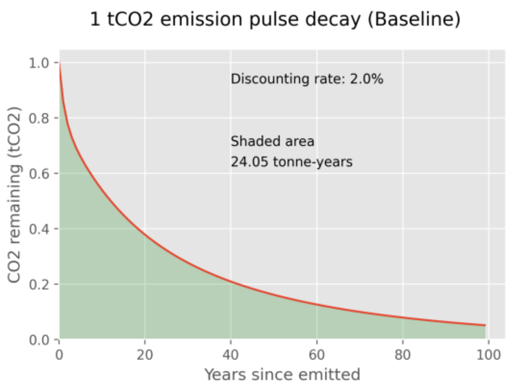
9. Applying a discount rate of 2 per cent results in the economic equivalent of the marginal cumulative radiative forcing caused by a 1 tCO_2 removal in year 0 followed by a 1 tCO_2 return in year 60 as shown in figure B.2.

10. Calculation of the areas under the two curves in figures B.2(a) and B.2(b) shows that at the end of the time horizon, the marginal cumulative radiative forcing caused by the baseline scenario is equivalent to 24.05 present tonne-years, while the marginal cumulative radiative forcing caused by the activity scenario is equivalent to 5.31 present tonne-years. Note that future tonne-years have been discounted to present tonne-years. The removal activity, which consists of removing 1 tCO_2 in year 0 and re-emitting 1 tCO_2 in year 60, effectively reduces the marginal cumulative radiative forcing by 77.91 per cent. The removal activity is therefore equivalent to a permanent emission reduction of 0.7791 tCO_2.

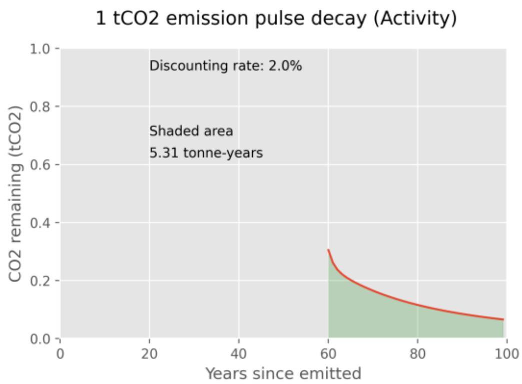
11. Using different discount rates with different storage periods produces the curves shown in figure B.2(c).

12. As the discount rate increases, the number of tonnes required to achieve 1 tCO_2 of mitigation over a given storage period decreases. Similarly, as the storage period increases, the crediting factor asymptotically approaches 1.0 for a storage period equal to the time horizon.

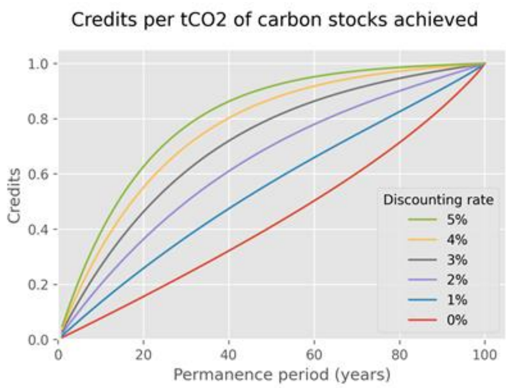
Figure B.2. Effect of 1 tCO_2 emission in year 0 compared to 1 tCO_2 removal followed by release in year 60, assuming a time horizon of 100 years and a discounting rate of 2 percent.



(a) Marginal cumulative forcing caused by a pulse emission of 1 tCO_2 in year 0 of the time horizon. The area under the curve is 24.05 present tonne-years.



(b) The present value of marginal cumulative forcing caused carbon dioxide remaining in the atmosphere following a pulse emission of 1 tCO_2 in year 60 of the time horizon. The area under the curve is 5.31 present tonne-years.



(c) Crediting factor curves for removal of 1 tCO_2 with different storage periods and discount rates.

13. Table B.1 provides the crediting factors at different storage periods and discount rates, assuming a time horizon of 100 years.

Table B.1. Crediting factors at different storage periods and discount rates[2]

Storage period (years)	0%	1%	2%	3%	4%	5%
1	0.007574	0.01402	0.0217	0.030134	0.038929	0.04783
2	0.015168	0.027912	0.042979	0.059392	0.076361	0.093383
3	0.022782	0.041677	0.063847	0.087801	0.112355	0.136767
4	0.030415	0.055316	0.084311	0.115385	0.146966	0.178086
5	0.038069	0.068832	0.104379	0.142169	0.180247	0.217438
6	0.045743	0.082224	0.124059	0.168175	0.212249	0.254916
7	0.053437	0.095495	0.143359	0.193426	0.243021	0.290611
8	0.061152	0.108646	0.162287	0.217944	0.272611	0.324606
9	0.068888	0.121679	0.180849	0.241752	0.301065	0.356983
10	0.076646	0.134594	0.199053	0.264868	0.328425	0.387819
11	0.084425	0.147392	0.216906	0.287314	0.354735	0.417187
12	0.092226	0.160076	0.234415	0.30911	0.380033	0.445157
13	0.100049	0.172646	0.251587	0.330273	0.404361	0.471796
14	0.107894	0.185104	0.268428	0.350823	0.427753	0.497167
15	0.115762	0.197451	0.284946	0.370778	0.450248	0.52133
16	0.123653	0.209689	0.301146	0.390154	0.471879	0.544344
17	0.131568	0.221817	0.317034	0.408969	0.492679	0.566262
18	0.139506	0.233839	0.332618	0.427239	0.512681	0.587137
19	0.147468	0.245755	0.347903	0.444981	0.531915	0.607019
20	0.155455	0.257566	0.362894	0.462209	0.55041	0.625955
21	0.163467	0.269273	0.377599	0.478938	0.568196	0.643989
22	0.171503	0.280879	0.392022	0.495183	0.585299	0.661166
23	0.179566	0.292383	0.40617	0.510959	0.601747	0.677525
24	0.187654	0.303788	0.420047	0.526279	0.617563	0.693106
25	0.195769	0.315094	0.43366	0.541156	0.632772	0.707946
26	0.203911	0.326303	0.447013	0.555603	0.647398	0.72208
27	0.21208	0.337416	0.460112	0.569633	0.661463	0.735542
28	0.220278	0.348434	0.472962	0.583258	0.674989	0.748363
29	0.228504	0.359358	0.485568	0.59649	0.687997	0.760575

[2] These factors are calculated using the Bern2.5CC model with the coefficients provided in the Fourth Assessment Report of the IPCC (IPCC-AR4-WG-I). The factors were independently calculated earlier in other published literature, i.e. Murray B. C. et al “Alternative approaches to addressing the risk of non-permanence in A/R projects under the CDM” (see a brief extract of crediting factors, without discounting, in Table 1 in Chapter 1 of the publication). Available at https://bit.ly/3xg3OUj.

