A6.4-SB003-AA-A04

Information note

Removal activities under the Article 6.4 mechanism

Version 02.0

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", 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 mechanism, 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 annex (Article 6, paragraph 4, activity cycle), to be considered at its fourth session (November 2022).

2. The Supervisory Body, at its first meeting (25–28 July 2022), requested the secretariat to prepare an information note providing technical information on the elements related to activities involving removals, 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 comprising its members and alternate members as well as the secretariat staff would work prior to the second meeting of the Supervisory Body to prepare draft recommendations to be considered by the Supervisory Body at its second meeting with a view to forwarding the recommendations to CMA 4.

3. The Supervisory Body, at its second meeting (19–22 September), agreed that the informal working group on removals will continue to work on the development of the information note.

4. The informal working group on removals agreed to forward the information note contained in this document to the Supervisory Body for its consideration at its third meeting (3–5 November 2022).

2. Purpose

5. This information note contains technical information as requested by the Supervisory Body and has the objective of supporting the work of the Supervisory Body for the development of recommendations on removal activities pursuant to the decision 3/CMA.3, paragraph 6 (c).

3. Key issues and proposed solutions

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

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

4. Impacts

8. This note will facilitate the consideration of the removal activities by the Supervisory Body.

5. Subsequent work and timelines

9. Further work will be taken up as agreed by the Supervisory Body.

6. Recommendations to the Supervisory Body

10. It is recommended that the Supervisory Body take this information note into consideration while developing recommendations requested by the CMA.

TABLE OF CONTENTS **Page**

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), with respect to different types of activities involving removals.

2. For the purpose of brevity, the term “removal activities” has been used in this note to imply “activities involving removals”.

3. Also, for reasons of brevity, the term “A6.4M-RMP” 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. 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) Other published literature.

2. Definitions

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

7. Terms other than those defined here should be understood as defined in

   (a) IPCC Glossary;[1]

[1] Available at https://bit.ly/3eoPVfK

(b) The A6.4M RMP.[2]

2.1. Terms defined in the IPCC glossary

8. The following definitions have been taken from the glossary of published IPCC reports:

(a) **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 sinks and direct air capture and storage but excludes natural CO_2 uptake not directly caused by human activities.[3]

(b) **Greenhouse gas removal (GGR)** Withdrawal of a greenhouse gas (GHG) and/or a precursor from the atmosphere by a sink.

Note 1: The term GGR is no longer used by the IPCC as clarified in its latest report. The sixth assessment report of the IPCC recommends use of the term CDR: "Measures that result in a net removal of GHGs from the atmosphere and storage in either living or dead organic material, or in geological stores, are known as CDR, and in previous IPCC reports were sometimes referred to as greenhouse gas removal (GGR) or negative emissions technologies" (IPCC AR6-WG-III, agreed text).

Note 2: Removal of GHGs other than CO2 is not a viable option for mitigation purposes: "As there are currently no removal methods for non-CO2 gases that have progressed beyond conceptual discussions (Jackson et al. 2021), achieving net zero GHG implies gross CO2 removals to counterbalance residual emissions of both CO2 and non-CO2 gases, applying GWP100 as the metric for reporting CO2-equivalent emissions, as required for emissions reporting under the Rulebook of the Paris Agreement" (IPCC AR6-WG-III, agreed text).

(c) **Carbon dioxide capture and storage (CCS)** A process in which a relatively pure stream of carbon dioxide (CO2) 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.[4]

(d) **Carbon dioxide capture and utilisation (CCU)** A process in which CO2 is captured and then used to produce a new product. If the CO2 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 CO2 recently removed from the atmosphere, can CCUS lead to carbon dioxide removal. CCU is sometimes referred to as Carbon dioxide capture and use.[5]

(e) **Bioenergy and carbon dioxide capture and storage (BECCS)** Carbon dioxide capture and storage (CCS) technology applied to a bioenergy facility. Note that

[2] Available at https://bit.ly/3wWHqPD

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

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

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

depending on the total emissions of the BECCS supply chain, carbon dioxide (CO2) can be removed from the atmosphere.[6]

(f) **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 to reduce greenhouse gas emissions from biomass and soils, and for carbon sequestration.[7]

2.2. Terms defined in the A6.4M RMP

9. The following definitions have been taken from decision 3/CMA.3, annex:

(a) An **"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).

(b) An **"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.

2.3. Terms defined specifically in the scope of this note

10. The following working definitions have been proposed within the scope of this note:

(a) **Achieved carbon stocks** The verified carbon stocks, net of the baseline removals, activity emissions, and leakage, that represent the amount of CO2 removed by an activity.

(b) **In-situ carbon stocks** The achieved carbon stocks at the site where these were accumulated by the removal activity.

(c) **Ex-situ carbon stocks** The achieved carbon stocks that were transported, moved or stored away from the site where these were accumulated but are within the activity boundary.

(d) **Holding period** Period in years for which the achieved carbon stocks are continuously held out of the atmosphere.

(e) **Time horizon** The time period in years that delineates the temporal boundary within which the impact of an action, activity, or policy is assessed.

(f) **Permanence period** The period over which the removed carbon must be held outside of the atmosphere in order to produce the same mitigation as produced by 1 tCO2 of permanent emission reduction. It is identical to the time horizon.

---

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

[7] IPCC, 2018: Global Warming of 1.5°C, Annex I: Glossary.

(g) **Crediting factor** A multiplicative factor applied to 1 tonne of achieved carbon stocks and held outside of the atmosphere over a period of time, in order to get the number of A6.4ERs. The value of the crediting factor depends upon the time horizon, the holding period of the achieved carbon stocks, and the discount rate applied for calculating the net present value of future mitigation, and is calculated as the ratio of the removal-caused decrease in cumulative forcing to the decrease in cumulative forcing caused by 1 tonne of emission reduction.

(h) **Tonne-years** The product of tonnes of the achieved carbon stocks and the respective holding period, in years, of these tonnes.

Note: Tonne-year is a two-dimensional[8] measurement unit that reflects the quantity of removals (tonne) and the time over which the removals are held out of the atmosphere. Although the tonne-year unit represents a quantitative measure of mitigation produced by a removal activity, the two dimensions are not symmetric in scaling the quantity of mitigation because of non-linear decay of CO2 emitted into the atmosphere. If x tonnes are removed and held outside of the atmosphere for y years, the product $q = xy$ is proportional to the quantity of mitigation produced. Doubling of x produces mitigation equal to $2q$ but doubling of y produces mitigation that is slightly more than $2q$.

(i) **Ex-post tonne-year crediting** Crediting method in which A6.4ERs issued are equal to the number of verified tonnes multiplied by a crediting factor based on the actual holding period of each tonne. Alternative terms: incremental tonne-year crediting.

(j) **Advance tonne-year crediting** Crediting method in which A6.4ERs issued are equal to the number of verified tonnes multiplied by a crediting factor based on the holding period equal to the number of years left until the end of the crediting period. Advance crediting is ex-ante crediting since the tonnes have been verified but the holding period has not been verified at the time of crediting. Alternative terms: ex-ante tonne-year crediting

(k) **Tonne-based crediting** Crediting method in which A6.4ERs issued are equal to the number of verified tonnes based on an assumption that the verified carbon stocks will have a holding period equal to the permanence period. Tonne-based crediting is ex-ante crediting since the tonnes have been verified but the holding period has not been verified at the time of crediting.

3. Types of removal activities

11. The following types of removal activities and associated carbon storage methods are considered in this note. The list is illustrative and not exhaustive.

(a) Removal through biosequestration/photosynthesis (land-based activities)

(i) Afforestation, reforestation and forest restoration;

(ii) Revegetation;

[8] IPCC-SR-LULUCF, see https://bit.ly/3yRAR1M

(iii) Improved forest management;

(iv) Wetland restoration;

(v) Agroforestry;

(vi) Urban forestry;

(vii) Soil carbon sequestration in croplands;

(viii) Soil carbon sequestration in grasslands;

(b) Removal through engineering/chemical methods (engineering-based activities)

(i) Direct air removal (DAC);

(ii) Enhanced rock weathering (EW);

(iii) Ocean alkalinization (OA);

(iv) Ocean fertilization (OF).

12. The following methods of long-term storage of the carbon stocks achieved by removal activities are considered:

(a) Ecosystem carbon pools;

(b) Long-lasting products:

(i) Timber in construction;

(ii) Biochar applied to soils;

(iii) Other bio-based products;

(iv) Other inert-carbon products;

(c) Geological storage;

(d) Mineralization.

13. The land-based removal activities can be categorized in two different ways:

(a) Activity types based on the biophysical characteristics of the vegetation;

(b) Activity types based on the dominant management objective.

14. Table 1 summarizes the categorization of removal activity types and provides examples under each dominant objective. It should be noted that a conservation activity can also result in some economic products, and a production activity can also provide environmental and conservation services, but the main goal of an activity differs from its co-benefits.

Table 1. 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 habits	-
Soil organic carbon enhancement	– Conservation tillage – Fallows	– Soil productivity improvement

15. The sections that follow provide information on the different issues listed under paragraph 4 above to be addressed under the activity types listed under paragraph 11(a) above, namely, the land-based activities. The activity types listed under paragraph 24(b), namely, the engineering methods, are addressed in section 5.

4. Methodological issues related to land-based removal activities

4.1. Monitoring

16. The monitoring of all removal activities is based on the quantification of carbon stocks.

17. In the case of land-based removal activities, the quantification of carbon stocks is carried out through a ‘carbon stock inventory’ based on sampling, field measurements and regression models. Remotely sensed data may be used in combination with the data from field measurements for cost-effective monitoring.

4.1.1. Quantification of carbon stocks

18. In the case of land-based activities, methods based on the IPCC Guidelines exist for the measurement and estimation of carbon stocks in all terrestrial carbon pools[9]. Estimates at successive points in time are used for calculating changes in the carbon stocks. The methods may vary in complexity, precision, accuracy and cost. Different methods are appropriate for different carbon pools at different temporal and spatial scales.

19. The most commonly used carbon stock quantification methods employ measurements conducted on vegetation (e.g. trees and shrubs) in field sample plots, in conjunction with biomass-allometry models that allow for the conversion of measured quantities into biomass.

20. It is possible to use remotely sensed data in combination with field measurements to reduce the number of required sample plots and thus reduce the cost of monitoring.[10]

21. The use of conservative default factors allows flexibility for activities that do not seek to measure some carbon pools due to cost considerations.

22. Conservative adjustments can be made by applying an uncertainty discount when the uncertainty in the estimated carbon stocks exceeds the permissible limits and when the activity participants do not wish to establish and measure additional plots for cost reasons.

23. As a further cost-saving measure, it is also possible for activities to exclude certain carbon pools from accounting where such exclusion results in conservative outcomes.

24. It is possible that different methods of carbon stocks inventorying will be required for carbon pools other than in-situ carbon stocks (e.g. the carbon pool of long-lasting wood products achieved under the activity).

25. The accuracy of measurements can be ensured by laying out in advance the specifications of data collection methods, such as relevant sampling methods, the calibration of equipment, the validation of models, and the specifications for the use of remote-sensing data.

26. Estimations should include the associated uncertainties, and the uncertainties should remain within the prescribed limits. In the event of uncertainties exceeding the prescribed limits, the estimates should be adjusted to make these conservative.

27. The use of digital tools can be leveraged for improving accuracy and reducing the cost of monitoring.

4.1.2. Frequency of monitoring

28. The efficient frequency of monitoring depends upon the rate of accumulation of the carbon stocks to justify the cost of monitoring. There needs to be a sufficient accumulation of carbon stocks before the initial verification of the carbon stocks achieved by an activity is carried out.

---

[9] IPCC GPG-LULUCF, IPCC 2006 with 2019 enhancement, IPCC KP-Supplement, IPCC Wetland Supplement

[10] See, for example, section 8.1.2 of the CDM methodological tool AR-TOOL14: Estimation of carbon stocks and change in carbon stocks of trees and shrubs in A/R CDM project activities.

29. As will be seen later, the timing for the first verification and the frequency of the subsequent verifications, as well as the maximum permissible period between successive mandatory verifications, will depend upon the type of storage, the crediting method used and the arrangements used for addressing reversals. In some cases, periodic monitoring may be a requirement even after the end of the crediting period (e.g. for ensuring that no reversals occur until the end of a specified period).

4.2. Reporting

30. Verified monitoring reports form the basis of the issuance of credits.

31. Monitoring reports summarize the monitoring outcomes. Monitoring reports are transmitted to a designated operational entity (DOE) which verifies the correctness of the monitoring results.

32. Verified monitoring reports form the basis of the issuance of credits.

33. Reports should be submitted soon enough after the quantification of the achieved carbon stocks to allow the DOE to visit the site and conduct sample checks as needed.

34. Monitoring report may either be required to contain all the relevant data, or if such data is too voluminous, to contain a summary of such data. In any case, the full data set should be made available to the verifier at the time of verification, except for the confidential data, if any.

35. Apart from the data related to carbon inventory, the reporting should include the records of events and incidents, such as fire, pest outbreak, harvests, leaks and seepage, that might have affected the carbon stocks in the intervening period.

