A6.4-SB002-AA-A06

Information note

Removal activities under the Article 6.4 mechanism

Version 01.0

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, 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.

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

2. Purpose

4. 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 of the CMA referred to in paragraph 1 above.

3. Key issues and proposed solutions

5. The key issues are considered from a broader perspective, and options for addressing the issues have been listed.

4. Impacts

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

5. Subsequent work and timelines

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

6. Recommendations to the Supervisory Body

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

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1. Introduction

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

9. **Greenhouse gas removal (GGR)** Withdrawal of a greenhouse gas (GHG) and/or a precursor from the atmosphere by a sink.[4]

10. **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.

11. **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.

12. **Bioenergy and carbon dioxide capture and storage (BECCS)** The application of Carbon Dioxide Capture and Storage (CCS) technology to bioenergy conversion processes. Depending on the total life cycle emissions, including total marginal consequential effects (from indirect land use change (iLUC) and other processes), BECCS has the potential for net carbon dioxide (CO2) removal from the atmosphere.

13. **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.

2.2. Terms defined in the A6.4M RMP

14. 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)

15. 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

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

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

[4] 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).

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

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

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

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

19. **Time horizon** The time period in years that delineates the temporal boundary within which the impact of a mitigation action or policy is assessed.

20. **Permanence period** Simplified and approximate holding period applied across all the achieved carbon stocks, that is long enough to approximately justify crediting of 1 credit per tCO2 of the achieved carbon stocks. Any permanence period of less than the time horizon is a non-conservative approximation that results in overcrediting.

21. **Crediting factor** A multiplicative factor applied to 1 tonne of CO2 removed in order to get the number of credits (i.e. A6.4ER). The value of the factor depends upon the time horizon, the holding period of the carbon stocks achieved, and the discount rate applied for valuation of future mitigation at the present time. The crediting factors are derived from the equivalence of marginal cumulative radiative forcing created by a 1 tCO2 pulse emission.

22. **Tonne-year crediting** Calculation of credits by applying an appropriate crediting factor to the achieved carbon stocks based on their actual holding period.

23. **Tonne-based crediting** Calculation of credits by applying a crediting factor of 1.0 to the achieved carbon stocks based on an assumption that these carbon stocks will have a holding period equal to the permanence period.

3. Types of removal activities

24. 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;

        (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).

25. 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;

(c) Geological storage.

26. 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.

27. 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

28. 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 24(a) above. The activity types listed under paragraph 24(b) (the engineering methods) are addressed in section 5.

4. Methodological issues related to land-based removal activities

4.1. Monitoring

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

30. 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

31. 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[5]. 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.

32. 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.

33. 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.[6]

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

35. 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.

36. 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.

37. 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).

38. 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.

39. 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.

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

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

[6] 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.

4.1.2. Frequency of monitoring

41. 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.

42. 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

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

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

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

46. 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.

47. 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.

48. 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.

49. 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.[7]

50. Reporting should be required to include information on how the environmental and socioeconomic impacts were assessed and addressed.[8]

51. Reporting should be required to include information on how the activity contributes to the sustainable development in the host Party.[9]

[7] 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”.

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

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

4.3. Accounting of removals

52. 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.

4.3.1. Baselines

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

54. 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

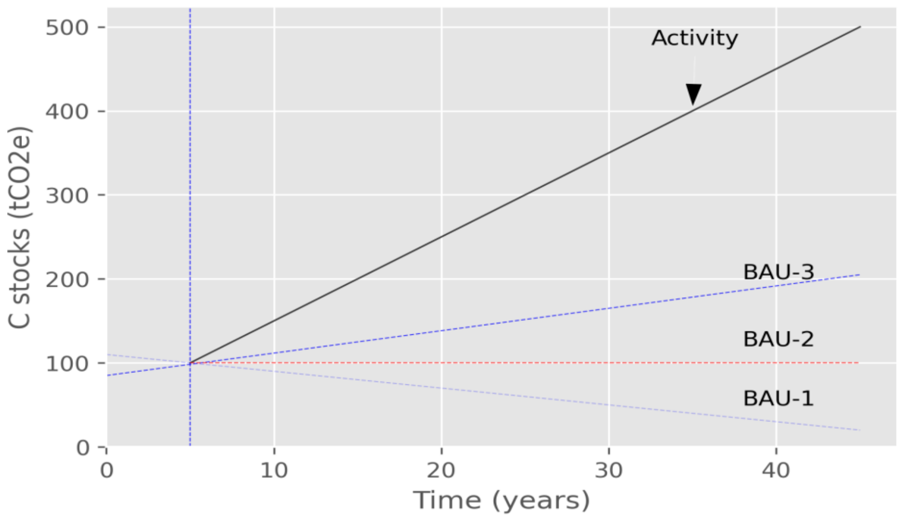
55. According to the “Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement” (RMP) agreed by decision 3/CMA.3, activities under the mechanism shall require the application of one of the following approaches to setting the baseline:

(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



The area between the first and second business-as-usual scenarios (BAU-1 and BAU-2) represents an emission reduction and not CO2 removals.

56. 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.

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

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

59. 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.

60. 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.

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

62. 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

63. 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).[10]

64. 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.

65. 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.

66. 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).

4.3.1.3. Periodic re-validation of the baseline

67. 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

68. 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.

69. 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

70. 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

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

[10] 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.

72. 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.

73. 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.

74. 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

75. 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.

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

77. 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.

78. 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.

79. 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.

80. 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.[11]

81. 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.

[11] 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

4.3.4. Double-counting

82. 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.

83. 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.

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

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

86. 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.

87. 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

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

89. 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.[12]

90. 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.

4.4. Crediting period

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

92. 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).

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

94. 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.

95. 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

96. 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 (unintentional reversal) or a decision of the activity participants (intentional reversal).

97. 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.

98. 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.

99. 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

[12] 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

dioxide achieved at the same point in time as the sequestration. This time period is called the “permanence period” in this note.

4.5.1. Determination of permanence period

100. The IPCC, when discussing this issue, quotes various sources providing time periods ranging from 42 years to 150 years as the duration of the storage of removed carbon that would qualify the removals as permanent.[13]

101. Some regulatory and voluntary carbon offset schemes have adopted permanence periods for removals achieved through land-based activities. The Australian Carbon Farming Initiative, the California Cap-and-Trade Program and the Verified Carbon Standard have adopted a permanence period of 100 years, whereas the American Carbon Registry has adopted a minimum activity term of 40 years.

102. The sections below provide an analysis of the approaches contained in the IPCC-SR-LULUCF in relation to permanence period.