Storage period (years)	0%	1%	2%	3%	4%	5%
30	0.236759	0.370191	0.497934	0.609341	0.700506	0.772206
31	0.245044	0.380932	0.510067	0.621821	0.712536	0.783284
32	0.253359	0.391583	0.521969	0.633942	0.724105	0.793835
33	0.261705	0.402145	0.533647	0.645714	0.735231	0.803885
34	0.270083	0.412621	0.545105	0.657147	0.745931	0.813457
35	0.278493	0.42301	0.556347	0.668252	0.756221	0.822574
36	0.286936	0.433314	0.567378	0.679037	0.766118	0.831258
37	0.295412	0.443534	0.578201	0.689513	0.775636	0.839529
38	0.303924	0.453673	0.588823	0.699688	0.78479	0.847408
39	0.312471	0.46373	0.599245	0.709572	0.793594	0.854912
40	0.321054	0.473707	0.609473	0.719173	0.802062	0.86206
41	0.329675	0.483606	0.619511	0.728499	0.810206	0.868869
42	0.338334	0.493427	0.629363	0.737558	0.81804	0.875354
43	0.347032	0.503173	0.639033	0.746359	0.825575	0.881532
44	0.355771	0.512844	0.648524	0.754909	0.832822	0.887416
45	0.364551	0.522442	0.65784	0.763215	0.839793	0.893022

14. The following observations can be made from table B.1:

    (a) The crediting factor of 1 cannot be achieved with a storage period shorter than the time horizon;

    (b) At a discount rate of 3 per cent, a storage period of 10 years gives a crediting factor of 0.26487. In other words, with a storage period of 10 years, every 3.78 tonnes of removals can result in a single credit;

    (c) With a storage period of 60 years and a discount rate of 3 per cent, 0.86307 credits can be issued for each tonne of removals. In other words, to obtain 1 credit 1/0.86307 or 1.159 tonnes of removals must be achieved.

15. It should be noted that a different time horizon results in a different set of crediting factors.

16. The permanence period is different from the activity period. The activity period may be shorter for underlying economic reasons or to match a shorter crediting period, but still can achieve the same level of permanence simply by storing more tonnes per credit.

17. The 'permanence' of mitigation achieved by removal activities is defined by the permanence period and not by the activity period.

18. Each credit generated by removal activities has the same mitigation value, i.e. it corresponds to the same amount of reduction in cumulative forcing, because the impact of the activity is assessed over the full permanence period.

19. Table B.2 contains a timeline of the consideration, application, and adoption of the tonne-year accounting approach in voluntary and compliance carbon markets.

Table B.2. Tonne-year accounting approach: A timeline

Period	**Event/activity relating to tonne-year accounting**
2000-2004	– Tonne-year accounting is discussed as a carbon accounting approach for Land Use, Land-use Change and Forestry (LULUCF) projects in the IPCC Special Report on LULUCF (R:26). – Tonne-year accounting is considered as an option during the negotiation of the CDM rules under the Kyoto Protocol. It finds some support among participants in the SBSTA workshop (R-64), during UNFCCC COP-8 deliberations (R-65), and in scientific and policy publications produced by international organizations (R-14).
2005	– Under the agreed A/R CDM rules, a modified version of tonne-year accounting is adopted in the form of expiring credits, called tCERs and lCERs, with reversal liability to be assumed by the buyers of the credits. The tonne-year approach is not adopted for reasons of political expediency (R-21) or perceived complexity (R-67:a). – In its Special Report on Carbon Capture and Storage, the IPCC describes tonne-year accounting as an option for dealing with reversals from geological storage of CO_2 (R-27).
2011	– Tonne-year approach is used to account for temporary carbon storage and delayed emissions in the British Standards Institution's PAS 2050 standard for the assessment of life cycle GHG emissions of goods and services (R-70:a). – Tonne-year accounting is discussed as an option to account for temporary storage of biogenic carbon in products at a workshop of the European Commission's Joint Research Centre (R-70).
2014	– UNFCCC technical paper for consideration by the SBSTA includes tonne-year accounting as an option to address non-permanence in the context of the revision of the CDM rules for the second commitment period of the Kyoto Protocol. Some Party and observer submissions support tonne-year accounting as an alternative approach to addressing non-permanence (R-66). Despite lengthy deliberations, the work will not be completed for political reasons.
2019-2021	Tonne-year accounting approach gains support in publications and carbon standards: – FAO publication on soil carbon stocks finds that tonne-year accounting based on the Lashof method is a sound basis for improved carbon accounting and that "regardless of the form of storage, the tonne-year unit is very appropriate for including biogenic carbon flows in GWP calculations" (R-03:b, R-03:c). – A Harvard Kennedy School paper on California compliance offsets recommends tonne-year accounting as a solution to the teeming problems and public criticism of their forestry projects (R-49:e). – Voluntary carbon market actor Climate Action Reserves (CAR) adopts tonne-year accounting as an option in its methodology entitled Canada Grassland Protocol (R-78). – Voluntary carbon market actor Natural Capital Exchange (NCX) adopts tonne-year accounting as the basis of its methodology for delayed timber harvesting (R-74).

Period	Event/activity relating to tonne-year accounting
	– The Institute of Foresters of Australia and Australian Forest Growers, in their submission to the New South Wales Legislative Council, recommend the adoption of tonne-year accounting to adequately value the carbon services provided by the forestry sector (R-67:b).
2022	– Voluntary carbon market actor Verra launches public consultation on the use of tonne-year accounting in its methodologies. Stakeholders respond both in favour and against the use of tonne-year accounting. Verra decides not to adopt tonne-year accounting, specifically because "the small volume of tonnes that can be credited at a 100 to 1 conversion rate makes the economics of using this approach challenging" (R-54:a). – The Government of Canada adopts the use of tonne-year accounting as an option for the removals quantification method in federal offset protocols under the Canadian Greenhouse Gas Offset Credit System (R-09). – CAR adopts tonne-year accounting as an option in its Soil Enrichment Protocol (R-72) and Mexico Forest Protocol (R-40). – Government of Quebec publishes regulation on afforestation and reforestation projects for the issuance of offset credits, requiring participants to use tonne-year accounting based on 100-year radiative forcing to quantify both removals and emissions (R-68:a). – Voluntary carbon market actor Nori uses tonne-year accounting as the basis for its NRT tokens, each of which represents 10 years of storage of removals (R-01). – Voluntary carbon market actor Integrity Council for Voluntary Carbon Markets (ICVCM) launches public consultation on its draft Core Carbon Principles in which tonne-year accounting is considered as a possible option for accounting removals in land-based project activities (R-51). – The private sector carbon accounting and reporting standard the Greenhouse Gas Protocol (GHG Protocol) launches public consultation on its draft guidance on land use and removals for pilot testing (R-77).
2022-23	More scientific papers are published furthering the understanding of tonne-year accounting approach. Some findings and observations are presented below: – The tonne-year is the most consistent accounting approach across project timelines, forest types and project configurations (R-23:b). – Under a "reimagined" tonne-year approach, tonne-year accounting could be effectively used as a metric to track the contribution of temporary carbon storage to climate change mitigation goals (R-73). – A new metric called Climate Benefit of Sequestration (CBS), based on radiative forcing, is proposed to quantify the impact of avoided warming. The authors conclude that "ton-year" accounting methods are similar to their approach to carbon sequestration (R48:a). - The tonne-year approach is applied to carbon pricing, considering that pricing on a per-tonne basis fails to take into account the duration of storage (R-79). Economic approaches based on discount rates are proposed as an alternative to tonne-year accounting based on cumulative radiative forcing:

Period	Event/activity relating to tonne-year accounting
	– Using a discount-rate-only formulation, a method called the Social Value of Offsets (SVO) finds that 2.5 offsets, each sequestering 1 tCO_2 for 50 years, are equivalent to 1 tCO_2 of permanent removal (P-18:b). – A discount-rate-only method called Permanent Additional Carbon Tonne (PACT) is developed and found to be applicable to a wide range of nature-based solutions and credit-generating projects (R-76). – The preference for early action leads to the conclusion that several tonnes of short-term carbon storage in ecosystem stocks can be considered to have the same value—in terms of the social cost of carbon—as 1 tonne of carbon permanently sequestered. (R-75).