36. Simplified monitoring and reporting is possible under certain circumstances, for example when the purpose of reporting is to ensure the continued existence of the carbon stocks for reasons of permanence; it cannot be used to seek the issuance of additional credits.[11]

37. Reporting should be required to include information on how the environmental and socioeconomic impacts were assessed and addressed.[12]

38. Reporting should be required to include information on how the activity contributes to the sustainable development in the host Party.[13]

4.3. Accounting of removals

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

[11] See, for example, 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”.

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

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

4.3.1. Baselines

40. Baselines are the reference scenario against which a change in carbon stocks and removals is measured.

41. There are three types of business-as-usual (BAU) scenarios possible (see Figure 1):

(a) Significant carbon stocks exist in the BAU scenario and the carbon stocks are growing. Both the initial carbon stocks and the BAU removals are non-zero in this case;

(b) Significant carbon stocks exist in the BAU scenario, but the carbon stocks are declining over time. The initial carbon stocks are non-zero, but the BAU removals are zero in this case;

(c) No significant carbon stocks exist in the BAU scenario. Both the initial carbon stocks and the BAU removals are zero in this case.

4.3.1.1. Determining the baseline scenario

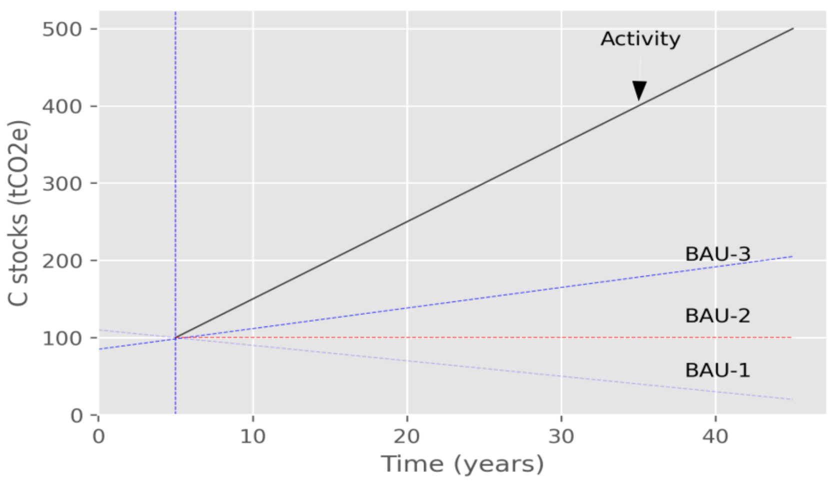
42. According to the “Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement” (RMP) agreed by decision 3/CMA.3, activities under the mechanism shall require the application of one of the following approaches to setting the baseline:

(a) A performance-based approach, taking into account the best available technologies that represent an economically feasible and environmentally sound course of action, where appropriate;

(b) An ambitious benchmark approach where the baseline is set at least at the average emission level of the best performing comparable activities providing similar outputs and services in a defined scope in similar social, economic, environmental and technological circumstances;

(c) An approach based on existing actual or historical emissions, adjusted downwards to ensure alignment with paragraph 33 of the annex to decision 3/CMA.3.

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



43. Baselines shall be set with justification for the appropriateness of the choices, including information on how the proposed baseline approach is consistent with paragraphs 33 and 34 of the annex to decision 3/CMA.3.

44. Baseline-setting rules shall recognize that a host Party may determine a more ambitious level at its discretion.

45. Baseline scenarios shall be consistent with the applicable legal and regulatory requirements.

46. Baselines could be set at a national, regional or activity level. National or regional baselines are also known as standardized baselines, and presumably these would 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 datasets.

47. The activity-specific setting of baselines can address the specificities of the carbon stocks as well as any other local conditions and is thus likely to yield a more accurate prediction of changes in carbon stocks.

48. Baselines developed by activity participants also pose a risk that the participants would choose scenarios that maximize their perceived benefits.

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

4.3.1.2. Quantification of baselines

50. Baselines are quantified ex ante and these estimates remain valid throughout the crediting period. Quantified baselines are based on the quantified projection of the growth or the decline of the carbon stocks over time. Methods for estimating the baselines could be the same quantification methods that are used for the purpose of monitoring (see 4.1.1 above) or simplified conservative default-based methods, particularly where baseline carbon stocks are relatively small (e.g. less than 10 per cent of the carbon stocks expected to be achieved under the activity).[14]

51. Where the carbon stocks are growing under BAU, the baseline is often quantified as the projection of the growth. Whether the projection is linear or non-linear would depend upon the availability of data and the specific attributes of the activity. Both types of projections need to be subject to the principle of conservativeness in terms of assumption and data uncertainties.

[14] 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% of emissions could be in the baseline; in an A/R project, baseline typically has less than 10% as much carbon stocks as are expected to be achieved by the activity. An uncertainty of 10% in the baseline estimation actually corresponds to 1% 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.

52. However, where significant removals are likely to occur under the baseline scenario, the baselines can also be estimated by using control areas where the baseline activities are expected to be continued.

53. The projections should take into consideration trends and events that are likely to affect the carbon stocks (e.g. changes in legislation, changes in market prices, changes in environmental awareness).

54. Where GHG emissions occur in the baseline of the activity and the implementation of the activity leads to reduction in those emissions, the emission reductions should not be accounted as credits. However, any increase in the GHG emissions, relative to the baseline, caused by the implementation of the removal activity, should be deducted from the achieved removals.

4.3.1.3. Periodic re-validation of the baseline

55. The baseline is set at the time of the validation and registration of the activity and is re-assessed at the time of the renewal of the crediting period

4.3.2. Activity boundaries

56. Accounting of net removals achieved by an activity are affected by the boundaries defined in terms of the physical boundaries (e.g. carbon pools, equipment and materials, sources of emissions related to the activity) and the greenhouse gases (GHGs) considered.

57. The choice of the carbon pools and the GHGs to be considered can be optionally simplified by allowing activities to exclude some of these if such exclusion results in a conservative outcome.

4.3.3. Additionality

58. A removal activity is required to demonstrate that changes in the removals associated with it are additional to the removals that would occur in the baseline.

4.3.3.1. Types of additionality

59. Financial additionality implies that the removal activity or its outcome would not have been realized without the revenue from the carbon credits.

60. Regulatory additionality implies that the activity would not be realized in the absence of its registration under the mechanism because of the mandatory requirements such as law, regulations, industry standards and/or enforced policies.

61. Common practice additionality implies that the activity goes beyond what is commonly practiced in similar socioeconomic, ecological, and technological environments, which is a proxy of the most economically attractive of the activities that do not face barriers.

62. Performance additionality implies that the activity represents GHG removals that exceed the average performance of the peer activities in the industry or the sector and match the best performing comparable activities providing similar outputs and services in a defined scope in similar social, economic, environmental and technological circumstances.

4.3.3.2. Demonstration of additionality

63. The fact that the baseline has been determined independently of the activity automatically satisfies the requirement of additionality specified under paragraph 53 above, since the net removals are to be estimated relative to the removals occurring in the baseline.

64. Financial additionality is demonstrated by carrying out a financial analysis showing that the activity is not financially viable without the carbon revenues.

65. Under most existing carbon market standards, including the clean development mechanism (CDM), financial additionality is not a mandatory requirement for removal activities, but an optional add-on test.

66. A removal activity can be economically attractive but still be additional because it faces non-financial barriers that prevent it from being realized in the absence of being registered under the mechanism, and the mechanism contributes in removing these barriers.

67. In this case, barrier analysis is carried out to demonstrate that the existence of specified barriers would effectively prevent the activity from being implemented without the added support from the mechanism. The types of barriers included could be adverse ecological conditions, the non-availability or high cost of investment capital, inadequate infrastructure, lack of capacity, cultural barriers, institutional barriers, local barriers, organizational barriers, prevailing practice barriers, property rights barriers, social barriers, technological barriers and barriers linked to tradition. For the barrier analysis to be credible, the activity participants have to demonstrate how the mechanism will contribute to overcoming the barriers.

68. Automatic additionality may be applied using approved positive lists based on certain criteria implying that removal activities are unlikely to be implemented in absence of the mechanism where such criteria are met.[15]

69. Regulatory additionality, common practice additionality and performance additionality are demonstrated by providing justification, supported by data and analysis where appropriate, as to why and how the removal activity passes these additionality tests.

4.3.4. Double-counting

70. Activity validation should take into account the possibility of double-counting, double issuance and double-claiming in the context of the different international collaboration instruments, mechanisms and registries.

71. Double issuance occurs if more than one unit is issued for the same removals, either under the same mechanism or under two or more different mechanisms.

72. Double use occurs when the same issued unit is used twice (e.g. sold twice if the inter-registry tracking is not fully secured).

73. Double-claiming occurs if the same removals are counted twice by both the buyer and the seller.

[15] See, for example, 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

74. There could be two principal methods to avoid double-counting:

    (a) Registry-level integrity checking and transaction processing, as well as linking of registries;

    (b) The host Party may be required to provide necessary affirmations, at the time of authorization letter is issued, that rules out the possibility of double-counting of any type.

75. More specifically, a Party to the Paris Agreement that intends to host an Article 6.4 land-based removal activities in an area covered by an activity under jurisdictional approaches to enhance forest carbon stocks shall specify in its approval and authorization letter of the activity that it agrees to the implementation of the Article 6.4 land-based removal activity in the area and shall demonstrate that:

    (a) Where the host country conducts monitoring 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 at the jurisdictional level, although a baseline can be set at the jurisdictional level;

    (b) The activity area credited under the activity under jurisdictional approaches to enhance forest carbon stocks is non-activity area for the Article 6.4 land-based removal activities. There is no overlap between the activity area credited under the activity under jurisdictional approaches to enhance forest carbon stocks and the activity area credited as Article 6.4 land-based removal activities and therefore, no double counting or double claim is taking place

76. Providing the accurate geolocation of a removal activity in the activity design document should be made mandatory.

77. Furthermore, to avoid double-counting the concept of "*nested accounting*" – where emissions are accounted for at one level of analysis (e.g., a specific improved forest management (IFM) project) and are factored into emissions at a higher level of analysis (e.g., a Party or group of Parties) – has been proposed. The nested accounting approach collects data at the smallest unit of analysis (i.e., the project) within nested jurisdictions and then rolls up into higher aggregation levels such as national inventories and submitted to international frameworks. To address the issue of assigning the emissions to the correct jurisdiction the nested accounting data shall be spatially referenced at the source through geotagging and timestamping. [16]

78. However further analysis on relationship between activities under the approaches to enhance forest carbon stocks and removal activities under 6.4 mechanism would be required to fully address any potential issues, including the relationship with the requirements under Article 5 of the Paris Agreement.

[16] M. Schletz, A. Hsu, B. Mapes and M. Wainstein. "*Nested Climate Accounting for Our Atmospheric Commons—Digital Technologies for Trusted Interoperability Across Fragmented Systems*" POLICY BRIEF article. Available at https://bit.ly/3xrFNcS

4.4. Crediting period

79. The crediting period for a removal activity is the period during which the activity is eligible to be issued credits.

80. The RMP contained in the annex of decision 3/CMA.3 requires that a crediting period in respect of activities involving removals shall not be more than 15 years (renewable maximum twice).

81. The host party may require that any shorter crediting period be applied for activities hosted within its jurisdiction.

82. The crediting period of a removal activity may be renewed in accordance with relevant requirements if the host Party has approved such renewal, following a technical assessment by a DOE to determine necessary updates to the baseline, and the ex-ante estimates of emission reductions.

83. The end of the crediting period of a removal activity is not necessarily the end of the obligations of the activity proponents to continue periodic monitoring of the carbon stocks against which credits were issued until such carbon stocks have been held out of the atmosphere for a period equal to the permanence period as described in the next section.

4.5. Addressing reversal

84. Reversal of removals occurs when the verified carbon stocks against which credits have been issued are released back into the atmosphere before the end of the required period for which credits were issued.[17] The causes of reversal can be common natural hazards (unintentional reversal) or a decision of the activity participants (intentional reversal).

85. Not all fluctuations in carbon stocks within the boundary of a removal activity lead to a reversal. Fluctuations in carbon stocks, whether due to natural hazards or intentional actions, that do not decrease the carbon stocks below the minimum level required by the issued credits do not qualify as reversals.

86. A basic question involved in addressing reversals is how long the activity participants should be accountable for monitoring the carbon stocks and compensating for any possible reversal. Evidently, an accountability for ever is not of practical value.

87. Answering the above question requires one to consider how long the carbon sequestered by a removal activity should be held outside of the atmosphere in order to provide the same mitigation value as that provided by an emission reduction of one tonne of carbon dioxide achieved at the same point in time as the sequestration. This time period has been called the “permanence period”.

4.5.1. Approaches to permanence

88. While in an accounting system that requires perpetual reporting, such as LUUCF reporting by the Annex-I Parties under the Kyoto Protocol, the issue of permanence is implicitly addressed through the perpetual reporting obligation. If carbon stocks are reversed during

[17] If the issuance is based on the period that has already elapsed (e.g. ex-post tonne-year crediting), the credits are calculated on the basis of the assumption of instant reversal after the issuance, and therefore the issue of addressing reversal does not arise in such cases.

a reporting period, these reversals will be captured in the next LULUCF inventory and the debit will be reflected in the concerned Party’s account.

89. In the case of project-based mechanism, however, the activity is undertaken over a finite period of time and the crediting occurs over a finite period of time. The issue of permanence of removals in this context therefore needs to addressed through different approaches.