4.5.1.1. Time horizon

103. 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.

104. 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.

105. A commonly adopted climate-relevant time horizon is 100 years and the same is used in the examples for the illustrative purposes in this note.

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

107. 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. Likewise, if one assumes that the global economy will be decarbonized by 2060, then a time horizon of 40 years may be appropriate.

4.5.1.2. Discount rate

108. 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

[13] IPCC Special report on Land Use, Land-Use Change and Forestry. Available at https://bit.ly/3wyGAIv

is efficient to discount the future mitigation value to its net present worth using the social discount rate relevant to climate policy.

109. 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).[14]

110. Another study finds that the mean recommended discount rate relevant to climate policy is 2.27%, with a range from 0 to 10 percent. Under this study, more than three-quarters of the experts interviewed were comfortable with the median discount rate of 2 percent, and over 90 percent of them found an discount rate in the range of 1 to 3 percent acceptable.[15]

111. Some of the common arguments seen in the economic literature relating to climate policy discounting are summarized below:[16]

(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.

(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.

112. 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

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

[15] Drupp, M. et al. Discounting disentangled (2015). Available at https://bit.ly/3QX2gGC

[16] 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

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.[17] However, small-scale and short-term activities can be incentivized with a higher discount rate (e.g. 3%).[18] This choice broadens the mechanism participation base in terms of the variety of removal activities involving different sizes, types, durations and actors.[19]

4.5.2. Equivalence of cumulative radiative forcing

113. 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.

4.5.2.1. Equivalence without discounting

114. 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 2(a) shows the decay profile of such a pulse.[20] The decay continues beyond the time horizon, but the portion beyond the time horizon is not taken into account.[21]

115. Figure 2(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

[17] 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.

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

[19] 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.

[20] 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.

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

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.

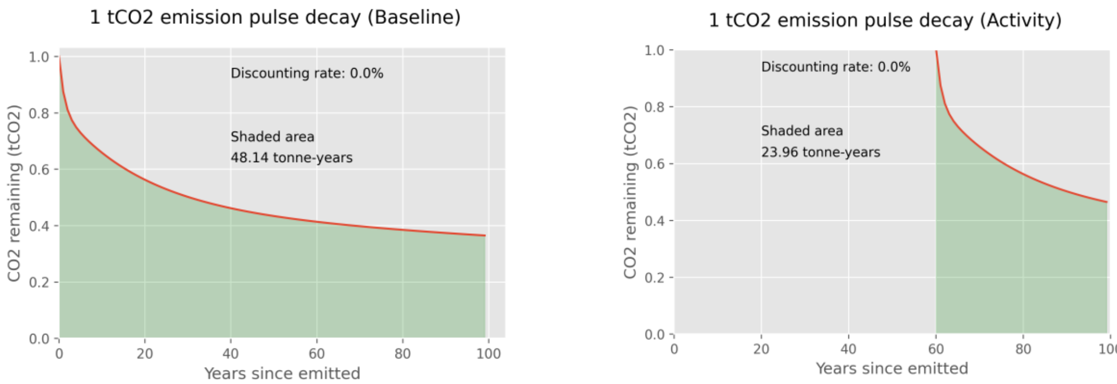
116. Calculation of the areas under the two curves Figure 2(a) and Figure 2(b) shows that at the end of the time horizon, marginal cumulative radiative forcing caused in the baseline scenario corresponds to 48.14 tonne-years whereas marginal cumulative radiative forcing caused in the removal activity 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.

117. 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, termed the holding period henceforth, by this factor gives the number of credits achieved by the removal activity.

118. 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.

119. 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 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 2. 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.

4.5.2.2. Equivalence with discounting

120. 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.

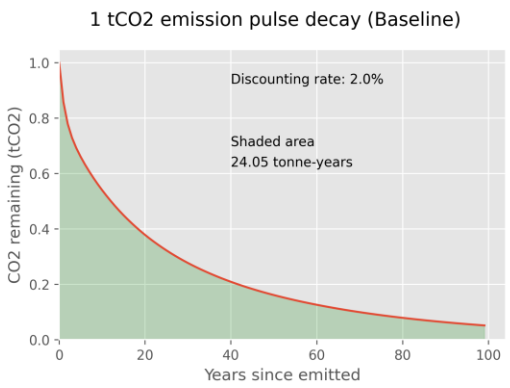
121. Applying a discount rate of 2% results in the tonne-years achieved by a 1 tCO2 removal in year 0 followed by a 1 tCO2 reversal in year 60 as shown in Figure 3.

122. Calculation of the areas under the two curves Figures 3(a) and 3(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 77.92%. The removal activity is thus equivalent to permanent emission reduction of 0.7792 tCO2.

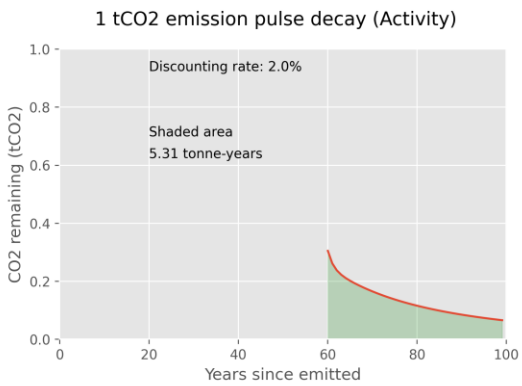
123. Using different discount rates with different holding periods results in the curves shown in Figure 3(c).

124. 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.

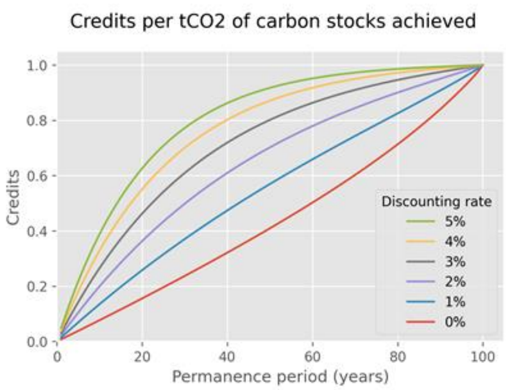
Figure 3. Effect of 1 tCO2 emission in year 0 compared to 1 tCO2 removal followed by reversal in year 60, assuming a time horizon of 100 years and a discounting rate of 2 percent.



(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.

125. Table 2 provides the crediting factors at different holding periods and discount rates, assuming a time horizon of 100 years.