Appendix C. Time horizon and its choice

1. All climate change policies are underpinned by objectives and targets to be achieved over a finite period of time. Therefore, in terms of policy relevance, the equivalence of mitigation services provided by avoided emissions and those provided by removals can only be compared within a common finite time horizon.

2. A time-horizon-based approach was used to compare the climate change impacts of emissions of different GHGs with different atmospheric residence times and radiative forcing per molecule. Global warming potentials (GWPs) are calculated by integrating the total radiative forcing of an emission pulse over a 100-year time horizon. Relative GWPs are calculated as the ratio of the cumulative radiative forcing caused by 1 tonne of a given GHG to that caused by 1 tonne of CO_2.

3. A commonly adopted climate-relevant time horizon is 100 years, as shown below:

   (a) In the IPCC 2019 refinements to the 2006 guidelines, the biochar methodology uses 100 years as the basis for permanence;

   (b) The British Standards Publicly Available Specification for the Assessment of Life Cycle Greenhouse Gas Emissions of Goods and Services (PAS 2050) uses the same approach for carbon storage as for delayed emissions and uses 100 years as the assessment period;

   (c) The International Life Cycle Data Handbook General Guide for Life Cycle Assessment (ILCD Handbook) recommends a time horizon of 100 years;

   (d) The forestry offset protocols of some existing mechanisms such as Climate Action Reserve (CAR), Regional Greenhouse Gas Initiative (RGGI), Australian Carbon Farming Initiative and California Air Resources Board (CARB) require monitoring, verification and reporting for a period of 100 years from credit issuance;

   (e) Other private organizations, such as Carbon Standards International's Carbon Sink Registry, use a 100-year time horizon to qualify permanence of removals (see https://bit.ly/3Mkm2KQ).

4. The choice of time horizon is a normative judgement rather than an expression of scientific consensus or physical reality.

5. Choosing a shorter time horizon implies that earlier climate action is more relevant compared to late climate action. Assuming that the global economy will be decarbonized by 2100, a time horizon of 75 years (i.e. from 2025 to 2100) may be appropriate, as any mitigation action after decarbonization will have little relevance to the objective of decarbonization.

Appendix D. Discount rate and its choice

1. Discounting is the mechanism by which the time value is accounted for in economic decision making. Mitigation value (which correlates with avoided damage) generated early is worth more than mitigation value generated late in the future. Therefore, it is efficient to discount the future mitigation value to its net present value using the social discount rate relevant to climate policy.

2. Various climate policy assessments have recommended different discount rates, such as 1.4 per cent (Stern 2007), 2.0 per cent (Cline 1992) and 4.3 per cent (Nordhaus 2007).[1]

3. Another study finds that the average recommended discount rate relevant to climate policy is 2.27 per cent , with a range from 0 to 10 per cent. In this study, more than three-quarters of the economists surveyed were comfortable with the median discount rate of 2 per cent, and more than 90 per cent of them found a discount rate in the range of 1–3 per cent acceptable. The same team of authors has since surveyed expert philosophers. For this group, the median responses are almost identical at 2.27 per cent. Over 90 per cent are comfortable with a discount rate of 2 per cent.[2]

4. Some of the common arguments found in the economic literature on the use of discounting in climate policy are summarized below:[3]

   (a) The social cost of carbon (SCC)—the cost to society of emitting an additional tonne of CO_2—is a measure of the impact of climate change on human society. Economists favour different values of SCC, leading to different policy prescriptions;

   (b) Projects, including those related to climate change, should be valued by discounting costs and benefits at the market rate of return, properly adjusted for uncertainty and for the inherent value of the environment;

   (c) Discounting should be seen only as a method for selecting projects, not as a method for determining our ethical obligations to the future;

   (d) The Ramsey discounting equation breaks down discounting rate into three factors as $r = \eta g + \delta$, where r is the discount rate, η is the elasticity of marginal utility of consumption, g is the growth rate of consumption, and δ is the pure rate of time preference;

   (e) Most economists believe that discount rates should be positive, both because people are impatient (positive rate of pure time preference) and because people will have higher incomes on average in the future (and hence lower marginal utility from additional consumption). The experience of the last few hundred years is consistent with this expectation;

[1] Goulder L. H. and Williams R. C. The choice of discount rate for climate change policy evaluation (2012) Available at https://stanford.io/3Reu4G1.

[2] Drupp, M. et al. Philosophers and Economists Can Agree on the Intergenerational Discount Rate and Climate Policy Paths (2022) Available at https://bit.ly/3D9jhrB.

[3] The summary largely follows this paper: Weisbach, D. and Sunstein C.R. Climate Change and Discounting the Future: A Guide for the Perplexed. Available at https://bit.ly/3cQzubJ.

(f) Discounting rate plays a role in determining whether to recommend policies that rapidly reduce emissions or policies that take a more gradual approach to reducing emissions.

5. When selecting a discount rate to value the mitigation contribution of removal activities, the following may be considered:

(a) A higher discount rate (e.g. 3 per cent) values earlier mitigation more than later mitigation (i.e. a greater sense of urgency for climate action). A zero per cent discount rate implies that it does not matter whether 1 tCO_2 of mitigation is achieved today or at some point in the future. Discounting at non-zero rates implies that mitigation in the near future is more valuable than mitigation far in the future;

(b) A higher discount rate (e.g. 3 per cent) gives removal activities a more important place in the mitigation strategy, alongside emission reduction activities;

(c) Both short-term and long-term removal activities have a mitigation value if the value is calculated based on the equivalence of the marginal cumulative radiative forcing. However, short-term activities are incentivized more when a higher discount rate (e.g. 3 per cent) is used.[4]

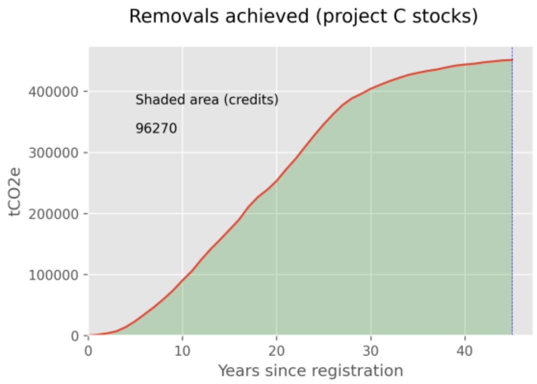
[4] A higher carbon price also incentivizes small-size activities participation in the mechanism. For example, with a carbon price of USD 100 per tCO_2, some small-holders in low-income countries may get motivated to participate in the mechanism even with crediting at a zero per cent discount rate.