90. One approach would be to arbitrarily select a minimum period for maintaining the verified carbon stocks and consider the removals as permanent when these have been maintained for the selected period. Existing regulatory and voluntary carbon offset market mechanisms have adopted different maintenance periods for removals achieved through land-based activities. The California Cap-and-Trade Program and Climate Action Reserve (CAR) require a 100-year commitment to maintaining carbon stocks from the date of final credit issuance. The Verified Carbon Standard have adopted a maintenance period of 30 years to 100 years for different projects, whereas the American Carbon Registry (ACR) has adopted a minimum activity term of 40 years.

91. While the removals credits issued by the different existing carbon market mechanisms have mitigation value, they all cannot have the same mitigation value.

92. There is a need, therefore, to agree on a method of quantification of mitigation achieved by removal activities and the timeframe to be used for such quantification.

93. Different timeframes or approaches have been proposed in this regard[18]:

(a) Perpetuity: Under this approach the carbon stocks must be maintained forever. While this approach ensures full environmental integrity, in practice it is impossible to implement in an activity-based mechanism;

(b) 100 years: Under this approach, the carbon stocks must be maintained for a period of 100 years to be consistent with the Kyoto Protocol's adoption of the IPCC's global warming potentials (GWPs) and the Protocol's 100-year reference time frame for calculation of the absolute global warming potential (AGWP) of CO2. Although this approach has limitations, it has been adopted for use in the Kyoto Protocol to account for total emissions of GHGs on a CO2-equivalent basis;

(c) Equivalence based: Under this approach, the carbon stocks must be maintained be maintained until they counteract the effect of an equivalent amount of GHGs emitted to the atmosphere, estimated on the basis of the cumulative radiative forcing effect of a pulse emission of CO2 during its residence in the atmosphere. However, considering that radiative forcing effect of a pulse emission of CO2 can last for hundreds, even thousands, of years, applying this approach, independent of a finite and feasible time horizon leads to the same limitation as under the perpetuity approach.

94. A consideration of the above approaches to permanence shows that the option of a finite time horizon, such as 100 years, appears to be the only practical option. That is, mitigation produced by a 100-year removal can be said to be equivalent to the mitigation produced by 1 tonne of permanent emission reduction. This period is also called the ‘permanence period’ since it is the underlying criterion for issuance of 1 permanent credit for 1 tonne of

[18] IPCC-SR-LULUCF, see https://bit.ly/3eHUh2d

CO2 removed. It is to be noted that the adoption of 100 years as permanence period is a normative judgement based on pragmatic considerations and is not a result of scientific reasoning.

95. Further details about the choice of time horizon are provided in appendix B.

96. Once the time horizon (the permanence period) been adopted, it is useful to decide how to assess mitigation achieved by activities that have a shorter duration than the time horizon. The options can be divided into two main approaches: [19]

(a) Full liability: In the event of reversal of achieved carbon stocks against which credits have been issued, activity proponents should return an amount of credits equal to the total amount of carbon stocks released before 100 years. This approach is consistent with the stock change method, which consists of giving credits to projects as carbon is fixed and removing credits if stocks of carbon diminish. This approach does not recognize the temporal value of carbon storage and is the only approach possible if it is decided that projects have to be run in perpetuity.

(b) Proportional liability: Projects should be debited an amount of credits proportional to the difference between the permanence period and the actual holding period. This method is applicable only if a finite permanence period is adopted. If a permanence period of 100 years is adopted, for instance, a plantation project that is harvested at 60 years (assuming that all carbon is released to the atmosphere) would be liable for not maintaining carbon stocks for the last 40 years of the time horizon. Different methods can be used for calculating this proportional liability:

(i) Linearly: Dividing the period of non-compliance by the required time horizon. In the foregoing example, the project would have to return 40 percent of the credits it earned;

(ii) Tonne-year based: Calculating the liability based on the tonne-year approach based on the amount of net cumulative radiative forcing reduced by the activity over the period of 100 years. Further details about the underlying rationale and the method for tonne-year based approach are provided in appendix A.

(iii) Adjusted for time preference: Using any of the methods described above but applying discount rates to reflect time preference. Further details about discounting and the choice of discounting rate are provided in appendix C.

4.5.2. Approaches to addressing reversals

97. The choice of method for dealing with risk of reversal and liability for reversal is linked with crediting methods and the timing of issuance of credits.

[19] IPCC-SR-LULUCF, see https://bit.ly/3eCJ5Eg

4.5.2.1. Crediting methods and timing of issuance

98. Having agreed upon the time horizon and the discount rate, the following options can be considered for crediting of mitigation achieved by removal activities:

(a) Temporary crediting: Credits are issued such that these have an expiry date and on that date the holder of the credit is required to replace the credits with other valid credits. This is the approach used under the CDM. Two types of credits are issued for A/R CDM project activities:

(i) tCERs:

a. “Temporary CER” or “tCER” is a credit that expires at the end of the commitment period following the one during which it was issued (originally, the commitment period was 5 years long);

b. tCERs are issued to a removal activity only once during the commitment period and are equal to the cumulative net tonnes achieved by the activity since its start date;

c. tCERs may be used by a Party included in Annex I towards meeting its commitment for the commitment period for which they were issued. The tCERs may not be carried over to a subsequent commitment period.

d. Each tCER expires at the end of the commitment period subsequent to the commitment period for which it was issued. The expiry date shall be included as an additional element in its serial number.

e. An expired tCER may not be further transferred.

f. A tCER that has been transferred to the retirement account or the tCER replacement account of a Party included in Annex I has to be replaced, before its expiry date, with a valid unit that could be another tCER that is issued for the next commitment period, or another type of credit such as an emission reduction credit.

(ii) lCERs:

a. “Long-term CER” or “lCER” is a credit that expires at the end of the crediting period of the removal activity;

b. lCERs are first issued to a removal activity at a time selected by the activity proponents. Subsequent lCERs are issued equal to the net tonnes achieved by the activity since the previous verification.

c. If the net tonnes achieved by the activity since the previous verification are negative (i.e. there has been a decrease since the previous verification), a notification to the Executive Board of the CDM is sent about reversal of verified carbon stocks.

d. lCERs may be used by a Party included in Annex I towards meeting its commitment for the commitment period for which they were issued. The lCERs may not be carried over to a subsequent commitment period.

e. Each lCER expires at the end of the crediting period or, where a renewable crediting period is chosen in accordance with paragraph 23 (a) above, at the end of the last crediting period of the removal activity. The expiry date is included as an additional element in its serial number.

f. An expired lCER may not be further transferred.

g. An lCER that has been transferred to the retirement account or the lCER replacement account of a Party included in Annex I has to be replaced, before its expiry date, with a valid emission reduction credit.

(b) Equivalence crediting: Credits are calculated based on the principle of equivalence of the marginal cumulative radiative forcing. A practical implementation of this equivalence would be to use the crediting factors as described in appendix A. Under this option, it is possible to use any holding period ranging from 10 year[20] to 100 year, since the mitigation credits will get scaled according to the holding period. While providing full flexibility to the activity proponents, the use of crediting factors encourages longer retention of carbon stocks because these factors scale faster as the holding period gets longer. The timing of crediting can create two sub-options under this method:

(i) Ex-post tonne-year crediting (Alternative term: incremental tonne-year crediting): Credits are issued on the basis of the actual mitigation produced up to the time of issuance. Credits issued are equal to the number of verified tonnes multiplied by a crediting factor based on the actual holding period of each tonne. This crediting method is the foundational method: it does not involve any assumptions; does not impose any conditions; does not require any deductions; leaves no reversal risks or uncertainties for the producers and the buyers of credits; and ensures that the actual mitigation produced is within the crediting period. However, under this method, a majority of the credits get issued later in the crediting period; relatively fewer credits get issued early in the crediting period. To bring forward the issuance of credits, the advance tonne-year crediting method can be considered as an option.

(ii) Advance tonne-year crediting (Alternative terms: ex-ante tonne-year crediting): Credits issued are equal to the number of verified tonnes multiplied by a crediting factor based on the time-till-end-of-the-crediting-period as the nominal holding period. For example, if a verification occurs in year 5 of an activity having a crediting period of 15 years, credits can be calculated based on a nominal holding period of 10 years, which results in each verified tonne getting 0.0766 credits (without discounting). If the crediting period is successfully renewed, the credits can be re-calculated, for the same tonnes, based on a nominal holding period of 25 years, which results in each verified tonne getting 0.1958 credits (without discounting).

[20] It is to be noted that in the case of land-based removal activities, an activity cannot achieve significant carbon stocks in less than 5 years. These stocks have to be held out of the atmosphere for 5 years to earn any credits.

The difference between the re-calculated credits and the previously issued credits is issued upon renewal. This crediting methods brings forward in time the availability of credits. However, it requires the activity participants, and potentially host Parties, to enter into contractual arrangements to ensure the continued existence of the carbon stocks until the end of the crediting period. The mechanisms for enforcing the contractual arrangements and managing the risks of reversals can include pooled buffer of credits, pooled buffer of credits backed up by host Party guarantee, or pooled buffer of credits backed up by commercial insurance. Practical application of tonne-year crediting method is described in appendix D. The details of the contractual arrangements for addressing reversals are described in appendix F.

(c) Tonne-based crediting: Under this method, each tonne is credited as one credit, under the assumption that each tonne removed will be held out of the atmosphere for the full permanence period, that is, for 100 years. Credits issued are equal to the number of verified tonnes at the first issuance. At each subsequent issuance, credits are issued equal to the incremental verified tonnes achieved by the activity. This method has the advantage of getting a large number of credits upfront. However, it requires the activity participants, and potentially host Parties, to enter into contractual arrangements to ensure the continued existence of the carbon stocks until the end of a period equal to the permanence period after the date of last issuance. For example, if a verification and issuance occurs in year 5 of an activity having a crediting period of 15 years, the activity participants, and the host Party, must enter into contractual arrangements to ensure the continued existence of the carbon stocks until the year 105. If the crediting period is successfully renewed, and the last issuance occurs in the year 45, contractual arrangements obligation for continued monitoring will last up to year 145. Practical application of tonne-year crediting methods are described in appendix E. The details of the contractual arrangements for addressing reversals are described in appendix F.

99. Table 3 summarizes the main characteristics of the different types of crediting methods.

100. To help appreciate the practical significance of the choices made in respect of quantification of credits, table 2 provides the average annual yield of credits per hectare resulting from a typical mixed-species watershed reforestation activity (see appendix D for the details of the activity).

Table 2. 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

	Crediting period		
5%	2.86	6.26	7.09
Tonne-based credits	11.5	13.47	10.03

[Source: Based on simulated forest growth]

Table 2. Crediting method options and sub-options and their characteristics

Characteristics	tCERs	lCERs	Ex-post tonne-year crediting	Advance tonne-year crediting	Tonne-based crediting
The basis of credits (the measured/verified quantity)	**Verified tonnes** achieved by the removal activity	**Verified tonnes** achieved by the removal activity	**Verified tonne-years** achieved by the removal activity	**Verified tonnes** achieved by the removal activity	**Verified tonnes** achieved by the removal activity
Calculation of credits from the basis	Number of credits is equal to the number of verified tonnes	Number of credits is equal to the number of verified tonnes	Number of credits is equal to the verified tonnes multiplied by the respective crediting factors for actual holding period of the tonnes.	Number of credits is equal to the verified tonne-years multiplied by the crediting factors corresponding to the end-of-crediting-period number of years.	Number of credits is equal to the verified tonnes
Credits are issued after actual mitigation	No	No	Yes	No	No
Mitigation period remains within the crediting period	Yes	Yes	Yes	Yes	No
Credits correspond to their net present value	Yes	No	Yes	No	No
Crediting is conservative	Not in themselves, but credits are later replaced by permanent credits, if these are used as offsets by an Annex I Party	Not in themselves, but credits are later replaced by permanent credits, if these are used as offsets by an Annex I Party	Yes	Yes	Yes
Activity participants are free from post-issuance liability	Yes	No	Yes	No	No
Buyers are free from cancellation risks	Yes. Buyers know the expiry date of the credits at the time of purchase.	No. The buyers are required to replace the credits in the case of a reversal.	Yes	No	No
Other pros	The credits allow the users to gain time for either procuring permanent credits or reducing their emissions		– Because of flexibility and simplicity, small-size land holders and a variety of actors can	More credits are issued upfront than in the case of ex-post crediting.	– Total number of credits issued is more than other crediting methods;

Characteristics	tCERs	lCERs	Ex-post tonne-year crediting	Advance tonne-year crediting	Tonne-based crediting
	by the next commitment period		participate in the mechanism (e.g. cities, communities, institutions, farmers, etc.) – Credits can be issued annually with simplified monitoring (“the no-decrease” monitoring report).		– Credits are issued earlier in the crediting period.
Other cons	The credits are not fungible with A6.4ERs and cannot be traded in market generally. These can only be used by countries to cover their shortfall in achieving NDC targets in a particular NDC period.	– Activity proponents are obliged to conduct periodic monitoring and reporting until the end of the crediting period. – The credits carry the “buyer-beware” caveat and hence there was no interest in lCERs under the CDM, compared to tCERs.	Majority of the credits get issued late in the crediting period. Fewer credits get issued earlier on.	– Requires the activity participants, and potentially host Parties, to enter into contractual arrangements to ensure the continued existence of the carbon stocks until the end of the crediting period; – Activity participants face unknown opportunity costs related to future land use and market developments; – Buyers are not free from cancellation risks and uncertainties.	– Requires the activity participants, and potentially host Parties, to enter into contractual arrangements to ensure the continued existence of the carbon stocks until 100 years after the end of the crediting period; – Activity participants face unknown opportunity costs related to future land use and market developments; – Buyers are not free from cancellation risks and uncertainties.