Table 2. Crediting factors at different permanence periods and discount rates[22]

Perm. pd. / discount rate	0%	1%	2%	3%	5%
10	0.07665	0.13459	0.19905	0.26487	0.38782
20	0.15546	0.25757	0.36289	0.46221	0.62596
30	0.23676	0.37019	0.49793	0.60934	0.77221
40	0.32105	0.47371	0.60947	0.71917	0.86206
50	0.40912	0.56938	0.70193	0.80134	0.91731
60	0.50220	0.65861	0.77906	0.86307	0.95134

126. The following observations can be made from Table 2:

(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 tCO2 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 tCO2 of the achieved carbon stocks. To achieve 1 credit, 1/0.86307 or 1.159 tCO2 needs to be achieved with a holding period of 60 years.

127. Although Table 2 provides crediting factors for holding periods at interval of 10 years, a table can also be computed for annual intervals ranging from 1 to 100 years.

128. As an example, if the harvest of carbon stocks is scheduled in year 0, but is moved forward to year 1, the corresponding crediting factors (for the holding period of 1 year) will be 0.007574, 0.01402, 0.02170, 0.030134, 0.038929 and 0.04783 for the discount rates of 0%, 1%, 2%, 3%, 4% and 5% respectively.

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

4.5.2.3. Crediting options

130. Choice of the time horizon and the discount rate is required to be made before mitigation achieved by removal activities can be quantified.

[22] 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

131. 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) 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 one AAU, CER, ERU, RMU or another tCER that is issued for the next commitment period.

(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. 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 one AAU, CER, ERU, RMU or another tCER that is issued for the next commitment period.

h. An lCER that has been transferred to the retirement account of a Party included in Annex I has to be replaced, before its expiry date, with one AAU, CER, ERU or RMU.

(b) 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 factors provided in Table 2 (the factors can be calculated at annual interval if so desired, see appendix 3). Under this option, it is possible to use any holding period ranging from 1 year to 100 year, since the mitigation credits will get scaled according to the holding period. This option will allow a broad range of removal activities, including short-term sequestration or delayed deforestation and delayed harvests to be credited. 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.

(c) Credits are calculated based on the simplifying assumption of a long-enough holding period to be the taken as the permanence period. As long as the permanence period is less than the time horizon, this assumption results in overestimation of credits and therefore a non-conservative outcome.

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

133. Table 4 summarizes the pros and cons of the different crediting methods with respect to the requirements provided in the A6.4M RMP for removal activities.

Table 3. Crediting method options and sub-options and their characteristics

Type of crediting	The basis of credits (measured quantity)	Calculation of credits from the basis	Credits are issued after actual mitigation	Mitigation period remains within the crediting period	Credits correspond to their net present value	Crediting is conservative	Activity participants are free from post-issuance liability	Buyers are free from cancellation risks	Other pros	Other cons
Temporary crediting (tCER/lCER)	**Verified tonnes** achieved by the removal activity	Number of credits is equal to the number of verified tonnes	No	Yes	tCER: Yes lCER: No	Not in themselves, but credits are later replaced by permanent credits, if these are used as offsets by an Annex I Party.	tCER: Yes lCER: No	tCER: Yes lCER: No	The credits allow the users to gain time for either procuring permanent credits or reducing their emissions by the next commitment period.	
Tonne-year crediting	**Verified tonne-years** achieved by the removal activity	Number of credits is equal to the verified tonne-years multiplied by the respective crediting factors that represent the actual mitigation achieved over the holding	Yes	Yes	Yes	Yes	Yes	Yes	– Activities of all sizes, at all time-scales can be undertaken without compromising environmental integrity. – Because of flexibility and simplicity, small-size	Majority of credits get issued late (i.e. the second half) in the crediting period. Fewer credits get issued earlier on.

Type of crediting	The basis of credits (measured quantity)	Calculation of credits from the basis	Credits are issued after actual mitigation	Mitigation period remains within the crediting period	Credits correspond to their net present value	Crediting is conservative	Activity participants are free from post-issuance liability	Buyers are free from cancellation risks	Other pros	Other cons
		period of each tonne. NB. At each issuance a different crediting factor would be used. Later issuances will tend to use higher crediting factor values as each tonne will tend to have longer holding period.							land holders and a variety of actors can participate in the mechanism (e.g. cities, communities, institutions, farmers, etc.) – Credits can be issued annually with simplified monitoring (“the no-decrease” monitoring report).	
		Number of credits is equal to total tonne-years divided by a fixed holding period (i.e. an assumed permanence period)	Yes	Yes	Yes	Yes/No. Conservative if the permanence period is longer than the crediting period; not conservative otherwise.	Yes	Yes	As above	Credits are not always conservative.
	Verified tonnes	Number of credits is	No	No	No	No	No	No	Credits are issued early	– Credits are conservative

Type of crediting	The basis of credits (measured quantity)	Calculation of credits from the basis	Credits are issued after actual mitigation	Mitigation period remains within the crediting period	Credits correspond to their net present value	Crediting is conservative	Activity participants are free from post-issuance liability	Buyers are free from cancellation risks	Other pros	Other cons
Tonne-based crediting	achieved by the removal activity	equal to the number of verified tonnes							in the crediting periods.	in the case where the permanence period is equal to the time horizon. – Credits face the risk of reversal. – In case of long-term activities (e.g. > 30 years, which is likely to be case) there is more uncertainty about future changes in the additionality-related parameters in the future; thus leading to decreased confidence in robust additionality.
		Number of credits is equal to the	No	Yes	No	No	No	No	As above	As above

Type of crediting	**The basis of credits (measured quantity)**	**Calculation of credits from the basis**	**Credits are issued after actual mitigation**	**Mitigation period remains within the crediting period**	**Credits correspond to their net present value**	**Crediting is conservative**	**Activity participants are free from post-issuance liability**	**Buyers are free from cancellation risks**	**Other pros**	**Other cons**
		number of verified tonnes divided by the ratio pp/crp_left, where pp is the permanence period in years and crp_left is the time to the end of the crediting period in years.								
		Number of credits is equal to the number of verified tonnes multiplied by the crediting factor calculated for the assumed permanence period.	No	No	No	Yes	No	No		As above
		Number of credits is	No	Yes	No	Yes	No	No	As above	As above

Type of crediting	The basis of credits (measured quantity)	Calculation of credits from the basis	Credits are issued after actual mitigation	Mitigation period remains within the crediting period	Credits correspond to their net present value	Crediting is conservative	Activity participants are free from post-issuance liability	Buyers are free from cancellation risks	Other pros	Other cons
		equal to the number of verified tonnes multiplied by the crediting factor calculated for the assumed permanence period and divided by the ratio pp/crp_left, where pp is the permanence period in years and crp_left is the time to the end of the crediting period in years.								
		Number of credits is equal to the number of verified tonnes multiplied by	No	Yes	Yes	Yes	No	No	As above	As above

Type of crediting	**The basis of credits (measured quantity)**	**Calculation of credits from the basis**	**Credits are issued after actual mitigation**	**Mitigation period remains within the crediting period**	**Credits correspond to their net present value**	**Crediting is conservative**	**Activity participants are free from post-issuance liability**	**Buyers are free from cancellation risks**	**Other pros**	**Other cons**
		the crediting factor calculated for the assumed permanence period, divided by the ratio pp/crp_left, where pp is the permanence period in years and crp_left is the time to the end of the crediting period in years, and discounted to the present value at the time of issuance using appropriate private sector discount rate.								