Appendix E. Tonne-year crediting: an illustrative example

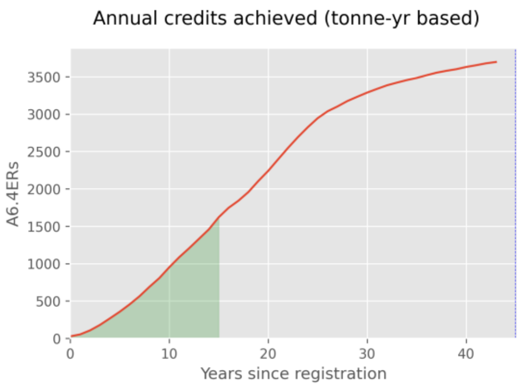
1. A removal activity consists of afforestation in a watershed with a total area of 1,150 hectares (ha) and a plantable area of 1,000 ha. The 1,000-ha activity area is planted in phases, with 200, 200, 350 and 250 ha planted in years 1, 3, 4 and 5 respectively. Local species are used, and local communities are allowed to harvest annually 5 t/ha of biomass from year 15 onwards. Two fire and pest events occur in years 12 and 21, with biomass losses of 10,000 and 5,000 tonnes respectively. Plant mortality occurs during the first 5 years and thinning of the plantation occurs in years 7 and 11. The tree species used have a growth profile such that the biomass per hectare reaches saturation (or equilibrium with the biomass extraction rate) in year 35. A crediting period of 45 years is assumed.

2. As shown in figure E.1(a), total biomass in the catchment reaches saturation at about 451,000 tCO_2. By the end of the crediting period, a total of 96,270 credits are achieved. Most of the credits get issued in the second half of the crediting period.

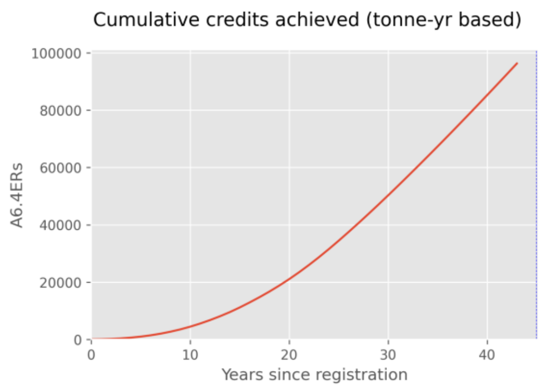
Figure E.1. Removal activity consisting of tropical watershed reforestation with mixed stands of local species (tonne-year accounting)



(a) Evolution of carbon stocks in the in-situ carbon pools



(b) Number of credits achieved per year (e.g. in and around year 20, approx. 4,000 credits are earned per year). Total credits achieved up to a year are represented by the green area under the curve.



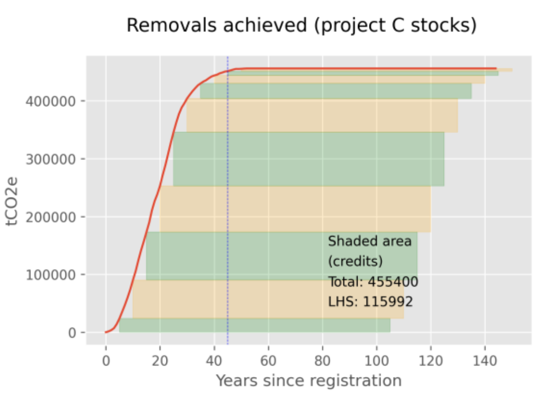
(c) Cumulative number of credits achieved. By the end of the crediting period (year 45) 96,270 credits are achieved.

Appendix F. Tonne-based crediting: an illustrative example

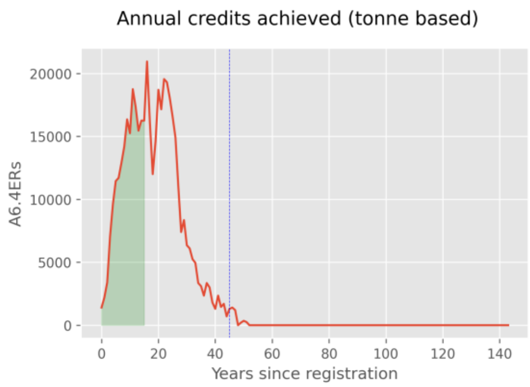
1. The same afforestation activity described in appendix E is credited using the tonne-based crediting method. As tonnes are verified at regular intervals (5 years in this example, but could be at any interval), credits are issued equal to the number of verified tonnes. This is on the condition that the tonnes of removals for which credits have been issued are stored for the full permanence period, i.e. 100 years from the date of issuance.

2. Figure F.1 shows the stocks of removals and credits resulting from tonne-based crediting for the same watershed reforestation example described in appendix E.

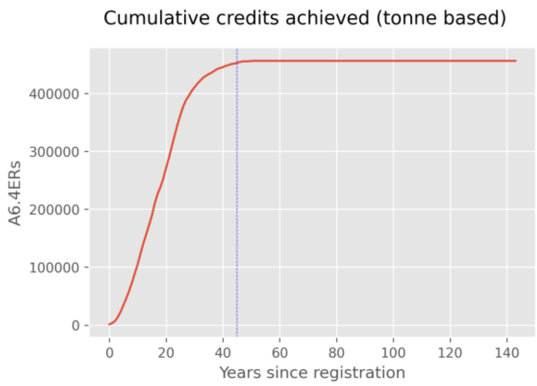
Figure F.1. Removal activity consisting of tropical watershed reforestation with mixed stands of local species (tonne-based crediting)



(a) Evolution of carbon stocks in the in-situ carbon pools.



(b) Number of credits achieved per year (e.g. in and around year 20, about 15,000 credits are earned per year). Total credits achieved by a year are represented by the shaded area under the curve.



(c) Cumulative number of credits achieved. By the end of the crediting period (year 45), 455,400 credits are achieved.

3. The shaded rectangular areas represent the credits resulting from verifications at each five-year interval. The figure shows that the stocks of removals associated with credits

issued in later years will need to be verified periodically over a longer period than the crediting period (i.e. up to year 145 from the start of the activity).

4. The shaded area includes mitigation produced in the years beyond the end of the crediting period. This results in a total of 455,400 credits, which is more than four times the number of credits that get issued under tonne-year crediting.

5. Under this approach most credits are issued in the first half of the crediting period.

Appendix G. Risk mitigation and compensation mechanism

1. A risk mitigation and compensation mechanism is established to address the reversal of removals when credits are issued prior to verification of the required storage.