4.6. Avoidance of leakage

101. “Leakage” is defined as the indirect increase in GHG emissions occurring outside the activity boundary and attributable to the activity. Leakage can be caused by various factors.

4.6.1. Leakage caused by shifting of baseline activities

102. If implementation of a removal activity excludes the activities occurring in the baseline scenario, the latter are likely to be shifted somewhere else. The emissions caused by the shifted activities could be either more or less than the emissions that were caused in the original location.

103. For removal activities implemented in lands that have no competing use, this type of leakage is unlikely to occur.

104. This type of leakage can be addressed through the design of the removal activity such that the baseline level of services continues to be provided within the removal activity. For example, in cases of fuelwood collection and livestock grazing activities occurring in the baseline, the demand for these services may be initially met through the staggered closure of areas over the years and finally by allowing local communities to collect fuelwood and fodder from the reforested areas under managed access.

105. If a solution by appropriate activity design is not possible, or only partially possible, leakage may be estimated by collecting monitoring data on the baseline activities (e.g. how many households no longer collect their fuelwood from the area). The receiving lands of the shifted activities may be identified, and a conservative estimate of carbon stocks lost due to the shifted activity may be made. 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.

4.6.2. Leakage caused by market effects

106. Market leakage is caused by the shift in the supply and demand equilibrium of a product. If the removal activity decreases or increases the supply of a marketable products, the market prices of the products may be driven up or down. The extent of the price changes will depend upon the size of the removal activity relative to the size of the reachable market. Higher prices may cause the product to be sourced from other lands that might be carrying higher carbon stocks per unit area than the activity lands. Lower prices may induce other producers of the same or similar product to shift to different activities that could possibly generate higher levels of emissions.

107. Since market leakage is indirect and diffuse, its effects cannot be isolated and directly measured. A possible solution is to use leakage adjustment factors based on the circumstantial probability and the relative size of the removal activity.

4.7. Avoidance of other negative environmental and social impacts

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

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

110. This section describes the negative environmental and social impacts and their avoidance.

4.7.1. Impacts on land, biodiversity and water

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

112. Large-scale afforestation and reforestation can lead to competition for land adversely affecting biodiversity conservation and food production.

113. Activities of agroforestry and enhanced of soil organic carbon can affect crop productivity adversely if not planned carefully and synergistically.

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

115. A removal activity that is designed to be implemented in the context of other activities delivering economic or ecological services, where removals are realized as co-benefits rather than the main benefit, is less likely to lead to adverse environmental and social impacts.

116. For example, a removal activity involving bioenergy with carbon dioxide capture and storage (BECCS) that is driven by the sole objective of maximizing carbon stocks achieved can lead to competition for land and drive out other higher-priority needs such as food security and fuelwood for cooking. Such an activity may also compete for land that is supporting biodiversity conservation. On the other hand, a BECCS-supported removal activity that is driven by the objective of unblocking the saturation of bio-sequestration sink in a vegetation system that provides economic or ecological services is complementary and synergistic with the underlying goal of meeting human needs or providing ecological services, and is thus less likely to cause adverse environmental and social impacts.

4.7.2. Impacts on food security and local livelihoods

117. Negative social impacts can result if removal activities are implemented on land for which communities have alternative priorities, such as agricultural production, and if communities are not effectively engaged in all phases of activity design and implementation.

118. This negative impact can be reduced by ensuring that the removal activity is consistent with long-term regional land-use plans and that community development priorities are effectively incorporated during activity design, development and implementation.

119. Afforestation or production of biomass crops for BECCS or biochar, when poorly implemented, can have adverse impacts on local livelihoods and on the rights of Indigenous Peoples, especially if implemented at large scales and where land tenure is not clearly defined.

120. Adverse impacts are less likely occur if free, prior and informed consent has been obtained from the relevant stakeholder groups before the activity is registered and stakeholder consultations are systematically followed.

121. Assessments of social and environmental impacts should be a requirement for the registration of a removal activity.

122. The scope of the assessments must cover human welfare and the conservation of biodiversity and other natural resources.

123. Periodic community consultations over the duration of the crediting period may be appropriate if applicable to the nature of the activities being undertaken.

124. Feedback and dispute resolution mechanisms to address matters related to adverse environmental and social impacts may be set up, allowing for feedback from employees, the local communities and relevant regional or national authorities.

125. Feedback and dispute resolution mechanisms should be easily accessible to the public and sufficiently advertised.

4.8. Long-term carbon storage methods in removal activities

126. Terrestrial carbon pools may store carbon for a long time if they have reached a state of equilibrium and the land use is not changed.

127. However, the in-situ carbon pools can eventually reach a state of saturation and thus further removals may slow down.

128. In order to ensure the continued sequestration of carbon, the biomass can be harvested at a sustained rate. The harvested biomass constitutes an ex-situ carbon pool that accumulates carbon stocks under certain circumstances.

129. Two methods for the long-term storage of carbon stocks in harvested biomass are possible:

(a) Geological storage;

(b) Storage in wood products and other inert carbon products such as biochar.

4.8.1. Geological storage

130. Underground accumulation of carbon dioxide (CO2) is a widespread geological phenomenon, with natural trapping of CO2 in underground reservoirs. Information and experience gained from the injection and/or storage of CO2 from a large number of existing enhanced oil recovery (EOR) and acid gas projects, as well as from the Sleipner, Weyburn and Salah projects[1], indicate that it is feasible to store CO2 in geological formations as a CO2 mitigation option.[2]

[1] Three large-scale CCS sites—Sleipner (Norwegian North Sea), Weyburn (Canada), and In Salah (Algeria).

[2] This brief summary of CCS is taken from IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage.

131. Industrial analogues, including underground natural gas storage projects around the world and acid gas injection projects, provide additional indications that CO2 can be safely injected and stored at well-characterized and properly managed sites.

132. While there are differences between natural accumulations and engineered storage, injecting CO2 into deep geological formations at carefully selected sites can store it underground for long periods of time. It is considered likely that 99% or more of the injected CO2 will be retained for 1000 years.

133. Depleted oil and gas reservoirs, possibly coal formations and particularly saline formations (deep underground porous reservoir rocks saturated with brackish water or brine), can be used for storage of CO2. At depths below about 800–1000 m, supercritical CO2 has a liquid-like density that provides the potential for efficient utilization of underground storage space in the pores of sedimentary rocks. Carbon dioxide can remain trapped underground by virtue of a number of mechanisms, such as trapping below an impermeable, confining layer (caprock); retention as an immobile phase trapped in the pore spaces of the storage formation; dissolution in the in situ formation fluids; and/or adsorption onto organic matter in coal and shale. CO2 may also be trapped by reacting with the minerals in the storage formation and caprock to produce carbonate minerals.

134. Models are available to predict what happens when CO2 is injected underground. By avoiding deteriorated wells or open fractures or faults, injected CO2 will be retained for very long periods of time. Moreover, CO2 becomes less mobile over time as a result of multiple trapping mechanisms, further lowering the prospect of leakage.

135. Apart from storing the CO2 captured from the flue gases resulting from of fossil fuel combustion or combustion of biomass, geological storage can be also employed for storing CO2 resulting from removal activity such as direct air capture (DAC).

136. When the CO2 captured from the flue gases resulting from of combustion of biomass sequestered within a removal activity is stored in geological formations, the combined system is called the bioenergy with carbon capture and storage (BECCS). Such a system has sustained potential for achieving removals over time.

137. However, when the biomass used for combustion comes from biomass waste or other sources outside of a removal activity (i.e. it was not sequestered within a removal activity), the resulting BECCS system achieves emission reductions, and not removals.[3]

138. Practical application of the storage method of CCS in a BECCS activity is described through an illustrative example in appendix G.

4.8.2. Storage in wood products

139. Much of the wood that is harvested from forest land, cropland and other types of land use remains in products for differing lengths of time. The time carbon is held in products will vary depending on the product and its uses. For example, fuelwood and mill residue may be burned in the year of harvest; many types of paper are likely to have a use-life less

[3] A removal activity must be registered as an A6.4 mechanism activity and then it must remove carbon dioxide. If trees were grown prior to the activity, or outside of the geographic boundary of the activity, the associated removals are not achieved within the activity and do not count as removals for the purpose of the activity.

than 5 years which may include recycling of paper; and sawn wood or panels used in buildings may be held for decades to over 100 years[4].

140. Discarded harvested wood products (HWP) can be deposited in solid waste disposal sites (SWDS) where they may persist for long periods of time.

141. Harvesting of wood products prevents a plantation from becoming saturated and allows for the continued sequestration of carbon.

142. Long-lasting harvested wood products constitute an off-site carbon pool that has to be monitored during the crediting period of the activity.

143. Practical application of the storage method of durable wood products is described through an illustrative example in appendix G.

5. Methodological issues related to engineering-based removal activities

144. This section provides information on removal activities that are based on engineering approaches and technologies. Since there is no experience with the implementation of these types of removal activities under existing market mechanisms, the information appearing below is based on the IPCC reports and other published scientific literature.

145. 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).

146. Summary description of each of these activity types is provided in appendix H.

147. IPCC guidance on quantifying removals is available for land-based biological CDR methods (IPCC, 2006 and 2019), but it has yet to be developed for other CDR methods. Challenges with the development of estimation algorithms, data collection and attribution between sectors and countries will need to be overcome. Trusted methodologies for measurement, reporting and verification, which is required to enable private sector participation, will need to address the permanence, leakage and saturation challenges associated with land and ocean-based biological methods.

148. International governance considerations include global technology transfer around CDR implementation options; land-use change that could affect food production and land conditions and cause conflict around land tenure and access; and efforts to create sustainable and just supply chains for CDR, such as resources used for BECCS, EW and/or OA.

149. International governance would be particularly important for methods posing transboundary risks, especially for ocean-based methods. Specific regulations have so far only been developed in the context of the London Protocol, an international treaty that

[4] 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4 AFOLU.

explicitly regulates OF and allows Parties to govern other marine CDR methods like ocean alkalinity enhancement.

150. The activities of enhanced rock weathering and the activities related to the oceans do not have any known method of monitoring, apart from the fact that there is considerable uncertainty about their environmental and social impacts. These types of activities are therefore not addressed under the sections that follow.

5.1. Monitoring

151. The monitoring of all removal activities is based on the quantification of carbon stocks.

152. In engineering-based removal activities, the quantities of carbon stocks are known through physical measurements such as the total mass of CO2.

153. The monitoring of removal activities using geological formations for storage should be carried out in accordance the relevant provisions contained in 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”.

5.1.1. Frequency of monitoring

154. The frequency of monitoring will depend upon the rate of accumulation of the carbon stocks to justify the cost of monitoring. There needs to be a sufficient accumulation of carbon stocks before the initial verification of the carbon stocks achieved by an activity.

155. As will be seen later, the timing or the first verification and the frequency of the subsequent verifications, as well as the length of time over which mandatory periodical verification is required, will also depend upon the type of storage, and options used for addressing reversals.

156. Periodic monitoring will be a requirement even after the end of the crediting period (e.g. for ensuring that no reversals through seepage occur until the end of a specified period).

5.2. Reporting

157. Verified monitoring reports form the basis of the issuance of credits.

158. Monitoring reports summarize the monitoring outcomes. Monitoring reports are transmitted to a DOE, which verifies the correctness of the monitoring results.

159. Verified monitoring reports form the basis of the issuance of credits.

160. Reporting must happen soon enough after the end of the monitoring operations in order to allow the DOE to visit the site and conduct sample checks on the measurement carried out during the monitoring operations.

161. Monitoring report may either be required to contain all the relevant data, or if such data is too voluminous, to contain a summary of such data. In any case, the full data set should be made available to the DOE at the time of verification, except for the confidential data, if any.

162. Apart from the data on carbon stocks achieved and stored in the geological formations, the reporting should include the records of events and incidents, such as seepage from already stored and verified carbon stocks in the intervening period.

163. Simplified reporting is possible under certain circumstances, for example when the purpose of reporting is to ensure the continued existence of the carbon stocks for reasons of permanence; it should not be used to seek the issuance of additional credits.

164. Reporting should be required to include information on how the environmental and socioeconomic impacts were assessed and addressed.[5]

165. Reporting should be required to include information on how the activity contributes to the sustainable development in the host Party.[6]

5.3. Accounting of removals

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

5.3.1. Baselines

167. Baselines are the reference scenario against which a change in carbon stocks and removals is measured.

168. In the case of engineering methods of removal, the baseline is zero in the case of a new facility.

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

5.3.1.1. Periodic re-validation of the baseline

170. The baseline is set at the time of the validation and registration of the activity and is re-assessed at the time of the renewal of the crediting period.

5.3.2. Activity boundaries

171. Accounting of net removals achieved by an activity are affected by the boundaries defined in terms of the physical boundaries (e.g. the plant, equipment and materials, sources of emissions related to the activity), and in the case of geological storage of achieved carbon stocks, meet the requirements contained in the annex to decision 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”.