Table 4. Pros and cons of the two options of crediting with respect to each requirement prescribed in the "Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement"

RMP requirement relating to credits	Temporary crediting (tCER/lCER)	Tonne-year crediting	Tonne-based crediting
Real[1]	Neither of these credits are issued after the actual mitigation has been fully achieved, and therefore these cannot be said to represent real mitigation.	The credits are issued after the actual mitigation has been achieved and therefore are real.	Credits are issued ex-ante and are based on promised mitigation. The credits are conditional to the continued existence of the carbon stocks and the actual mitigation is achieved later into the future. However, the credits are based on verified carbon stocks and therefore are analogous to the credits that would be issued to an emission reduction activity upon verification of the construction of a renewable energy power plant that has yet to feed electricity into the grid.
Transparent	The basis of the credits is not transparent. There is an assumption that 1 tCO2 of removal (with any holding period, selected by the activity proponents) is equal to 1 credit.	The credits are calculated on the basis of the mitigation metric of marginal cumulative radiative forcing. The credits are transparent since anyone can reproduce the calculations that these are based on.	The credits are based on a non-transparent assumption that 1 tonne of CO2 removed and held out of the atmosphere for the assumed permanence period create the same mitigation as 1 CO2 emission reduction. However, for a permanence period equal to the time horizon, the credits are transparent.

[1] Since no specific definition of real is given in the RMP, the dictionary meaning is assumed (i.e. that which exists, or ex-post facto). Real also implies earned, not fortuitous (i.e. not caused by the circumstances that are beyond the control of the activity participants).

RMP requirement relating to credits	Temporary crediting (tCER/lCER)	Tonne-year crediting	Tonne-based crediting
Conservative	The credits are not conservative in themselves but considering that these are used as an ad-interim measure by the users and are subsequently replaced with a valid CER or equivalent credit, the overall effect is conservative. However, in the cases where the replacement obligation does not arise (e.g. the credits are not retired by an Annex I Party but are used for voluntary cancellation), the conservativeness is not ensured.	– The credits are conservative. Each credit represents mitigation equal to 1 tCO2 removal. However, some of the mitigation (the linear portion of growth curve) are not included in the issuance and thus represent slightly more mitigation value than credited. – Credits generated by smaller size activities and smaller crediting period provide greater confidence in the integrity of baselines since the baseline periods are generally shorter. – Credits generated by large-size activities and longer crediting period less confidence in the baselines since projection of the baseline over a longer period is inherently more uncertain.	– Credits generated by removal activities with a permanence period equal to the time horizon are conservative. – Credits generated by removal activities with a permanence period less than the time horizon are non-conservative, since the mitigation value produced by each tonne of removal is less than the mitigation of 1 tCO2 emission reduction. – Credits generated by smaller size activities and smaller crediting period provide greater confidence in the integrity of baselines since the baseline periods are generally shorter. – Credits generated by large-size activities and longer crediting period less confidence in the baselines since projection of the baseline over a longer period is inherently more uncertain.
Credible	In absence of transparency and conservativeness, and the credibility of the credits is low, but the total risk is low because these can be use as offsets only for a short period of time.	The credits are issued ex-post and are conservative and therefore have credibility.	Credits are credible if the permanence period is equal to the time horizon.

RMP requirement relating to credits	Temporary crediting (tCER/lCER)	Tonne-year crediting	Tonne-based crediting
Additionality	In the case of shorter-term removal activities, there is less uncertainty about future changes in the additionality-related parameters. Further, the carbon price is more likely to make an impact on the decision making of small-scale holders, thus increasing the confidence in robust additionality. In the case of long-term activities and large-size activities, there is more uncertainty about future changes in the additionality-related parameters and the carbon price is less likely to make an impact on the decision making of large-scale investments, thus decreasing the robustness of additionality.	In the case of shorter-term removal activities, there is less uncertainty about future changes in the additionality-related parameters. Further, the carbon price is more likely to make an impact on the decision making of small-scale holders, thus increasing the confidence in robust additionality. In the case of long-term activities and large-size activities, there is more uncertainty about future changes in the additionality-related parameters and the carbon price is less likely to make an impact on the decision making of large-scale investments, thus decreasing the robustness of additionality.	In the case of shorter-term removal activities, there is less uncertainty about future changes in the additionality-related parameters. Further, the carbon price is more likely to make an impact on the decision making of small-scale holders, thus increasing the confidence in robust additionality. In the case of long-term activities and large-size activities, there is more uncertainty about future changes in the additionality-related parameters and the carbon price is less likely to make an impact on the decision making of large-scale investments, thus decreasing the robustness of additionality.
Avoid leakage	Probability and size of leakage is lower for smaller size activities. For larger activities, the leakage probability is higher.	Probability and size of leakage is lower for smaller size activities. For larger activities, the leakage probability is higher.	Probability and size of leakage is lower for smaller size activities. For larger activities, the leakage probability is higher.
Encourage broad participation	Activities of all sizes, including small and large, having different activity periods can be undertaken.	– Activities of all sizes, at all time-scales can be undertaken. Because of flexibility and simplicity, small-size land holders and a variety of actors can participate in the mechanism (e.g. cities, communities, institutions, farmers, etc.). Larger size activities, however, are also possible. Thereby broader participation is encouraged. – Aggregators and activity developers can mobilize land-holder groups in developing countries with less capacity and provide support to their cooperative activities. Such contractual arrangements are less likely to be feasible when the activity duration is long (e.g. more than 30 years). Because of fast-changing socio-economic conditions in developing countries, the land-holders tend not to enter into contractual arrangements that are effectively trans-generational.	Long-term activities (e.g. term equal to the time horizon) in general tend to be of large size and actors tend to be limited to certain categories (e.g. energy companies in the case of BECCS, timber companies in case of HWP). The participation base is not likely to be broad.