2. A mandatory post-issuance monitoring report is required at fixed intervals to monitor any reversals.

3. A mandatory post-issuance monitoring report is also required whenever an event occurs that could potentially lead to release of stocks of removals into the atmosphere such that the remaining stocks could be less than the verified tonnes for which credits were issued.

4. If a required monitoring report is not received within the prescribed time, it is assumed that all the stocks of removals have been released into the atmosphere, and the reversal compensation process should be triggered.

5. A risk mitigation and compensation mechanism could operate as follows:

    (a) A percentage of the credits is set aside in a buffer pool of credits at the time of issuance. In the event of a reversal, an equivalent number of credits from the buffer pool are used to replace the credits affected by the reversal;

    (b) A pooled buffer enables sharing of risk by the activities that have subscribed to it. However, at any given time, the buffer may or may not have sufficient resilience to absorb simultaneous reversals from several activities. If the buffer is exhausted before all reversals have been compensated, the liability is assumed by the host Party or by a commercial insurer;

    (c) Since the buffer pool at a given point in time will consist of credits of different "maturity" (i.e. different verified storage periods relative to the required storage period), it will be necessary to decide which credits are used to compensate for a particular event of reversal;

    (d) A buffer at individual activity level means that an activity can only use its own buffered credits in the event of a reversal. Any reversal that exceeds the size of the buffer cannot be compensated. A particular difficulty arises when the activity participants decide to abandon the activity. For example, in year 5, the removal activity X is issued with 100 credits, of which 70 are held by the activity participants and 30 are held in the buffer. In year 10, the activity participants no longer wish to continue the activity and reverse all the removals. At this point, the 30 credits held in the buffer are also invalidated, since the tonnes underlying these credits have been reversed. In view of these considerations, a permanence buffer at individual activity level does not appear to be feasible;

    (e) A guarantee from the host Party or an entity designated by it, or a commercial insurer, could assume liability for intentional reversals and the portion of unintentional reversals exceeding the capacity of the buffer. The buffer could be required to be segmented by host Party countries, as activities hosted in one Party may report reversals more often than another. A guarantee from the host Party could also be required in the early stages of the mechanism until the buffer pool of credits is capitalized to a sufficient level of resilience. How a host Party compensates for reversals will need to be decided by that Party. For example, the host Party may use public funds to purchase A6.4ERs from the market, or they may levy a financial contribution from all registering activities to create a fund to purchase A6.4ERs to be used to meet the liability;

(f) The percentage of credits to be contributed by a removal activity to the permanence buffer could be determined on the basis of the risk rating of the activity. This percentage could be either determined ex-ante at the time of registration of the activity or re-assessed ex post at the time of verification as the risk profile of the activity could change over time;

(g) Credits accumulated in the permanence buffer could be permanently retained or returned to the activity participants once all credits issued for a removal activity have met the permanence requirement. Retaining credits would increase the resilience of the permanence buffer. Another option could be to return the credits to the activity participants where an activity did not experience reversals. This option would incentivize good risk management by activity participants.

Reliability

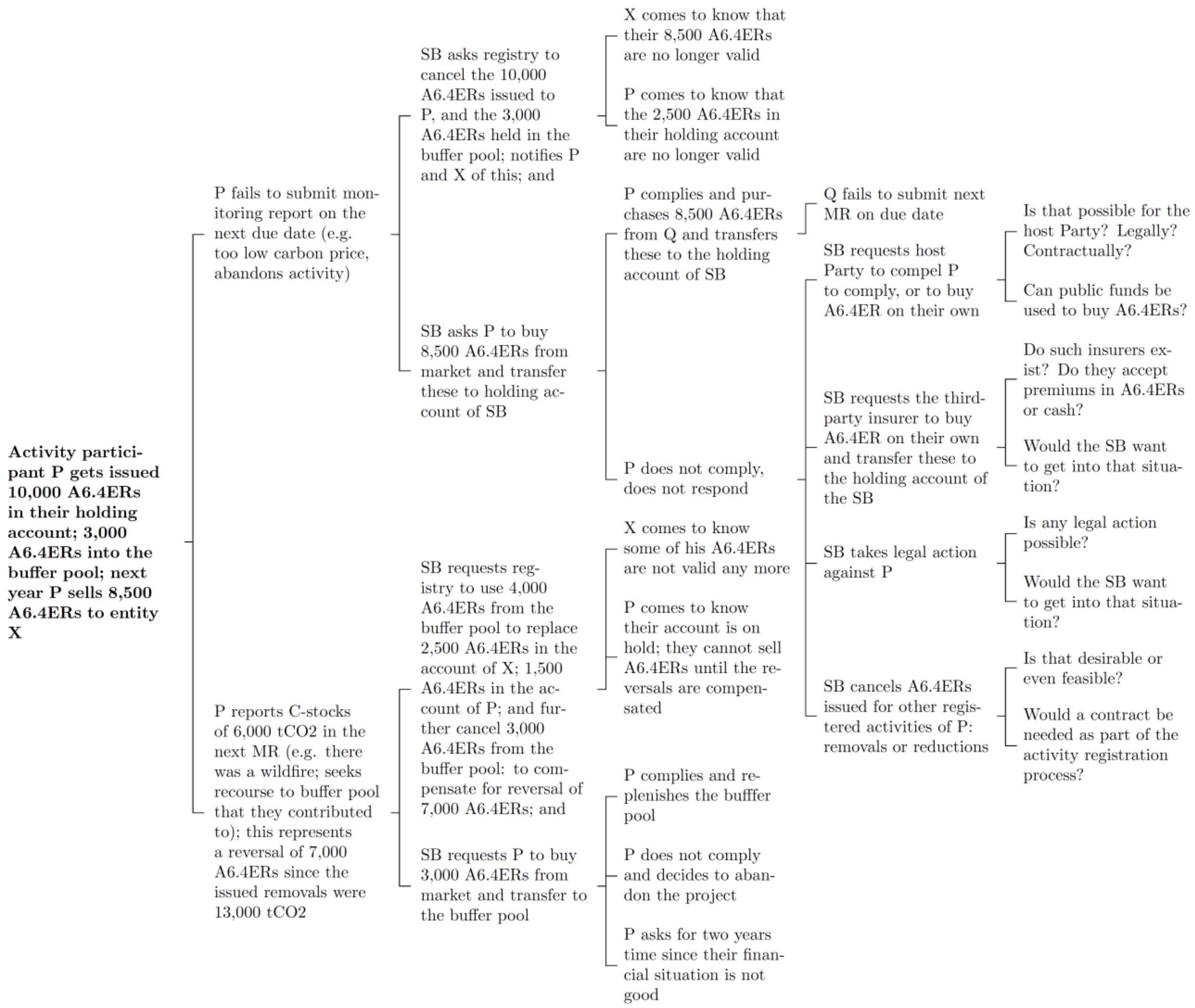
6. The adequacy of a risk mitigation and compensation mechanism should be assessed by considering how well it can address the worst-case scenario.