5.3.3. Additionality

172. A removal activity is required to demonstrate that changes in the removals associated with it are additional to the removals that would occur in the baseline.

173. If an activity uses the removed carbon dioxide for economically useful products, financial additionality also needs to be demonstrated.

174. Regulatory additionality should be demonstrated by proving that that the activity would not be realized in the absence of its registration under the mechanism because of the

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

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

mandatory requirements such as law, regulations, industry standards and/or enforced policies.

5.3.4. Double-counting

175. Activity validation should take into account the possibility of double-counting, double issuance and double-claiming in the context of the different international collaboration instruments, mechanisms and registries.

176. Double issuance occurs if more than one unit is issued for the same removals, either under the same mechanism or under two or more different mechanisms.

177. Double use occurs when the same issued unit is used twice (e.g. sold twice if the inter-registry tracking is not fully secured).

178. Double-claiming occurs if the same removals are counted twice by both the buyer and the seller.

179. There could be two principal methods to avoid double-counting:

(a) Registry-level integrity checking and transaction processing, as well as linking of registries;

(b) The host Party may be required to provide necessary affirmations, at the time of authorization letter is issued, that rules out the possibility of double-counting of any type.

180. Providing the accurate geolocation of a removal activity in the activity design document should be made mandatory.

5.4. Crediting period

181. The crediting period for a removal activity is the period during which the activity is eligible to be issued credits.

182. The RMP contained in the annex of decision 3/CMA.3 requires that a crediting period in respect of activities involving removals shall not be more than 15 years (renewable maximum twice).

183. The host party may require that any shorter crediting period be applied for activities hosted within its jurisdiction.

184. The crediting period of a removal activity may be renewed in accordance with relevant requirements if the host Party has approved such renewal, following a technical assessment by a DOE to determine necessary updates to the baseline, and the ex-ante estimates of emission reductions.

185. The end of the crediting period of a removal activity is not necessarily the end of the obligations of the activity proponents to continue periodic monitoring of the carbon stocks against which credits were issued until such carbon stocks have been held out of the atmosphere for a period equal to the permanence period as described in the next section.

5.5. Addressing reversal

186. Reversal of removals occurs when the carbon stocks accumulated and verified under a removal activity are released back into the atmosphere. The causes of reversal can be common natural hazards, seepage or other unforeseen events.

187. Not all fluctuations in carbon stocks within the boundary of a removal activity lead to a reversal. Fluctuations in carbon stocks, whether due to natural hazards or intentional actions, that do not decrease the carbon stocks below the minimum level required by the issued credits do not qualify as reversals.

188. The activity participants should periodically monitor the geological storage facility to ensure that no seepage or other form of reversal happens for the duration of the permanence period after the last verification of the carbon stocks.

5.6. Avoidance of leakage

189. Leakage is defined as the indirect decrease or increase in carbon stocks occurring outside the activity boundary.

5.6.1. Leakage caused by resource competition

190. If implementation of an engineering-based removal activity uses resources (e.g. energy, water, PV panels, windmills) that in the baseline scenario would have been used by some other activity, the latter will likely be shifted to some other resource (e.g. take recourse to less clean energy). The emissions caused by the resource shifted should be accounted as leakage.

191. 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 opportunity cost.

192. If a solution by appropriate activity design is not possible, or only partially possible, leakage may be estimated by collecting monitoring data on the baseline activities (e.g. how much resource shift has taken place). A conservative estimate of consequent emissions may 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.

5.6.2. Leakage caused by market effects

193. Market leakage is caused by the shift in the supply and demand equilibrium of resources such as energy and water. If the removal activity decreases the availability of energy or water by competing for the resources, the market prices of the resources may be driven up or down. The extent of the price changes will depend upon the size of the resources used by the activity relative to the amount of resources available in the reachable market. Higher prices may cause the resources (e.g. energy, water) to be derived from more emitting sources and technologies.

194. Since market leakage is indirect and diffuse, its effects cannot be isolated and directly measured. A possible solution is to use leakage adjustment factors based on the circumstantial probability and the relative size of the removal activity.

5.6.3. Addressing seepage in geological storage

195. Seepage of carbon stocks in geological storage should be addressed in accordance with relevant provisions contained in 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”.

5.7. Avoidance of other negative environmental and social impacts

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

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

198. This section deals with the negative environmental and social impacts and their avoidance in relation to engineering-based removal activities.

5.7.1. Impacts on land, biodiversity and water

199. Large-scale engineering-based removal activities, such as DACCS, can lead to competition for resources such as clean energy and water. This may affect energy security and access to water in the areas immediate vicinity of the activity site.

200. If waste products of the activity such as used chemicals and effluent water are not handled safely, these can cause toxicity and other harm to the land, biodiversity and water resources.

5.7.2. Impacts on food security and local livelihoods

201. Negative social impacts can result if removal activities implemented compete for resources used by local vulnerable populations.

202. This negative impact can be reduced by ensuring that the removal activity is appropriately sited and uses resources that do no have opportunity cost.

203. Assessments of social and environmental impacts should be a requirement for the registration of a removal activity.

204. The scope of the assessments must cover human welfare and the conservation of biodiversity, water and other natural resources.

205. Feedback and dispute resolution mechanisms to address matters related to adverse environmental social impacts may be set up, allowing for feedback from employees, the local communities and relevant regional or national authorities.

206. Feedback and dispute resolution mechanisms should be easily accessible to the public and sufficiently advertised.

5.8. Long-term carbon storage methods in removal activities

207. Engineering-based removal activities can store the achieved carbon stocks in two ways:

(a) Make long-lasting useful products out of the carbon;

(b) Store the carbon in a certified geological storage site.

208. In order to ensure the continued existence of carbon in carbon products, scientific evidence may be provided that these products do not decay with time.

209. In order to ensure the continued existence of carbon in geological storage sites, the relevant requirements contained in 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” should be met.

Appendix A: Equivalence of cumulative radiative forcing

1. To analyse the equivalence between emission reductions and removals, a hypothetical example is used in the sections below for the purpose of illustration, in which a pulse emission is balanced by a removal over an assumed time horizon of 100 years as an example.

Equivalence without discounting

2. A pulse emission of 1 tCO2 into the atmosphere results in a marginal change in the atmospheric concentration of carbon dioxide and causes a marginal radiative forcing. The amount of pulse CO2 remaining in the atmosphere declines over time as the CO2 is absorbed into the ocean, the biosphere and other terrestrial sinks. Figure A1(a) shows the decay profile of such a pulse.[1] The decay continues beyond the time horizon, but the portion beyond the time horizon is not taken into account.[2]

3. Figure A1(b) shows a removal of 1 tCO2 that occurs at the same time as the emission pulse. As long as that removal is in effect, and is not reversed, the net change in the atmospheric CO2 concentration is zero and hence the marginal cumulative radiative forcing is zero. If the removal is reversed before the end of the time horizon, for example in year 60, then the area under the decay curve of the new pulse emission represents the atmospheric damage (i.e. the cumulative radiative forcing) caused by this reversal.

4. Calculation of the areas under the two curves Figure A1(a) and Figure A1(b) shows that at the end of the time horizon, marginal cumulative radiative forcing caused in the baseline scenario corresponds to 48.14 tonne-years whereas marginal cumulative radiative forcing caused in the removal activity scenario corresponds to 23.96 tonne-years. The removal activity, which consists of removing 1 tCO2 in year 0 and re-emitting 1 tCO2 in year 60, effectively reduces the marginal cumulative radiative forcing by 50.22%. The removal activity is thus equivalent to a permanent emission reduction of 0.5022 tCO2.

5. The factor, such as 0.5022 in this case, has been termed the crediting factor in this note, since multiplying the net carbon stocks achieved and held continuously out of the atmosphere for a definite period (henceforth termed the holding period) by this factor gives the number of credits achieved by the removal activity.

6. From the above, it becomes clear that a 1 tCO2 of removal can be equated to 1 tCO2 emission only if the removed carbon stock is held out of the atmosphere for the period of the time horizon, i.e. until 100 years. Thus, in absence of discounting, the permanence period of removals is equal to the length of the time horizon.

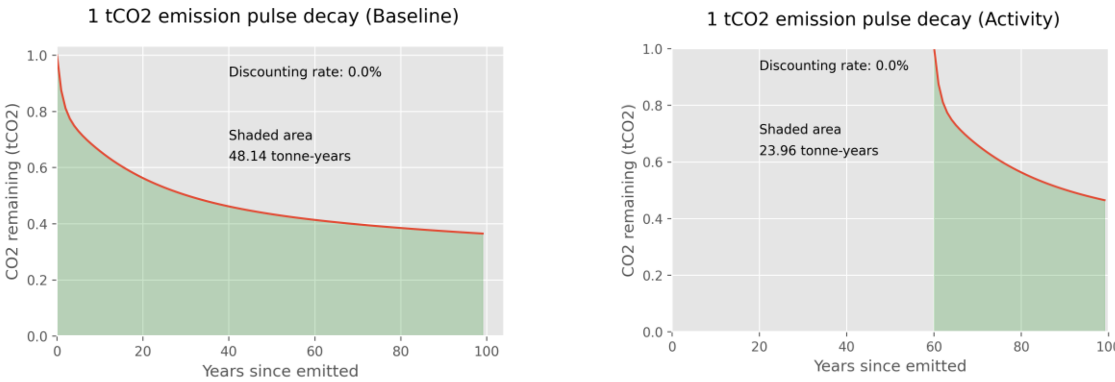
7. However, considering that the marginal cumulative radiative forcing is equal to the product of the tonnes of CO2 removed and the number of years over which the removed carbon stocks are held out of the atmosphere, the permanent mitigation value equal to 1 tCO2

[1] The curve in the diagram is generated from the Bern2.5CC model with the coefficients provided in the Fourth Assessment Report of the IPCC (IPCC-AR4-WG-I). The area under the of tonne-year curve is therefore 48.14 tonne-years which differs from 46 tonne-years as reported in the IPCC-SR-LULUCF.

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

can be achieved within 60 years if the amount of the removal is 1/0.5022 or 1.99 tCO2 instead of 1 tCO2. In other words, removal of 1.99 tCO2 with a holding period of 60 years results in mitigation equal to 1 tCO2.

Figure A1. Effect of 1 tCO2 emission in year 0 compared to 1 tCO2 removal followed by reversal in year 60, assuming a time horizon of 100 years and no discounting



(a) Carbon dioxide remaining in the atmosphere following a pulse emission of 1 tCO2 in year 0 of the time horizon. The area under the curve is 48.14 tonne-years. The area is proportionate to the marginal cumulative radiative forcing.

(b) Carbon dioxide remaining in the atmosphere following a pulse emission of 1 tCO2 in year 60 of the time horizon. The area under the curve is 23.96 tonne-years.

Equivalence with discounting

8. If discounting is used, current mitigation is valued more than the future mitigation. In the same way, current damage (cost) is valued more than the future damage.

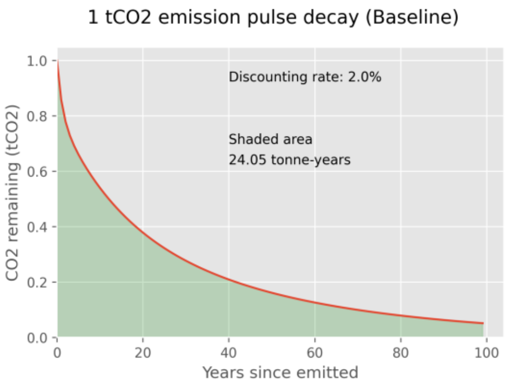
9. Applying a discount rate of 2% results in the tonne-years achieved by a 1 tCO2 removal in year 0 followed by a 1 tCO2 reversal in year 60 as shown in Figure A2.

10. Calculation of the areas under the two curves Figures A2(a) and A2(b) shows that at the end of the time horizon, marginal cumulative radiative forcing caused in the baseline scenario corresponds to 24.05 present tonne-years whereas marginal cumulative radiative forcing caused in the activity scenario corresponds to 5.31 present tonne-years. It should be noted that the future tonne-years have been discounted to the present tonne-years. The removal activity, which consists of removing 1 tCO2 in year 0 and re-emitting 1 tCO2 in year 60, effectively reduces the marginal cumulative radiative forcing by 77.91%. The removal activity is thus equivalent to permanent emission reduction of 0.7791 tCO2.

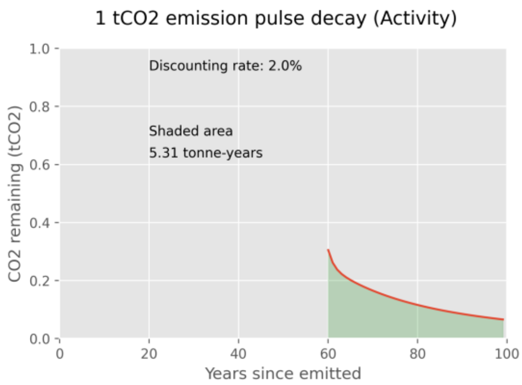
11. Using different discount rates with different holding periods results in the curves shown in Figure A2(c).

12. It is noted that as discounting rate increases, less amount of initial removal is required to achieve 1 tCO2 of mitigation over a given holding period. Similarly, as holding period increases, the crediting factor asymptotically approaches 1.0 at a holding period equal to the time horizon.