RMP requirement relating to credits	Temporary crediting (tCER/lCER)	Tonne-year crediting	Tonne-based crediting
Recognize suppressed demand	Suppressed demands, such as demands for fuelwood for cooking, fodder for livestock, etc. can be met through removal activities implemented by or for small-holder communities. Where there is long-overdue need to address land degradation (due to lack of public finance) that causes water scarcity and scarcity of biomass, removal activities such as watershed reforestation can be undertaken at all scales to allow meeting of long-suppressed community needs.	Suppressed demands, such as demands for fuelwood for cooking, fodder for livestock, etc. can be met through removal activities implemented by or for small-holder communities. Where there is long-overdue need to address land degradation (due to lack of public finance) that causes water scarcity and scarcity of biomass, removal activities such as watershed reforestation can be undertaken at all scales to allow meeting of long-suppressed community needs.	Long-term activities (e.g. term equal to the time horizon) in general tend to be of large size and actors tend to be limited to certain categories (e.g. energy companies in the case of BECCS, timber companies in case of HWP). The principle of suppressed demand does not apply to commercial enterprises.
Address reversals	Reversals are fully addressed for the credits that are retired by an Annex I Party. These credits get replaced with permanent emission reduction credits. For credits that are used for other purposes, e.g. voluntary retirement, unaccounted and uncompensated reversal can occur after the end of the crediting period.	Reversal is not possible since reversal is already included in the calculation of crediting factors. Crediting factors are based on the conservative assumption that the removals will be reversed and the consequent damage to the atmosphere is deducted from the mitigation achieved up to that point. Thus the risk of reversal is fully addressed.	– Reversal is addressed through an activity-specific or a pooled buffer of credits and therefore the risks are managed appropriately. – In the exceptional cases of intentional abandonment of activities, or exhaustion of the buffer pool, occurring after issuance and sale of credits, the risk of cancellation is either borne by the buyers of the credits or is overtaken by the host Party.

RMP requirement relating to credits	**Temporary crediting (tCER/lCER)**	**Tonne-year crediting**	**Tonne-based crediting**
Avoid negative env and social impacts	– In case of small-size activities and local actors, the negative environmental and social impacts are less likely to occur. The incidents of land-grabbing or displacement of people with traditional or informal tenures is less likely to occur. However, these negative impacts can happen where large and powerful actors undertake larger scale activities. – Local communities and farmers tend to use local species that are of economic importance to them, hence there is less risk of invasion by alien species and biodiversity loss. – Competition for land and water resources is less likely to occur. – However, all these negative impacts are more likely to occur in the case of powerful actors undertaking large scale activities.	– In case of small-size activities and local actors, the negative environmental and social impacts are less likely to occur. The incidents of land-grabbing or displacement of people with traditional or informal tenures is less likely to occur. However, these negative impacts can happen where large and powerful actors undertake larger scale activities. – Local communities and farmers tend to use local species that are of economic importance to them, hence there is less risk of invasion by alien species and biodiversity loss. – Competition for land and water resources is less likely to occur. – However, all these negative impacts are more likely to occur in the case of powerful actors undertaking large scale activities.	– In view of the large size of activities, the actors are likely to be have more power and influence and the social and environmental impacts such loss of biodiversity and loss of livelihoods, land deprivation of people with traditional informal tenures, are more likely to happen. – Land competition and competition for resources such as land water can cause impacts on food security and water security. – Biodiversity can be endangered since larger activities tend to employ monoculture of fast growing species under projects such as BECCS and timber production.

Note) Other considerations

Apart from the above analysis, the following points can be noted:

(a) In general, the A6.4-RMP favour shorter periods of activities than under the CDM. For example, removal activities could be of maximum 60 years under the CDM which is 45 years under the RMP. Renewable crepitating periods are limited to 15 years compared 20 years in the CDM. Tonne-year based activities are thus better aligned with the tendency of shorter crediting periods.

(b) Under the RMP, host Parties can require shorter crediting periods than 15 years. This is consistent with shorter holding periods, which is possible under the tonne-year crediting approach. Under the tonne-based crediting, holding periods tend to be more than to 40 years although generally longer than this.

(c) Markets function efficiently when a large number of actors participate in it. With a broader participation of different types of actors and activities of different sizes, the market is more like to function closer to the ideal of a perfect market. In the case of limited number of suppliers and a few buyers of the credits, the market are not likely reach the efficiency of carbon price and are vulnerable to control and distortions by a few participants.

4.5.3. Approaches to addressing reversal

134. The approach to addressing the reversal of carbon stocks achieved by a removal activity depends upon the method of crediting described below:

(a) Temporary crediting;

(b) Tonne-year crediting;

(c) Tonne-based crediting.

135. Temporary crediting under the CDM has been described under paragraph 131(a) above. Reversals under temporary crediting are addressed through replacement of the credits with permanent credits after their expiry, in the cases where these credits are used as offset by an Annex I Party. However, if the temporary credits are not used as offsets by an Annex I party, reversals are not addressed.

136. The sections that follow describe the practical application the other two types of crediting methods and analyses the overcrediting or undercrediting associated with different parameters, using a simulated removal activity as an illustrative example.

137. 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.

138. The analysis is based on the simplified assumption of a fixed permanence period that is less than the time horizon and the exact crediting factors are not applied. Adopting a time horizon different from 100 years will result in different quantitative outcomes (e.g. the extent of overcrediting or undercrediting will be different), but the same qualitative outcomes (i.e. the relative outcomes).

4.5.3.1. Tonne-year crediting

139. Under this method, credits are issued equal to the product of the tonnes of carbon stocks and the years that the carbon stocks have been held out of the atmosphere, divided by the permanence period. It is assumed that a carbon stocks of 1 tonne held out of the atmosphere for 60 years provides the same mitigation value as a carbon stock of 60 tonnes held out of the atmosphere for 1 year.[1]

140. Ex-post credits are permanent and do not carry any residual liability after the verification of carbon stocks.

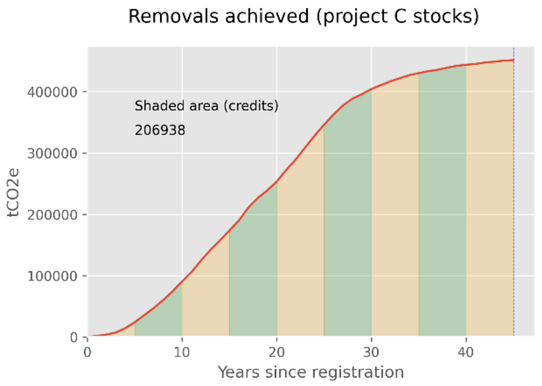
[1] Although this assumption does not strictly hold true as evidenced by the factors provided in Table 2, this inaccuracy does not affect the core principles relevant to addressing the reversals.