7. Figure G.1 shows an example of a chain of events that may or may not be fully addressed by pooled buffer arrangements backed by a host Party guarantee, depending on the options and choices available to host Parties under the domestic socio-legal environment.

8. There are also other unresolved enforceability issues, such as: what to do in the event of non-payment of the risk premium to the insurer; the level of assurance that host Parties will have the financial means to compensate for any reversals; what to do if commercial insurance for this type of activity is not available in a host Party.

Figure G1. Possible issues that can arise in risk management and compensation: a hypothetical event tree (abbr. used SB: Supervisory Body)

Abbreviations: A6.4ERs: Article 6, paragraph 4, emission reductions; SB: Supervisory Body



Appendix H. Land-based removal activity supported by long-term storage of removals

1. Removal activity with bioenergy with carbon capture and storage

1. To illustrate how bioenergy with carbon capture and storage (BECCS) can increase the removal potential of a given area of land, consider the reforestation simulation example described in appendix E with some modifications. An area of 1,000 hectares (ha) is afforested using relatively fast-growing species with a 15-year rotation. To ensure a constant flow of biomass to drive the energy system, the area is planted in 15 stands, each one year apart. After 15 years, the mature stand is harvested each year and the biomass is used for energy purposes. The carbon dioxide from the combustion of biomass is captured and stored in a geological formation. The carbon capture and storage (CCS) facility is assumed to be 80 per cent efficient in capturing and storing the carbon contained in the biomass.

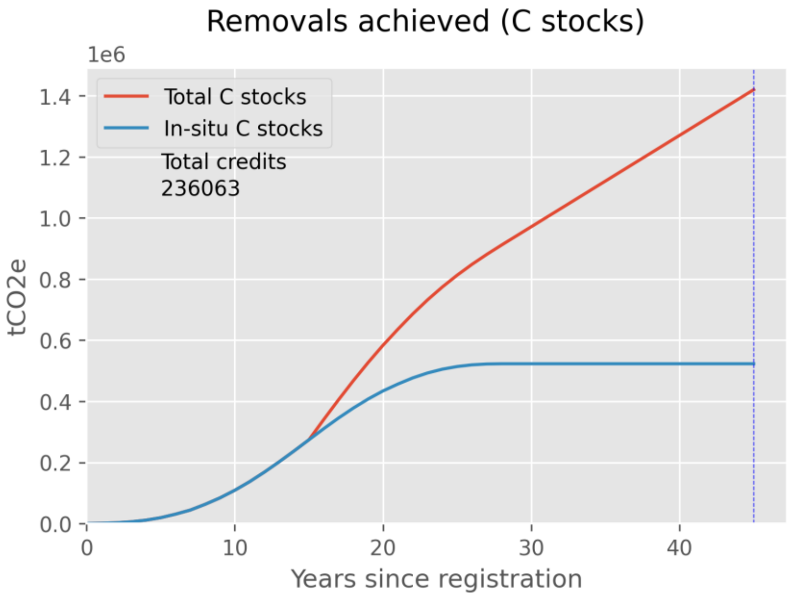
2. The resulting carbon stocks and removal credits generated by the activity are shown in Figure H.1. Credits are estimated on a tonne-year basis without discounting.

3. Figure H.1 shows that total carbon stocks of 1.4 million tonnes of carbon dioxide ($MtCO_2$) are achieved over the crediting period of 45 years. The in-situ carbon stocks are saturated by year 25, but the continued removal of biomass opens up a biosequestration stream and the carbon is transferred from the atmosphere to geological storage via the CCS component, while the in-situ component (the growing stock) remains constant.

4. A total of 236,063 credits are generated at the end of the crediting period (compared to 96,270 credits in the case of watershed reforestation).

5. Emissions associated with plantation establishment and the energy used to operate the CCS system and transport emissions are not included in this simulation. If significant, these would have to be deducted from the credits shown in the example.

Figure H.1. Removal activity consisting of afforestation with fast-growing species with biomass feeding into bioenergy with carbon capture and storage (tonne-year crediting). The plot shows the evolution of carbon stocks in the in-situ carbon pools and in geological storage



2. Removal activity with storage in durable products

6. To illustrate how long-lived harvested wood products (HWP) can increase the removal potential of a given area, consider the afforestation simulation example in appendix E with some modification. An area of 1,000 ha is afforested using relatively fast-growing species with a 15-year rotation and a sustained-yield design. To ensure a sustained yield of wood products, the area is planted in 15 stands, each one year apart. After 15 years, the mature stand is harvested each year and the wood products from the harvest are used for their economic value. It is assumed that the annual harvest yields four different types of wood products with the following fractional weights: sawn wood 0.30; veneer 0.20; paper 0.30; and fuelwood and fodder 0.20. Of these, the last type (fuelwood and fodder) is not a long-lived product and the carbon stocks contained in this fraction of biomass are assumed to be emitted immediately. For the remaining three fractions (sawn wood, veneer and paper), the Intergovernmental Panel on Climate Change (IPCC) default half-lives of 35 years, 30 years and 2 years are assumed.

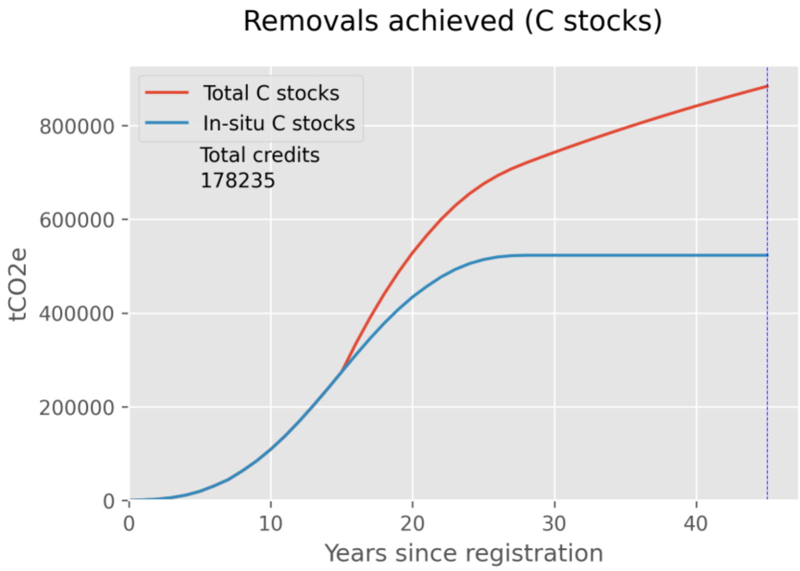
7. The resulting carbon stocks and removal credits generated by the activity are shown in Figure H.2. Credits are estimated on a tonne-year basis without discounting.

8. Figure H.2 shows that total carbon stocks of 850,000 tCO_2 are achieved over the crediting period of 45 years. The in-situ carbon stocks are saturated by year 25, but the continued removal of biomass opens up the biosequestration flux and the carbon is transferred from the atmosphere to the wood products pool.

9. A total of 178,235 credits are achieved by the end of the crediting period (compared to 96,270 credits for watershed reforestation and 236,063 credits for afforestation with BECCS).