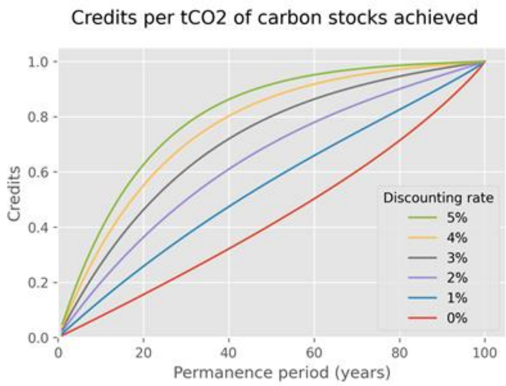
Figure A2. Effect of 1 tCO2 emission in year 0 compared to 1 tCO2 removal followed by reversal in year 60, assuming a time horizon of 100 years and a discounting rate of 2 percent.



(a) Marginal cumulative forcing caused by a pulse emission of 1 tCO2 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 tCO2 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 tCO2 with different holding periods and discount rates.

13. Table A1 provides the crediting factors at different holding periods and discount rates, assuming a time horizon of 100 years.

Table A1. Crediting factors at different holding periods and discount rates[3]

Holding 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

[3] 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

Holding 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 A1:

    (a) The crediting factor of 1 cannot be achieved with a holding period that is less than the time horizon;

    (b) At a discount rate of 3%, a post-10-year reversal results in credit factor of 0.26487. In other words, with a holding period of 10 years, every 3.78 tCO_2 of the achieved carbon stocks can result in a single credit;

    (c) At a holding period of 60 years and a discount rate of 3%, 0.86307 credits can be issued for each tCO_2 of the achieved carbon stocks. To achieve 1 credit, 1/0.86307 or 1.159 tCO_2 needs to be achieved with a holding period of 60 years.

15. It is to be noted that adopting a different time horizon will result in a different set of crediting factors.

16. The permanence period (i.e. the time horizon) is distinct from the activity period. The activity period can be shorter for the underlying economic reasons or to fit in with a shorter crediting period.

17. The ‘permanence’ of mitigation achieved by removal activities is defined by permanence period (i.e. the time horizon), and not by the activity period.

18. Each credit produced by the removal activities has the same mitigation value, i.e. it corresponds to the same amount of decrease in cumulative forcing, since the impact of the activity is assessed over the full period of the time horizon.

Appendix B: Time horizon and its choice

1. All climate action is underpinned by policy objectives and goals to be achieved over a finite period of time. In terms of policy relevance, therefore, the equivalence of mitigation services produced by avoided emissions and achieved by removals could be assessed only within the framework of a finite time horizon.

2. A time-horizon-based approach has been used to compare the climate-change impacts of emissions of different GHGs that have different residence times in the atmosphere as well as different radiative forcing per molecule. Global warming potentials (GWPs) are calculated by integrating the total radiative forcing of an emissions pulse over a 100-year time horizon. The 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 CO2.

3. A commonly adopted climate-relevant time horizon is 100 years as is seen in the following:

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

   (b) British Standards: Specification for the assessment of the life cycle greenhouse gas emissions of goods and services (PAS 2050) uses the same approach for carbon storage (release) as for delayed emissions and uses 100 years as assessment period;

   (c) Life Cycle Impact Assessment in the European context (ILCD handbook) recommends a time horizon of 100 years;

   (d) Forestry-related offset protocols of some existing mechanisms such as Climate Action Reserve (CAR), Regional Greenhouse Gas Initiative (RGGI), 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 the Carbon Sink Registry of Carbon Standards International uses 100 year time horizon to qualify permanence of removals (see https://bit.ly/3Mkm2KQ).

4. Choosing a time horizon is a normative judgement rather than the expression of a scientific consensus or physical reality.

5. Selecting a shorter time horizon implies earlier climate action is more relevant to policy objective. If one assumes that the global economy will be decarbonized by year 2100, then a time horizon of 75 years (i.e. from 2025 to 2100) would be appropriate since any post-decarbonization mitigation action will not have value.

Appendix C: Discount rate and its choice

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

2. Various climate policy assessments have recommended the discount rates variously, such as 1.4% (Stern 2007), 2.0% (Cline 1992) and 4.3% (Nordhaus 2007).[4]

3. Another study finds that the mean recommended discount rate relevant to climate policy is 2.27%, with a range from 0 to 10%. Under this study, more than three-quarters of the expert economists surveyed were comfortable with the median discount rate of 2%, and over 90% of them found a discount rate in the range of 1 to 3% acceptable.[5] The same team of authors have since surveyed expert philosophers. For this group, the mean responses are almost identical at 2.27%. Over 90% are comfortable with a discount rate of 2%.[6]

4. Some of the common arguments seen in the economic literature relating to climate policy discounting are summarized below:[7]

    (a) The social cost of carbon—the cost to society of an additional ton of CO2 emissions—is a crucial measure of the desirable intensity of climate policy. The models economists use to calculate it, however, are highly sensitive to the choice of discount rate, which measures our concern for the well-being of future generations. Different economists favour different values, and this leads to radically different policy prescriptions.

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

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

    (d) The Ramsey discounting equation can then be written 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.

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

[5] Drupp, M. et al. Discounting disentangled (2018). Available at https://bit.ly/3yW7N9u

[6] 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

[7] 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

(e) Most economists think that discount rates should be positive both because people are impatient (positive rate of pure time preference) and because people will have higher income on average in the future (and hence lower marginal benefits from additional consumption). Experience of the past several hundred years is consistent with this expectation.

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

5. While selecting a discount rate for valuing the mitigation contributed by removal activities, the following considerations may be kept in view:

(a) Adopting a higher discount rate (e.g. 3%) values earlier mitigation more than later mitigation (i.e. a sense of urgency for climate action). A 0% discount implies that it does not matter whether 1 tCO2 is mitigated today or any time in the future. Discounting at non-zero rates implies that mitigation taking place now, or in the near future, is more valuable than the mitigation taking place far in the future.

(b) Adopting a higher discount rate (e.g. 3%) accords the removal activities a more significant place in the mitigation strategy, along with the emission reduction activities;

(c) Both short-term and long-term removal activities have mitigation value when the value is calculated on the basis of the equivalence of the marginal cumulative radiative forcing.[8] However, small-scale and short-term activities can be incentivized with a higher discount rate (e.g. 3%).[9] This choice broadens the mechanism participation base in terms of the variety of removal activities involving different sizes, types, durations and actors.[10]

[8] While two activities A (1000 tonnes held over 10 years) and B (1000 tonnes held over 10 years) produce slightly less mitigation than activity C (1000 tonnes held over 20 years), the mitigation value of A and B combined is exactly equal to twice the mitigation value of A. Thus a large number of short-term and small-size activities can be as effective as, or more effective than, a few long-term and large-size removal activities.

[9] Participation by small and micro businesses in the mechanism is to be encouraged. See, A6.4-RMP, paragraph 5(g).

[10] A higher carbon price also incentivizes small-size activities participation in the mechanism. For example, with a carbon price of USD 100 per tCO2, some small-holders in the low-income countries may get motivated to participate in the mechanism even with crediting at a 0% discount rate.

Appendix D: Tonne-year crediting: an illustrative example

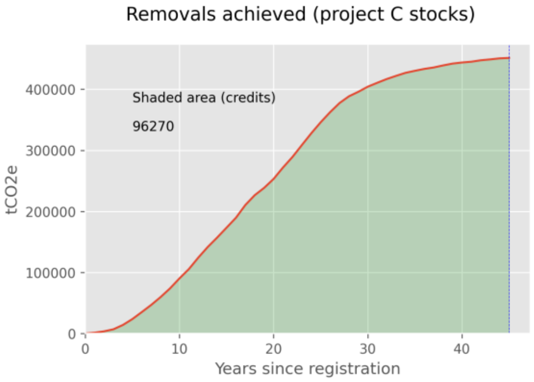
1. The example removal activity consists of reforestation in a watershed with a total area of 1,150 hectares (ha) and a plantable area of 1,000 ha. The activity area of 1,000 ha is planted in parts, covering 200, 200, 350 and 250 ha during years 1, 3, 4 and 5, respectively. Local species are used, and the local communities are allowed to extract 5 tonnes/ha of biomass starting from year 15. Two incidents of fire and pests are simulated to occur in years 12 and 21, with biomass losses of 10,000 and 5,000 tonnes, respectively. The mortality of plants are assumed during first 5 years and the thinning of the plantation at years 7 and 11 are also assumed. The tree species used have a growth profile such that the plantation biomass reaches saturation (or rather an equilibrium with the biomass extraction rate) at year 35. A crediting period of 45 years is assumed.

2. Figure D1 shows the growth of carbon stocks under the activity and credits resulting from tonne-year crediting.

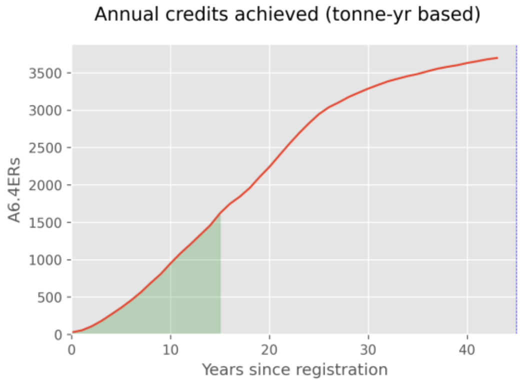
3. Figure D1(a) shows that total carbon stocks in the watershed become saturated at about 451,000 tCO2. By the end of the crediting period, a total of 96,270 credits are achieved.

4. It can be seen that under this approach, the major portion of credits are issued in the second half of the crediting period.

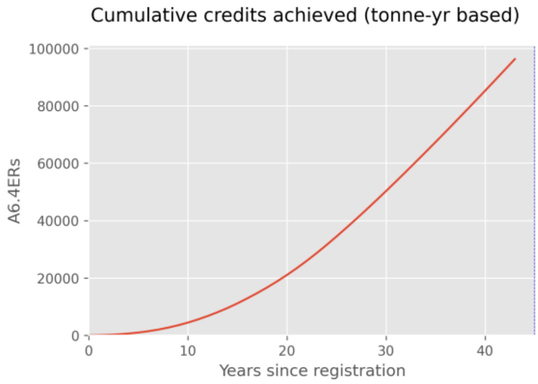
Figure D1. Removal activity consisting of tropical watershed reforestation with mixed stands of local species (tonne-year accounting)



(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.



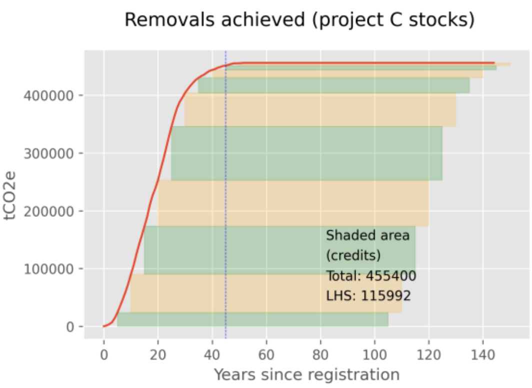
(c) Cumulative number of credits achieved. By the end of the crediting period (year 45) 96,270 credits are achieved.

Appendix E: Tonne-based crediting: an illustrative example

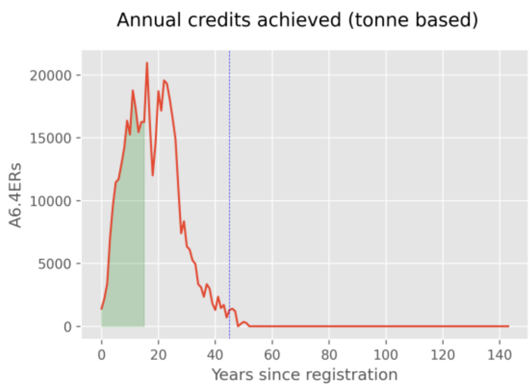
1. The same reforestation activity described in appendix D is credited by using the tonne-based crediting. As tonnes are verified at periodical intervals (5 years in this examples, but could be at any interval), credits equal to the number of verified tonnes are issued. This is under the condition that the carbon stocks against which credits have been issued will be preserved for the full permanence period, that is, for 100 years from the date of issuance.

2. Figure E1 shows the carbon stocks and the credits resulting from tonne-based crediting under the same example of watershed reforestation described in appendix D.

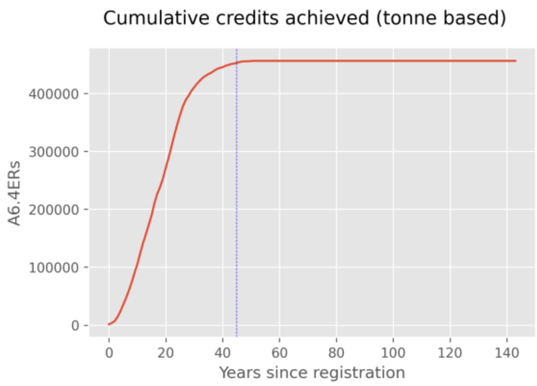
Figure E1. Removal activity consisting of tropical watershed reforestation with mixed stands of local species (tonne-based crediting)



(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 horizontal shaded rectangular areas represent the credits resulting from verifications at the five-year interval. The figure shows that the carbon stocks related to credits issued in later years will have to be periodically verified for a longer period beyond the crediting period (i.e. up to year 145 from the start of the activity).