141. Figure 4 shows the growth of carbon stocks under the activity and credits resulting from ex-post crediting.

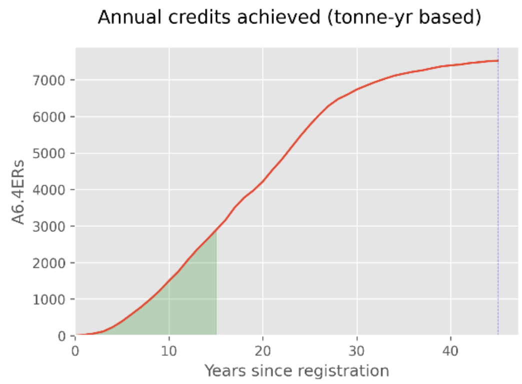
142. Figure 4(a) shows that total carbon stocks in the watershed become saturated at about 400,000 tCO2. The area under the curve in figure 4(a) represents total tonne-years achieved. This area divided by 60 gives the number of total credits (approx. 200,000 credits). The area of each shaded strip represents credits issued at successive five-year verifications.

143. It can be seen that under this approach, the major portion of credits are issued in the second half of the crediting period. If the activity participants anticipate a higher carbon price in future years compared to now, they might prefer this approach.

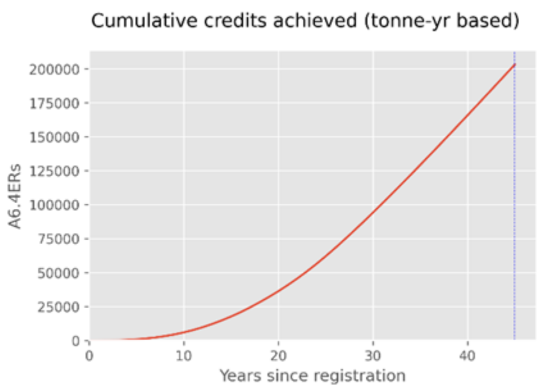
Figure 4. Removal activity consisting of tropical watershed reforestation with mixed stands of local species (tonne-year accounting)



(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), circa 200,000 credits are achieved.

144. On the other hand, the number of credits issued in the early years is small. Although this seems to restrict the value of carbon revenue as upfront capital to financially support the establishment of the plantation, the advance purchase agreements with buyers can redress this limitation. The advance purchase agreements may protect the buyers against risks of increased carbon prices in the future, while providing early financial resources to the activity proponents to implement the activity.

145. Under this approach, neither the buyers nor the activity participants nor the regulators have any concerns about the reversal of the carbon stocks. The activity proponents are free to harvest their carbon stocks (which would not be of interest in the example of watershed reforestation but could be of interest in other types of plantations) at any time after the issuance of credits without affecting the mitigation value of the credits issued. On the other hand, the activity participants will have a strong incentive to preserve their carbon stocks since these become progressively more valuable over time in terms of the yield of carbon credits.

4.5.3.2. Overcrediting or undercrediting due to simplification

146. It is to be noted that in the above example a fixed time has been used to scale tonne-years into credits. This is a simplification and results in either overestimation or underestimation of the credits compared to actual mitigation achieved, depending upon the discount rate, the permanence period and the crediting period length. To compute the actual mitigation produced, each tonne needs to be multiplied by the corresponding crediting factor which depends upon the holding period of that tonne.

147. A quick calculation shows that the above activity would get approx. 92,435 credits with 0% discount rate, and 246,635 credits with a 3% discount rate. In comparison, using the simplified method with a fixed permanence period of 60 years gives 206,938 credits, which corresponds to a 124% over crediting compared to the case of 0% discount and 16% under crediting compared to the case of 3% discount.

148. According to the A6.4-RMP, any simplification should be based on assumptions that result in a conservative outcome i.e. simplifying assumptions should lead to an underestimation rather than overestimation of the credits.

4.5.3.3. Tonne-based crediting

149. Under this method, upon verification of carbon stocks, credits are issued equal to the number of tonnes of carbon stocks achieved since the previous verification. This is ex-ante crediting since the tonnes by themselves do not represent the mitigation value provided by the activity. Mitigation value is to be achieved in future, as each tonne of verified carbon stocks is held out of the atmosphere over the permanence period. To ensure this, in the case of the example above, verified carbon stocks will have to be monitored periodically over a period of 60 years from the time of the initial verification and, in the event of any reversal occurring, the reversal will have to be compensated through one of the methods described later in this section.

150. Figure 5 shows the carbon stocks and the credits resulting from tonne-based crediting under the same example of watershed reforestation described in paragraph 137 above.

151. 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 105 from the start of the activity).

152. 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 two times the credits issued under tonne-year crediting.

153. If only the mitigation value produced within the crediting period is to be considered creditable, the number of credits at each verification will have to be scaled down by a factor equal to the number of years left until the end of the crediting period divided by 60. For example, in the case of verification occurring in year 15, only 30 years are left until the end of the crediting period. Therefore, for each tonne of the verified carbon stocks, 30/60, or 0.5, credits should be issued. In other words, progressively more tonnes will be required to be able to receive a credit as the end of the crediting period approaches.

154. Applying this scaling results in a total number of credits that is approximately equal to the number of credits under the tonne-year crediting method. In the case of the watershed reforestation example, 193,320 credits will be issued compared to 206,938 credits under the ex-post crediting. The reason for the difference is the approximation of the area under the curve. If verification and issuance is assumed to occur every year, which in practice is not feasible for cost reasons, then the total number of credits issued under the two methods will be the same.

155. It can be seen that under this approach the majority of credits are issued in the first half of the crediting period. If the activity participants assume a higher carbon price earlier rather than in later years, they might prefer this approach.

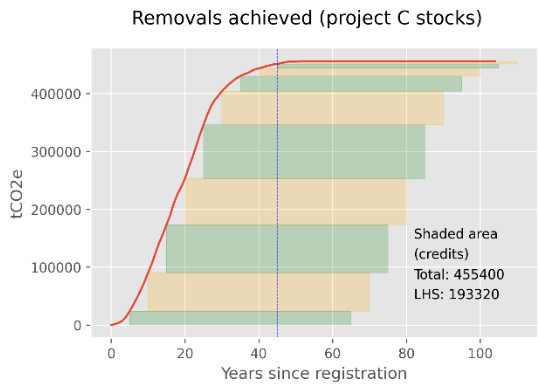
156. Even though the credits are issued relatively early, they still might not be useful for raising capital finance since a major part of the expenditure (usually up to 80 percent) occurs during the establishment of the plantations, and much less expenditure is needed for maintenance. For this reason, the activity proponents might want to enter into an advance purchase agreement with the buyers if early finance, rather than maximization of the revenue from carbon credits, is their main need.