10. Emissions associated with plantation establishment and energy used to operate the CCS system and transport emissions are not included in this simulation. If significant, these would have to be deducted from the credits shown in the example.

Figure H.2. Removal activity consisting of afforestation with fast-growing species with sustained harvesting of long-lasting wood products (tonne-year crediting)



Appendix I. Summary descriptions of engineering-based removal activities

1. Direct air carbon capture and storage

1. Direct air carbon capture and storage (DACCS) involves the capture of CO_2 from ambient air by chemical processes and subsequent storage of the captured CO_2 in geological formations. While the theoretical potential for DACCS is mainly limited by the availability of safe and accessible geological storage, the concentration of CO_2 in ambient air is 100-300 times lower than in thermal power plants and therefore requires much more energy than flue gas CO_2 capture. There is little agreement in the literature on the metrics associated with DACCS (energy use, water use, cost, etc.). Cost estimates range from USD 20 to USD 1,000 per tonne of CO_2. Given the early stage of development of the technology and the limited number of demonstrations, large-scale deployment remains a significant challenge, although there are both optimistic and pessimistic outlooks.

2. DACCS has the same transport and storage components as conventional CCS, but differs in its capture part.

3. An alternative approach is direct air carbon capture and utilisation (DACCU), where the captured CO_2 is used to make useful products. The duration of removal by DACCU varies with the lifetime of the products, ranging from weeks to months for synthetic fuels to centuries or more for building materials (e.g. concrete cured by mineral carbonation).

4. The efficiency and environmental impact of DACCS and DACCU options depend on the carbon intensity of the input energy (electricity and heat) and other LCA considerations. An important metric is the net CO_2 removal of DACCS over its life cycle. Some research has reported that the net lifecycle emissions of DACCS systems can even be negative for existing supply chains and energy mixes.

5. **Status** - There are a few demonstration projects by start-up companies and academic researchers. They are developing various types of direct air capture (DAC) technologies, including the use of aqueous potassium solvents with calcium carbonation and solid sorbents for heat regeneration. These projects are mostly supported by private investment and grants and sometimes serve niche markets (e.g. CO_2 for beverages, greenhouses, and enhanced oil recovery).

6. **Potentials** - There is no specific study on the potential of DACCS, but the literature suggests that the technical potential of DACCS is virtually unlimited, provided that high energy demands can be met, as DACCS faces fewer non-cost constraints than any other CDR process. It has been reported that, focusing on the Maghreb region alone, there is an optimistic potential to remove 150 gigatonnes of carbon dioxide (Gt CO_2) by 2050 at less than USD 61 per tonne of CO_2. Other studies suggest a potential of 0.5-5 Gt CO_2 per year by 2050 due to environmental side effects and limitations of underground storage.

7. **Risks and impacts** - DACCS requires significant amounts of energy and, depending on the technology, large amounts of water and make-up sorbents, but its land footprint is small compared to other CDR methods. However, depending on the energy source for DACCS (e.g. renewable versus nuclear), it could also require a significant land footprint. The theoretical minimum energy requirement for separating CO_2 gas from air is about 0.5 gigajoules (GJ) per tonne of CO_2. Other studies have estimated the energy requirement

for current technologies at around 4–10 GJ per tonne of CO_2, with heat accounting for about 80 per cent and electricity for about 20 per cent. At a sequestration rate of 10 Gt CO_2/yr-1, this would correspond to 40–100 exajoules (EJ)/yr-1 of energy consumption, compared to the current primary energy supply of about 600 EJ/yr^{-1}.

8. **Co-benefits** - It has been suggested that solid sorbent-based DAC plants could use surplus renewable electricity (at times of low or negative prices), although such operation would involve additional costs. Plants would have to be designed to operate intermittently (i.e. at low load factors), which would have a negative impact on capital and operating costs. Solid sorbent DAC designs can potentially remove more water from the ambient air than is needed for regeneration, thereby providing surplus water that would contribute to Sustainable Development Goal (SDG) 6 (Clean water and sanitation) in arid regions.

9. **Trade-offs and spill over effects** - Liquid solvent DACCS systems require significant amounts of water, although much less than BECCS systems. Although the high energy demand of DACCS could have a negative impact on SDG 7 (Affordable and clean energy) through potential competition or a positive impact through learning effects, its impact has not yet been thoroughly assessed.

2. Enhanced rock weathering

10. Enhanced rock weathering (EW) involves mining rocks containing minerals that naturally absorb CO_2 from the atmosphere over geological timescales (as they are exposed to the atmosphere through geological weathering), crushing these rocks to increase their surface area, and spreading these crushed rocks on soils to react with atmospheric CO_2. Construction and mining waste can also be used as a source of EW. Silicate rocks (such as basalt), which contain minerals rich in calcium and magnesium and are deficient in metal ions such as nickel and chromium, are the most suitable rocks for EW.

11. **Status** - EW has been demonstrated in the laboratory and in small-scale field trials, but has yet to be demonstrated on a large scale. The chemical reactions are well understood, but the behaviour of the fractured rock in the field and the potential benefits and side effects of EW are uncertain. Small-scale laboratory experiments have calculated weathering rates that are orders of magnitude slower than the theoretical limit. Uncertainties regarding the rates of dissolution of silicate minerals in soils, the fate of released products, the extent of legacy reserves of mining by-products that could be exploited, the location and availability of rock extraction sites, and impacts on ecosystems remain poorly quantified and require further research to better understand the feasibility of EW as a removal activity.

12. **Costs** - Costs are closely related to the source of the rock, the technology used to crush the rock, and the transportation of the material. Due to differences in methodologies and assumptions between studies, cost ranges in literature are highly variable from USD 15 to USD 3,460 per tCO_2. One study suggested a cost range of 50–200 per tCO_2 for a removal potential of 2–4 $GtCO_2$ per year from 2050.

13. **Potentials** - There is limited evidence and little agreement on the mitigation potential of EW. The highest reported regional sequestration potential, 88.1 $GtCO_2$ per year is reported for pulverised rock spreading over a very large area in the tropics, a region considered promising due to higher temperatures and rainfall. Considering only arable land, the potential annual carbon removal is estimated to be 95 $GtCO_2$ for dunite and 4.9 $GtCO_2$ for basalt. Another study estimated a lower potential of 3.7 $GtCO_2$ by 2100, but with mean annual removals at 0.2 $GtCO_2$.

14. **Risks and impacts** - Mining rock for EW will have local impacts and risks similar to those associated with the mining of mineral aggregates, with the possible additional risk of greater dust generation from fine crushing and land application. In addition to direct habitat destruction and increased traffic to access mining sites, there could be adverse impacts on local water quality.

15. **Co-benefits** - EW can improve plant growth by increasing mineral supply and can enhance soil carbon sequestration in some soils. Through these actions, it can contribute to SDGs 2 (Zero hunger), 15 (Life on land, by reducing demand for arable land), 14 (Life under water, by mitigating ocean acidification) and 6 (Clean water and sanitation). There are potential poverty reduction benefits from the employment of local workers in mining.