4. Mitigation value produced during the years beyond the end of the crediting period is also included in the shaded area. This results in a total of 455,400 credits, which is more than four times the credits issued under tonne-year crediting.

5. It can be seen that under this approach the majority of credits are issued in the first half of the crediting period.

Appendix F: Risk mitigation and compensation mechanism

1. A mechanism for risk mitigation and compensation will be required for addressing the reversal of carbon stocks after the carbon stocks have been verified and credited under the advance tonne-year crediting and the tonne-based crediting method.

2. A mandatory post-issuance monitoring report will be required at a fixed interval in order to observe any reversals.

3. A mandatory post-issuance monitoring report will also be required whenever an event occurs that could potentially result in a reversal of carbon stocks. Such an event could be a forest fire, a pest outbreak and/or an intentional or planned human activity affecting the carbon stocks.

4. If a required monitoring report is not received within prescribed time, it would be assumed that full reversals occurred, and the reversal compensation procedure would be triggered.

5. A risk mitigation and compensation mechanism could be based on one of the options described below.

Permanence buffer backed up by host Party guarantee

6. The permanence buffer backed up by a host Party guarantee works as follows:

   (a) Under this option, a percentage of credits to be issued to a removal activity is set aside into 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 implies a sharing of risk by the activities that have subscribed to and keep contributing to the buffer. However, at any given time, the buffer may or may not have enough resilience to absorb simultaneous reversals from several activities. If the buffer is exhausted before compensating all the reversals, the liability needs to be taken over by the host Party. The fate of the credits issued and the consequences for the holders of the credits (in the event that these have been sold) would also need to be addressed;

   (c) As the buffer pool at a given time will be made of credits that have different 'maturity' (different holding periods since the verification of the corresponding carbon stocks, possibly none of these having completed the permanence period), the credits that will be selected to compensate a particular reversal will need to be decided (a stack-based or queue-based order);

   (d) An individual activity-level buffer implies that an activity, in the event of a reversal, can only have recourse to their own buffered credits. Any reversal beyond the size of the buffer may not be compensated. Particular difficulty arises when the activity participants decide to abandon the activity. For example, removal activity X is issued 100 credits in year 5, of which 70 are held by the activity participants and 30 are held in the buffer. In year 10, the activity participants no longer want to continue the activity and reverse all the carbons stocks. At this time, the 30 credits held in the buffer have also been invalidated. They have no compensatory value since the carbon stocks underlying these credits have been reversed;

(e) A guarantee by the host Party or an entity designated by it could assume the liability for intentional reversals and the portion of unintentional reversals exceeding the capacity of the permanence buffer pool. The buffer might be required to be segmented by the host Party countries, since activities hosted in one Party may report more reversals than another. Host Party a guarantee could also be required in the early phase of the mechanism until the buffer pool of credits is built up to a sufficient level of resilience. How a host Party compensates the reversals will need to be decided by them: whether to use public funds to buy A6.4ERs from market, or to charge a financial contribution from all registering activities to constitute a fund for purchase of A6.4ERs to be used for meeting the liability, or some other mechanism might be required.

(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 fixed 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) The credits accumulated in the permanence buffer could be retained permanently, or they could be returned to the activity participants once all the credits issued to a removal activity have fulfilled the permanence requirement. Retaining credits would increase the resilience of the permanence buffer. Another option could be to return the credits to those activities that did not experience any reversals and did not have recourse to the permanence buffer. This option would incentivize good risk management by activity participants.

Commercial insurance

7. The option of commercial insurance can work as follows:

(a) Under this option, the activity participants would buy insurance from a third-party insurer against the potential reversal of credited removals. The insurer would provide a guarantee to the Supervisory Body on behalf of the activity participants to compensate for any reversals of verified carbon removals. This would be similar to the commercial third-party liability insurance plans, since the Party injured in the case of reversals would be the atmosphere (i.e. the mechanism regulator, on its behalf) and not the activity participants who are free to abandon the activity at any time;

(b) The viability of such an insurance would depend upon the insurability in terms of the potential size of losses, the ability to quantify the risks, and the corresponding risk premiums that would be built into the insurance costs.

Menu of options

8. The availability of multiple options, including a combination of the options specified above, would allow activity participants to select the option that would best suit the needs and circumstances of their activity.

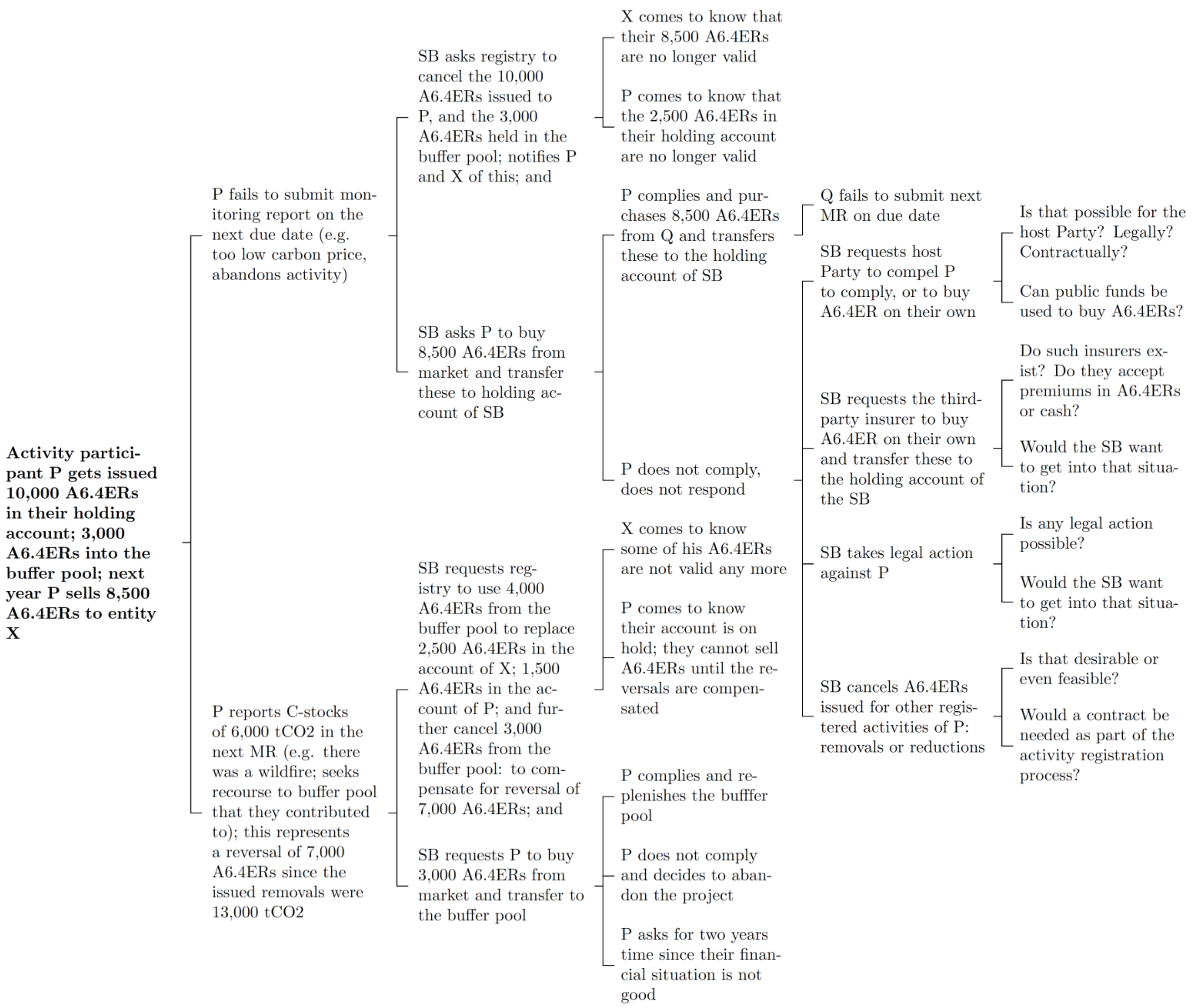
Reliability

9. The performance or adequacy of risk management arrangements should be assessed by considering how well these arrangements can address the worst case scenarios.

10. Figure F1 shows an example of chain of events that may or may not be fully addressed by the arrangements of pooled buffer backed up by a host Party guarantee, depending upon the options and choices available to host Parties under the domestic socio-legal environment.

11. There also remain other open enfocreability issues such as: e.g. what to do in case of non-payment of risk premium to the insurer; the level of assurance that host countries will have the financial means to compensate for eventual reversals; what if there is no availability of commercial insurance in the host Party for this type of activities.

Figure F1. Possible issues that can arise in risk management and compensation: a hypothetical event tree (abbr. used SB: Supervisory Body)



Appendix G: Removal activity supported by long-term storage of carbon stocks

Removal activity with BECCS

1. As an illustration of how BECCS can increase the removal potential of a given area of land, consider the simulation example of reforestation described in appendix D 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 constant flow of biomass to drive the energy system, the area is planted in 15 stands, each staggered by one year in its planting. After 15 years, the mature stand is harvested every year and the biomass is used for energy purposes with the carbon dioxide resulting from its combustion being captured and stored in a geological formation. It is assumed that the carbon capture and storage (CCS) component has 80 per cent efficiency in capturing and storing the carbon contained in the biomass combusted.

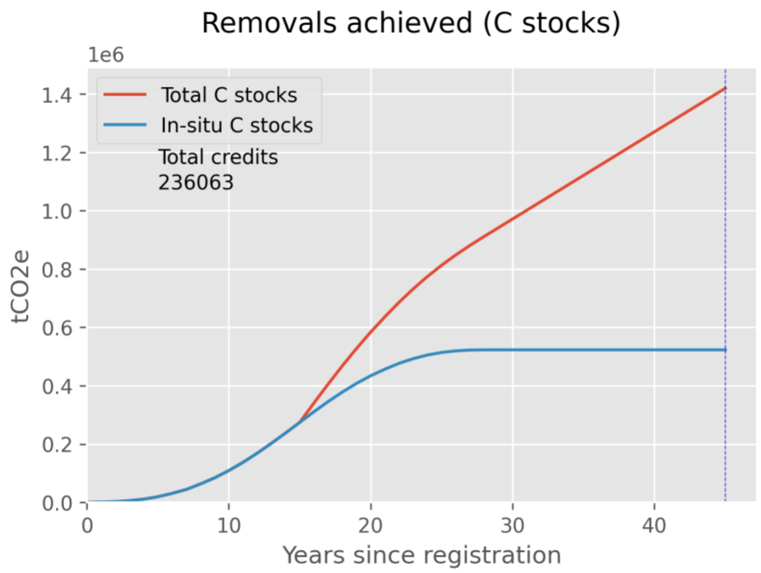
2. The resulting carbon stocks and the removal credits generated from the activity are shown in Figure G1. Credits are estimated based on tonne-year crediting (no discounting).

3. Figure G1 shows that total carbon stocks of 1.4 million tCO2 (MtCO2) are achieved over the crediting period of 45 years. The in-situ carbon stocks become 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 through the CCS component, while the in-situ component (the growing stock or the capital stock) remains constant.

4. By the end of the crediting period, a total of 236,063 credits are achieved (compared to 96,270 credits in the case of watershed reforestation).

5. The emissions associated with the establishment of the plantations and the energy consumed to drive the CCS system as well emissions associated with transportation are not included in this simulation. If significant, these will have to be deducted from the credits shown in the example.

Figure 6. 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 evolution of carbon stocks in the in-situ carbon pools and in geological storage.



Removal activity with storage in durable products

6. As an illustration of how long-lasting HWP can increase the removal potential of a given area of land, consider the reforestation simulation example in appendix D 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 staggered by one year in planting. After 15 years, the mature stand is harvested every year, and the wood products resulting from the harvest are used for their economic value. It is assumed that the annual harvest yields four different types of wood products with their fractional weights as follows: saw wood 0.30; veneer wood 0.20; paper 0.30; and fuelwood and fodder: 0.20. Of these, the last type (fuelwood and fodder) is not a long-lasting product, and the carbon stocks contained in this fraction of biomass are assumed to be emitted instantaneously. For the remaining three fractions (saw wood, veneer wood and paper), the IPCC default half-lives of 35 years, 30 years and 2 years, respectively, are assumed.

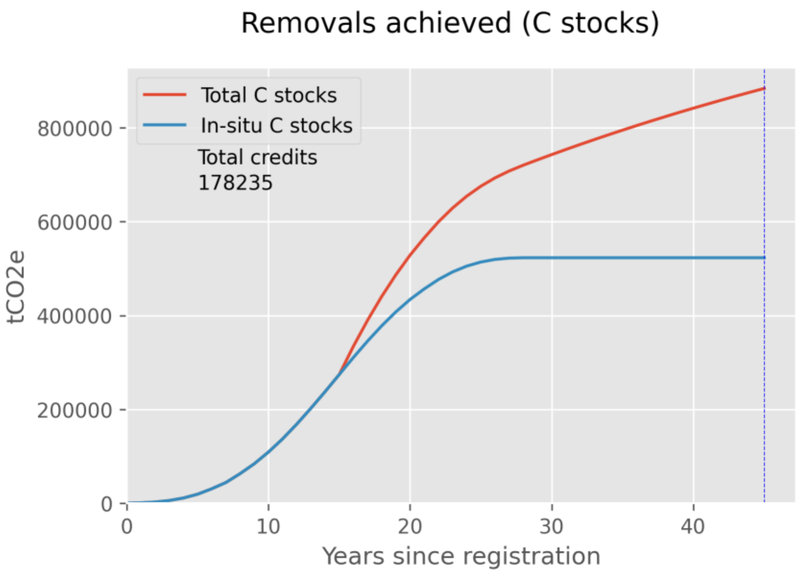
7. The resulting carbon stocks and the removal credits generated from the activity are shown in Figure G2. Credits are estimated based on tonne-year crediting (no discounting).