157. One disadvantage of this this approach is that the activity proponents as well as buyers of credits face the risk of reversal of the credits. The arrangements for managing this risk are discussed in the next section.

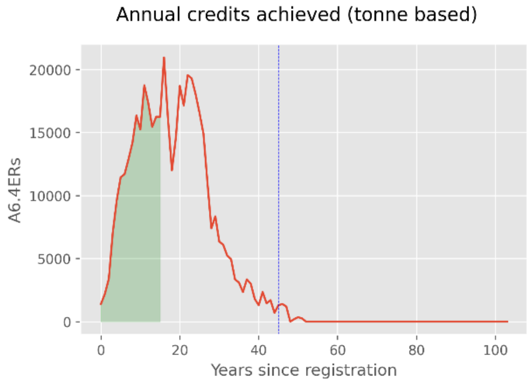
4.5.3.4. Overcrediting due to simplification

158. It is to be noted that in the above example, the simplification that assumes a crediting factor of 1.0 results in overestimation of the credits compared to actual mitigation achieved. To compute the actual mitigation produced, each tonne needs to be multiplied by the corresponding crediting factor depending upon how many years that tonne has been held out of the atmosphere.

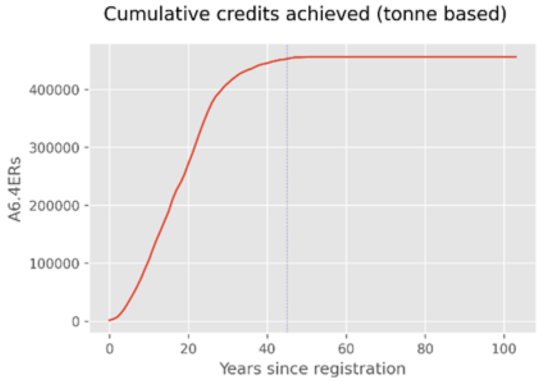
Figure 5. Removal activity consisting of tropical watershed reforestation with mixed stands of local species (tonne-based crediting)



(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. However, if credits are scaled to stay within the crediting period, 193,320 credits will be issued.

159. Table 5 provides the extent of over crediting that would occur in a tonne-based crediting approach with permanence periods less than the time horizon of 100 years.

Table 5. Extent of over crediting when a fixed permanence period is used tonne-based crediting (percent)

Discount rate (%)	**Permanence period (years)**						
	40	**50**	**60**	**70**	**80**	**90**	**100**
0	211	144	103	66	40	19	0
1	111	76	54	34	21	10	0
2	64	42	30	18	11	5	0
3	39	25	17	10	6	3	0
4	24	15	9	5	3	1	0
5	16	9	5	3	1	0.6	0

160. According to the Article 6.4 RMP, any simplification should be based on assumptions that result in a conservative outcome i.e. these should lead to an under-estimation rather than over-estimation of the credits.

4.5.3.5. Overcrediting due to inclusion of mitigation occurring beyond crediting period

161. As was seen in paragraphs 152-153 above, the 1-tonne-equals-1-credit method also takes into account the mitigation produced between year 45 (end of the crediting period) and the year 105 (due to obligation of completing permanence years for the last batch of issuance). This results in over crediting if one assumes that only the credits produced within the crediting period should be eligible to be credited, as is the case with the emission-reduction activities.

4.5.3.6. Overcrediting due to advance issuance

162. In the tonne-based crediting method, the credits are issued for the mitigation that will take place in the future and therefore should be discounted at a suitable rate to calculate their present value. Since a removal activity is privately owned, a private discount rate should be used instead of the social discount rate (SDR).

4.5.4. Risk mitigation and compensation mechanism

163. 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 tonne-based crediting method.

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

165. A mandatory post-verification 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.

166. 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.

167. A risk mitigation and compensation mechanism could be based on one of the options described in the sections 4.5.4.1 to 4.5.4.3 below.

4.5.4.1. Permanence buffer backed up by host Party guarantee

168. 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 some entity. 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;

(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, in which case the buffer pool has to be segmented by the host Party countries where removal activities are hosted. Such a guarantee would 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;

(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.

4.5.4.2. Commercial insurance

169. 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.

4.5.4.3. Menu of options

170. 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.

4.6. Avoidance of leakage

171. Leakage is defined as the indirect decrease or increase in carbon stocks occurring outside the activity boundary. An increase in carbon stocks outside the activity boundary is positive leakage and is not be accounted.

4.6.1. Leakage caused by shifting of baseline activities

172. 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.

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

174. 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.

175. 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

176. 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.

177. 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

178. 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.

179. 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.

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

4.7.1. Impacts on land, biodiversity and water

181. 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.

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

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

184. 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.

185. 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.

186. 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

187. 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.

188. 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.

189. 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.

190. 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.

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

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

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

194. 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.

195. 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

196. 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.

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

198. 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.

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

(a) Geological storage;

(b) Storage in wood products.

4.8.1. Geological storage

200. 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[2], indicate that it is feasible to store CO2 in geological formations as a CO2 mitigation option.[3]

201. 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.

202. 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.

203. 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.

204. 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.

205. 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).

206. 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.

207. 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.

4.8.2. Removal activity with BECCS

208. As an illustration of how BECCS can increase the removal potential of a given area of land, consider the simulation example of reforestation discussed earlier. 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,

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

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

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.

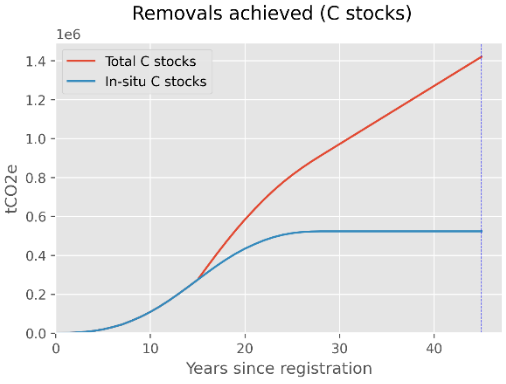
209. The resulting carbon stocks and the removal credits generated from the activity are shown in Figure 6. Credits are estimated based on tonne-year crediting.