16. **Trade-offs and spillover effects** - Air quality could be adversely affected by the spread of rock dust, although this can be partly mitigated by water spraying. As noted above, any significant expansion of the mining industry would require careful assessment to avoid potential adverse impacts on biodiversity. Processing an additional 10 billion tonnes of rock would require up to 3,000 terawatt-hours of electricity, which could be about 0.1-6 per cent of the world's electricity in 2100. The emissions associated with this additional power generation could reduce net CO_2 removal by up to 30 per cent with today's average grid emissions, but this efficiency loss would be reduced with low-carbon electricity.

3. Ocean alkalinization

17. CDR through ocean alkalinity enhancement or artificial ocean alkalinization (OA) is based on the dissolution of natural alkaline minerals added directly to the ocean or coastal environment, the dissolution of such minerals upstream of the ocean, the addition of synthetic alkaline materials directly to the ocean or upstream, and the electrochemical processing of seawater. These processes result in the chemical transformation of CO_2 and its sequestration as bicarbonate and carbonate ions in the ocean. Imbalances between the fluxes of alkalinity into and out of the ocean can lead to changes in global oceanic alkalinity and hence in the ocean's capacity to store carbon. Such alkalinity-induced changes in the partitioning of carbon between the atmosphere and the ocean are thought to play an important role in controlling climate change on timescales of 1,000 years and longer.

18. **Status** - OA has been demonstrated by a small number of laboratory experiments.

19. **Costs** - Techno-economic assessments of ocean alkalinity enhancement focus largely on quantifying the total energy and carbon balances. Costs range from USD 40–260 per tCO_2. Considering the lifecycle carbon and energy balances for different OA options, adding lime or other reactive calcium or magnesium oxide/ hydroxides to the ocean could cost USD 64–260 per tCO_2.

20. **Potentials** - The ocean theoretically has the capacity to store thousands of Gt CO_2 (cumulatively) without exceeding pre-industrial levels of carbonate saturation, if the impacts are evenly distributed across the surface ocean. The potential to increase ocean alkalinity may be limited by (i) the limited capacity to extract, process and trigger chemical reactions; (ii) the demand for co-benefits; and/or (iii) the need to minimize impacts around the points of addition. Important challenges to the detailed quantification of CO_2 sequestration efficiency include non-stoichiometric dissolution, reverse weathering and potential porewater saturation when adding minerals to shallow coastal environments. Some researchers suggest storage potentials of 1–100 $GtCO_2$ per year.

21. **Risks and impacts** - The marine biological impacts of OA are largely unknown. The ecological and biogeochemical consequences of OA depend largely on the minerals used. If natural minerals such as olivine are used, the release of additional silicon and iron could have fertilizing effects. In addition to the disturbance of marine ecosystems through the reorganization of the community structure, the release of toxic trace metals from some deposited minerals is a potential adverse effect of OA that needs to be investigated.

22. **Co-benefits** - The deliberate addition of alkalinity to the oceans through OA would reduce the risk to marine ecosystems from the CO_2-induced effects of ocean acidification on marine biota and the global carbon cycle. OA could be implemented in conjunction with EW, with the finely crushed rock being applied in the ocean rather than on land. Regional alkalinization could be effective in protecting coral reefs from acidification. Coastal OA could be part of a broader strategy for geochemical management of the coastal zone to protect specific coastal ecosystems from the adverse effects of ocean acidification.

23. **Trade-offs and spillover effects** - There has been very little research on the biological effects of alkalinity addition. The few studies that have examined the effects of increased alkalinity on marine ecosystems have largely been limited to single species experiments and a limited field study to quantify the net calcification response of a coral reef flat to alkalinity enhancement. The rate of addition would need to be high enough to overcome mixing of local seawater with the surrounding environment, but not so high as to adversely affect ecosystems. Further research is needed to assess where this might be feasible and how such a system might operate. The environmental impact of the large-scale release of natural dissolution products into the coastal environment will depend strongly on the scale of olivine application, the characteristics of the coastal water body (e.g. residence time) and the particular biota present (e.g. coral reefs will react differently to seagrasses). Model simulations suggest that large-scale cessation of OA under a high CO_2 emission scenario could pose high risks to biological systems sensitive to rapid environmental change, as it would cause a sharp increase in ocean acidification.

4. Ocean fertilization

24. Ocean fertilization (OF) is based on the idea that increasing nutrient availability would stimulate the uptake of CO_2 by phytoplankton through photosynthesis to produce organic matter, some of which would be exported to the deep ocean, sequestering carbon. In areas of the ocean where macronutrients (nitrogen, phosphorus) are abundant, phytoplankton growth is limited by the lack of trace elements such as iron. Thus, OF can use two implementation options to increase phytoplankton productivity: macronutrient enrichment and micronutrient enrichment. Iron fertilization is the best studied OF option to date, but knowledge is still insufficient to predict global ecological and biogeochemical consequences.

25. **Status** - OF options appear to be technologically feasible, and the enhancement of photosynthesis and CO_2 uptake from surface waters is confirmed by a number of field experiments conducted in different areas of the ocean, but there is scientific uncertainty about the proportion of newly formed organic carbon that is transferred to the deep ocean and the longevity of storage. The efficiency of OF also depends on the region and experimental conditions, particularly in relation to the availability of other nutrients, light and temperature. In the case of macronutrients, very large quantities are required and the proposed scaling of this technique has been considered unrealistic.

26. **Costs** - OF Costs depend on the production of the nutrient and its delivery to the site of application. Costs range from USD 2 per tCO_2 for iron fertilisation to USD 457 per tCO_2

for nitrate. The median of the OF cost estimates (USD 230 per tCO_2) indicates low cost-effectiveness, although the uncertainties are large.

27. **Potentials** - Estimates indicate potentially achievable net sequestration rates of 1-3 Gt CO_2 per year for iron fertilisation, resulting in a cumulative CDR of 100–300 $GtCO_2$ by 2100, while OF with macronutrients has a theoretical potential of 5.5 $GtCO_2$ per year. Modelling studies show a maximum effect on atmospheric CO_2 of 15–45 ppm by 2100.

28. **Risks and impacts** - Several of the mesoscale iron enrichment experiments have seen the emergence of potentially toxic diatom species. There is also evidence of increased concentrations of other greenhouse gases, such as methane and nitrous oxide, during the subsurface decomposition of sinking particles from iron-stimulated blooms. The effects on marine biology and the food web structure are not well understood. OF on a larger scale could cause changes in nutrient distribution or anoxia in subsurface waters. Other potential risks include perturbation of marine ecosystems through the reorganization of community structure, enhanced acidification of the deep ocean and effects on the human food supply.

29. **Co-benefits** - Co-benefits of OF include a potential increase in fish biomass through enhanced biological production and reduced ocean acidification in the short term in the upper ocean.

30. **Trade-offs and spillover effects** - Potential trade-offs include subsurface ocean acidification and deoxygenation, altered regional meridional nutrient supply and fundamental changes in food webs, and increased production of nitrous oxide and methane. OF is considered to have negative impacts on eight SDGs, and a combination of both positive and negative impacts on seven SDGs.

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