8. Figure G2 shows that total carbon stocks of 850,000 tCO2 are achieved over the crediting period of 45 years. The in-situ carbon stocks become saturated by year 25, but the continued removal of biomass opens up the biosequestration stream and the carbon is transferred from the atmosphere to the pool of wood products.

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

10. The emissions associated with the establishment of the plantations and the energy consumed to drive the CCS system as well as emissions associated with transportation are not included in the simulation. If significant, these will have to be deducted from the credits shown in the example.

Figure 7. Removal activity consisting of afforestation with fast-growing species with sustained harvesting of long-lasting wood products (tonne-year crediting).



Appendix H: Summary descriptions of engineering-based removal activities

1. Direct air carbon capture and storage

1. Direct air carbon capture and storage (DACCS) captures CO_2 from ambient air through chemical processes and subsequently stores 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 CO_2 concentration in ambient air is 100–300 times lower than that at thermal power plants, thus requiring more energy than flue gas CO_2 capture. The literature on metrics related to DACCS (energy use, water use, cost, etc.) has low agreement. Cost estimates range from USD 20 to 1,000 per t CO_2. Given the technology's early stage of development and few demonstrations, deploying the technology at scale is still a considerable challenge, though both optimistic and pessimistic outlooks exist.

2. DACCS shares the same transport and storage components as conventional CCS, but it is distinct in its capture part. The duration of storage is an important consideration; geological reservoirs or mineralization result in the safe storage of carbon for more than 1,000 years.

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

4. The efficiency and environmental impacts of DACCS and DACCU options depend on the carbon intensity of the energy input (electricity and heat) and other life-cycle assessment considerations. Another key consideration is the net carbon CO_2 removal of DACCS over its life cycle. It has been reported in some research findings that that the life-cycle net emissions of DACCS systems can be negative, even for existing supply chains and some current energy mixes.

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

6. **Potentials** There is no specific study on the potential of DACCS, but the literature has assumed that the technical potential of DACCS is virtually unlimited provided that high energy requirements could be met since DACCS encounters fewer non-cost constraints than any other CDR method. It has been reported that, when focusing only on the Maghreb region, there is an optimistic removal potential of 150 gigatonnes of carbon dioxide (Gt CO_2) at less than USD 61 per t CO_2 by 2050. Other research suggests a potential of 0.5–5 Gt CO_2 per year by 2050 because of environmental side effects and limits to underground storage.

7. **Risks and impacts** DACCS requires a considerable amount of energy and, depending on the type of technology, high amounts of water and make-up sorbents; however, its land footprint is small compared to other CDR methods. However, depending on the source of energy for DACCS (e.g. renewables versus nuclear), it could also require a significant land footprint. The theoretical minimum energy requirement for separating CO_2 gas from the air is about 0.5 gigajoules (GJ) per t CO_2. Other research reports the estimates of energy requirements for the current technologies as approx. 4–10 GJ per t CO_2, with heat accounting for about 80 per cent and electricity about 20 per cent. At a 10 Gt CO_2/yr^{-1} sequestration scale, this would translate into 40–100 exajoules (EJ)/yr^{-1} of energy consumption, which can be contrasted with the current primary energy supply of approx. 600 EJ/yr^{-1}.

8. **Co-benefits** It has been proposed that solid sorbent-based DAC plants could use excess renewable power (at times of low or even negative prices), even though such an operation would add additional costs. Installations would need to be designed for intermittent operations (i.e. at low load factors), which would negatively affect capital and operation costs. Solid sorbent DAC designs can potentially remove more water from the ambient air than needed for regeneration, thereby delivering 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 need substantial amounts of water, although much less than BECCS systems. Although the high energy demand of DACCS could negatively affect SDG 7 (Affordable and clean energy) through potential competition or positively through learning effects, its impact has not been thoroughly assessed yet.

2. Enhanced rock weathering

10. Enhanced rock weathering (EW) involves the mining of rocks containing minerals that naturally absorb CO_2 from the atmosphere over geological timescales (as they become exposed to the atmosphere through geological weathering), the comminution of these rocks to increase the surface area, and the spreading of these crushed rocks on soils so that they react with atmospheric CO_2. Construction waste and waste materials from mining can also be used as a source material for EW. Silicate rocks (such as basalt), which contain minerals rich in calcium and magnesium and lack metal ions such as nickel and chromium, are the most suitable for EW; they reduce soil solution acidity during dissolution and promote the chemical transformation of CO_2 to bicarbonate ions.

11. **Status** EW has been demonstrated in the laboratory and in small scale field trials, but has yet to be demonstrated at scale. The chemical reactions are well understood, but the behaviour of the crushed rocks in the field and potential co-benefits and adverse-side effects of EW are uncertain. Small scale laboratory experiments have calculated weathering rates that are orders of magnitude slower than the theoretical limit for mass transfer-controlled forsterite and basalt dissolution. Uncertainty surrounding silicate mineral dissolution rates in soils, the fate of the released products, the extent of legacy reserves of mining by-products that might be exploited, the location and availability of rock extraction sites, and the impact on ecosystems remain poorly quantified and require further research to better understand feasibility.

12. **Costs** Costs are closely related to the source of the rock, the technology used for rock grinding, and material transport. Due to differences in the methods and assumptions between studies, literature ranges are highly uncertain and range from

USD 15–40/t CO_2^{-1} to USD 3,460/tCO2^{-1}. One study suggested a cost range of USD 50–200/tCO_2^{-1} for a removal potential of 2–4 Gt CO_2/yr^{-1} from 2050.

13. **Potentials** There is limited evidence and low agreement on the mitigation potential of EW. The highest reported regional sequestration potential, 88.1 Gt CO_2 yr^{-1}, is reported for the spreading of pulverized rock over a very large land area in the tropics, a region considered promising given the higher temperatures and greater rainfall. Considering cropland areas only, the potential carbon removal is estimated to be 95 Gt CO_2/yr^{-1} for dunite and 4.9 Gt CO_2/yr^{-1} for basalt. In another study, lower potentials were estimated at 3.7 Gt CO_2 yr^{-1} by 2100, but with mean annual removals an order of magnitude less at 0.2 Gt CO_2 eq yr^{-1}.

14. **Risks and impacts** Mining of rocks for EW will have local impacts and carries risks similar to that associated with the mining of mineral construction aggregates, with the possible additional risk of greater dust generation from fine comminution 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 pH modification and increased 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 land demand for croplands), 13 (Climate action) (through CDR), 14 (Life below water) (by ameliorating ocean acidification) and 6 (Clean water and sanitation). There are potential benefits in poverty reduction through the employment of local workers in mining.

16. **Trade-offs and spillover effects** Air quality could be adversely affected by the spreading of rock dust, though this can be partly ameliorated via water spraying. As noted above, any significant expansion of the mining industry would require careful assessment to avoid possible detrimental effects on biodiversity. The processing of an additional 10 billion tonnes of rock would require up to 3,000 terawatt-hours, which could represent approximately 0.1–6 percent of global electricity in 2100. The emissions associated with this additional energy generation may reduce the net CO_2 removal by up to 30 per cent with present day average grid emissions, but this efficiency loss would decrease with low-carbon power.

3. Ocean alkalinization

17. CDR, through ocean alkalinity enhancement or artificial ocean alkalinization (OA), can be based on the dissolution of natural alkaline minerals that are added directly to the ocean or coastal environments; the dissolution of such minerals upstream from 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 input and removal fluxes of alkalinity can result in changes in global oceanic alkalinity and therefore the capacity of the ocean 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 in 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 largely focus on quantifying overall energy and carbon balances. Cost ranges are USD 40–260/tCO_2^{-1}.

Considering the life-cycle carbon and energy balances for various OA options, adding lime (or other reactive calcium or magnesium oxide/hydroxides) to the ocean would cost USD 64–260/tCO_2^{-1}.

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 were distributed evenly across the surface ocean. The potential of increasing ocean alkalinity may be constrained by (i) the limited capability 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 with respect to the detailed quantification of CO_2 sequestration efficiency include nonstoichiometric dissolution, reversed weathering and potential pore water saturation in the case of adding minerals to shallow coastal environments. Some researchers suggest storage potentials of 1–100 Gt CO_2/yr^{-1}.

21. **Risks and impacts** For OA, the marine biological impacts are largely unknown. Ecological and biogeochemical consequences of OA largely depend on the minerals used. When natural minerals such as olivine are used, the release of additional silicon and iron could have fertilizing effects. In addition to perturbations to marine ecosystems via the reorganization of community structure, the potentially adverse effects of OA that should be studied include the release of toxic trace metals from some deposited minerals.

22. **Co-benefits** The intentional addition of alkalinity to the oceans through OA would decrease the risk to ocean ecosystems caused by the CO_2-induced impact of ocean acidification on marine biota and the global carbon cycle. OA could be jointly implemented with EW, spreading the finely crushed rock in the ocean rather than land. Regional alkalinization could be effective in protecting coral reefs against acidification. Coastal OA could be part of a broader strategy for the geochemical management of the coastal zone, safeguarding specific coastal ecosystems from the adverse impact of ocean acidification.

23. Trade-offs and spillover effects There has been very little research on biological effects of alkalinity addition. The very few studies that have explored the impact of elevated alkalinity on ocean ecosystems have largely been limited to single species experiments and a constrained field study quantifying the net calcification response of a coral reef flat to alkalinity enhancement. The addition rate would have to be great enough to overcome the mixing of the local seawater with the ambient environment, but not sufficient to detrimentally impact ecosystems. More research is required to assess locations in which this may be feasible, and how such a scheme may operate. The environmental impact of the large-scale release of natural dissolution products into the coastal environment will strongly depend 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 compared with seagrasses). Model simulations suggest that the termination of OA implemented on a massive scale under a high CO_2 emission scenario might pose high risks to biological systems sensitive to rapid environmental changes because 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 through phytoplankton photosynthesis producing organic matter, some of which would be exported into the deep ocean, sequestering carbon. In areas of the ocean where macronutrients (nitrogen, phosphorus) are available in sufficient quantities, the growth of phytoplankton is limited by the lack of trace elements such as

iron. Thus, OF CDR can utilize two implementation options to increase the productivity of phytoplankton: macronutrient enrichment and micronutrient enrichment. Iron fertilization is the best studied OF option to date, but knowledge so far is still inadequate to predict global ecological and biogeochemical consequences.

25. **Status** OF options may appear 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 deep ocean and the longevity of storage. The efficiency of OF also depends on the region and experimental conditions, especially in relation to the availability of other nutrients, light and temperature. In the case of macronutrients, very large quantities are needed, and the proposed scaling of this technique has been viewed as unrealistic.

26. **Costs** OF costs depend on nutrient production and its delivery to the application area. The costs range from USD 2/tCO_2^{-1} for fertilization with iron to USD 457/tCO_2^{-1} for nitrate. The median of OF cost estimates (USD 230/tCO_2^{-1}) indicates low cost-effectiveness, albeit the uncertainties are large.

27. **Potentials** Estimates indicate potentially achievable net sequestration rates of 1–3 Gt CO_2/yr^{-1} for iron fertilization, translating into cumulative CDR of 100–300 Gt CO_2 by 2100, whereas OF with macronutrients has a theoretical potential of 5.5 Gt CO_2/yr^{-1}. Modelling studies show a maximum effect on atmospheric CO_2 of 15–45 parts per million by volume in 2100.

28. **Risks and impacts** Several of the mesoscale iron enrichment experiments have seen the emergence of potentially toxic species of diatoms. There is also evidence of increased concentrations of other GHGs such as methane and nitrous oxide during the subsurface decomposition of the sinking particles from iron-stimulated blooms. Impacts on marine biology and food web structure are not well known. OF at larger scales could cause changes in nutrient distributions or anoxia in subsurface water. Other potential risks are perturbation to marine ecosystems via the reorganization of community structure, enhanced deep ocean acidification and effects on the human food supply.

29. **Co-benefits** The 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 drawbacks include subsurface ocean acidification and deoxygenation; altered regional meridional nutrient supply and fundamental alteration of food webs; and increased production of nitrous oxide and methane. OF is considered to have negative consequences for eight SDGs and a combination of both positive and negative consequences for seven SDGs.

- - - - -

Document information

Version	*Date*	*Description*
02.0	25 October 2022	Published as an annex to the annotated agenda of SB 003. This version incorporates comments from the Supervisory Body at SB 002 (SB 002, para. 12).
01.0	15 September 2022	Published as an annex to the annotated agenda of SB 002.

Decision Class: Operational, Regulatory
Document Type: Information note
Business Function: Methodology
Keywords: Article 6.4 Mechanism, data collection and analysis, emission removal activities, methodologies