210. Figure 6(a) 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.

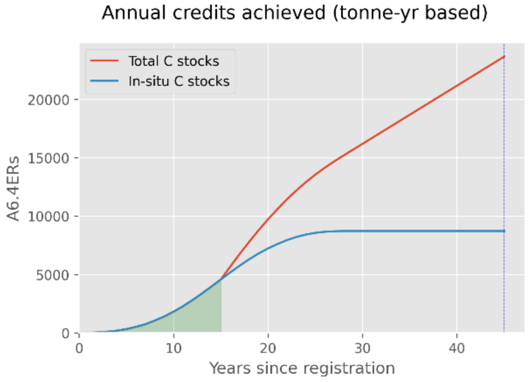
211. Figures 6(b) and 6(c) show the annual credits and the cumulative credits achieved. By the end of the crediting period, a total of 500,000 credits are achieved (compared to 200,000 credits in the case of watershed reforestation). As is the case with any removal activity opting for tonne-year crediting, the majority of the credits are achieved in the second half of the crediting period.

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.

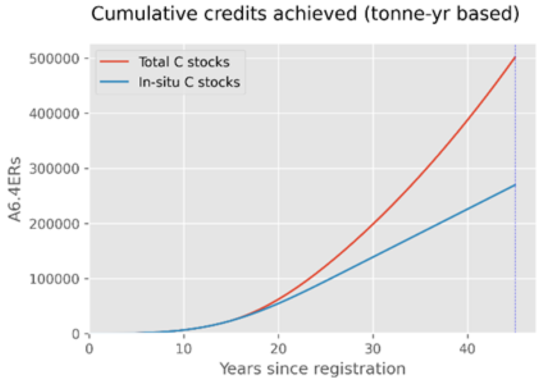
Figure 6. Removal activity consisting of afforestation with fast-growing species with biomass feeding into bioenergy with carbon capture and storage (tonne-year crediting)



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



(b) Number of credits achieved per year (e.g. in and around year 20, about 10,000 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), 500,000 credits are achieved.

4.8.3. Storage in durable wood products

212. 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 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].

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

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

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

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

4.8.4. Removal activity with storage in durable products

216. As an illustration of how long-lasting HWP can increase the removal potential of a given area of land, consider the simulation example discussed earlier. 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.

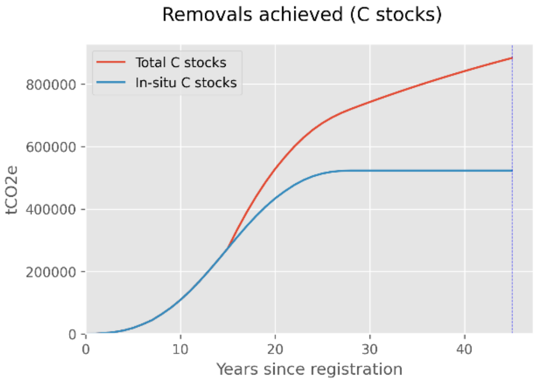
217. The resulting carbon stocks and the removal credits generated from the activity are shown in Figure 7. Credits are estimated based on tonne-year crediting.

218. Figure 7(a) 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.

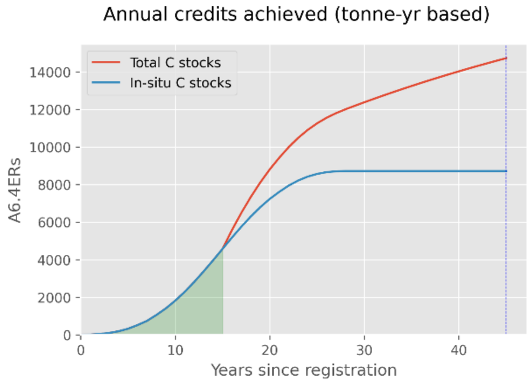
219. Figures 7(b) and 7(c) show the annual credits and cumulative credits achieved. By the end of the crediting period, a total of 375,000 credits are achieved (compared to 200,000 credits in the case of watershed reforestation and 500,000 in the case of afforestation with BECCS). As is the case with any removal activity opting for tonne-year crediting, the majority of the credits are achieved in the second half of the crediting period.

220. 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.

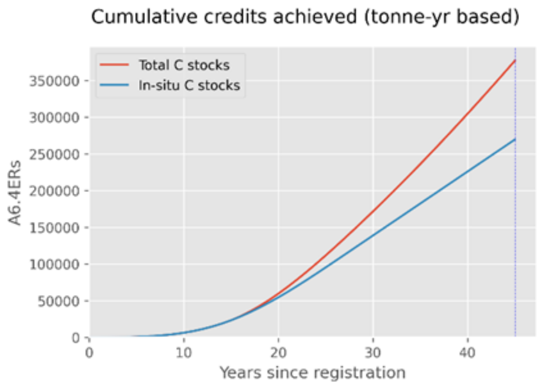
Figure 7. Removal activity consisting of afforestation with fast-growing species with sustained harvesting of long-lasting wood products (tonne-year crediting)



(a) Evolution of carbon stocks in the in-situ carbon pools and in the wood products pool.



(b) Number of credits achieved per year (e.g. in and around year 20, about 8,500 credits are earned per year). Total credits achieved by a particular 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), approx. 375,000 credits are achieved.

5. Methodological issues related to engineering-based removal activities

221. 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.

222. The following types of engineering-based removal activities are considered:[5]

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

[5] Summary descriptions of these activities, based on the approved text of the IPCC AR6, WG-III, is contained in the appendix of this note.

(b) Enhanced rock weathering (EW);

(c) Ocean alkalinization (OA);

(d) Ocean fertilization (OF).

223. 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.

224. 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.

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

226. 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

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

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

229. 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

230. 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.

231. 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.

232. 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

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

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

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

236. 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.

237. 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.

238. 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.

239. 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.

240. Reporting should be required to include information on how the environmental and socioeconomic impacts were assessed and addressed.[6]

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

5.3. Accounting of removals

242. 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

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

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

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

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

245. 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

246. 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

247. 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

248. 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.

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

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

5.3.4. Double-counting

251. 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.

252. 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.

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

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

255. 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.

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

5.4. Crediting period

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

258. 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).

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

260. 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.

261. 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

262. 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.

263. 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.

264. 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

265. 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

266. 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.

267. 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.

268. 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

269. 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.

270. 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

271. 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

272. 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.

273. 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.

274. 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

275. 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.

276. 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

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

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

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

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

281. 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.

282. 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

283. 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.

284. 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.

285. 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. Summary descriptions of engineering-based removal activities[1]

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–

[1] The summary descriptions of the engineering-based removal activities in this appendix are based on the approved text of the IPCC AR6, WG-III.

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.

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