



# 10

## Technical appendix

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# Technical appendix | Chapter 10

## A10.1 Data

**A database of monitoring, reporting, and verification (MRV) protocols was compiled by the chapter authors.**

The MRV protocol database developed for this chapter expands on Arcusa and Sprenkle-Hyppolite (2022)<sup>1</sup>, which mapped the Carbon Dioxide Removal (CDR) certification and standards ecosystem for the year 2021-2022. The database can be found on the State of CDR data portal.

## A10.2 Methods

**The chapter draws on quantitative and qualitative assessment methods.**

The methods used in the chapter are described in Box 10.2 of the main text.

## A10.3 Caveats and Limitations

**Some analyses in the chapter are embedded in larger works in progress.**

Box 10.3 summarizes limitations of the chapter and highlights ongoing research, some of which informs this chapter. Findings presented in the chapter may differ slightly from research results presented in future academic publications that expand on analyses in this chapter, though the overall messages should remain consistent. For example, revisions to analyses may occur during manuscript preparation and journal peer-review processes.

## A10.4 Literature Review

**The chapter draws on existing literature by using systematic map and traditional review methods.**

Chapter 10, Box 10.1 outlines contested terms and critical open questions related to MRV of CDR. Table A provides examples of peer-reviewed and grey literature that provide more discussion of these issues.

The section “State of science on MRV” in Chapter 10 presents an overview table of current tools and techniques available to support the MRV of CDR. The table synthesizes existing literature and was then expanded on with input provided by CDR-method specific experts. Table B is a more detailed version of the overview table (Table 10.3) provided in the main chapter text.

The section “Evaluations of the MRV system” in Chapter 10, references a range of existing peer-reviewed and grey literature that conduct evaluations of different aspects of the MRV system or outline criteria for evaluation. Table C provides some examples of this literature.

## Table A. Literature on debated terminology

Term	Examples of further reading
Durability	<p>Arcusa et al., 2022<sup>2</sup></p> <p>Burke &amp; Schenuit, 2023<sup>3</sup></p> <p>Groom &amp; Venmans, 2023<sup>4</sup></p> <p>Matthews et al., 2023<sup>5</sup></p> <p>Mitchell-Larson et al., 2022<sup>6</sup></p> <p>Parisa et al., 2022<sup>7</sup></p> <p>TSVCM, 2021<sup>8</sup></p>
Double counting	<p>Höglund, 2023<sup>9</sup></p> <p>Romm, 2023<sup>10</sup></p> <p>Schneider et al., 2015<sup>11</sup></p> <p>Schneider and La Hoz Theuer, 2019<sup>12</sup></p> <p>Tamme and Zakkour, 2024<sup>13</sup></p>
Quantification	<p>Arcusa et al., 2022<sup>2</sup></p> <p>Chay et al., 2022<sup>14</sup></p> <p>Lackner et al., 2023<sup>15</sup></p>
Additionality	<p>Arcusa et al., 2022<sup>2</sup></p> <p>Gillenwater, 2012<sup>16</sup></p>

Table B. Detailed overview of MRV tools and techniques

CDR method	Measurement and quantification	Monitoring approaches and technologies	Operationalisation in protocols (see Table 10.2 for number of protocols)
<p>Afforestation, reforestation, agroforestry, forest management (A/R)<sup>17-22</sup></p>	<ul style="list-style-type: none"> <li>• Directly measuring the amount of CO<sub>2</sub> captured due to anthropogenic activity is not possible</li> <li>• Carbon stock changes (fluxes) can be estimated via measurements of carbon pools, such as above-ground biomass, below-ground biomass, dead wood, litter and/or soil carbon. These are often calculated based on allometric relationships, e.g., stem diameter measurements or LiDAR measurements of tree height. Stock changes can be converted into emissions and removals. Alternatively, emissions factors, flux measurements, or models can be used to calculate fluxes</li> <li>• The temporal profile of removals and permanence is very variable according to e.g., species, habitat. A key unknown is future disturbances including management, drought, floods and fires</li> <li>• Approaches to estimating fluxes due to forest management activities are variable and subject to high uncertainties. Carbon stocks, growth rates and decomposition high heterogeneity spatially and over time due to environmental and climate drivers. In some cases, the carbon storage, and change in storage compared to a baseline, is contested</li> </ul>	<p>One or more of the following may be used:</p> <ul style="list-style-type: none"> <li>• Field samples / in-situ data (e.g., forest growth plot measurements of stem diameter, basal area)</li> <li>• Remote sensing</li> <li>• Empirical or process-based models</li> <li>• Airborne laser scanning</li> <li>• Allometric equations</li> </ul>	<ul style="list-style-type: none"> <li>• National GHG inventory guidelines available for the Agriculture, Forestry and Other Land Use (AFOLU) sector.</li> <li>• Major accounting discrepancies exist between independent global model estimates of net land flux and what is reported by countries in National Greenhouse Gas Inventories<sup>23</sup> (see Chapter 7 - Deployment).</li> <li>• Some key barriers to comparability include approaches to establishing what is anthropogenic (including definitions of “forest” and “forest management”), approaches to baselines and additionality, permanence of storage, data availability and access, costs, and technical capability.</li> <li>• Various regional, national and sub sectoral mandatory and voluntary methods, monitoring schemes, protocols and certifications exist, each using different data sources and methods e.g., <ul style="list-style-type: none"> <li>• CDM (Clean Development Mechanism under UNFCCC)</li> <li>• REDD+ (project based international approach for estimating reduced emissions from deforestation and degradation and sustainability)</li> <li>• GOCF-GOLD (Global Observations of Forest Cover and Land-use Dynamics - international forum to coordinate satellite observations, and provide a framework for long-term monitoring systems)</li> <li>• EU Forest Observatory (global forest monitoring including commodities and trade)</li> <li>• EU LULUCF regulation - sets out EU targets but also mandatory accounting rules</li> <li>• Voluntary market certification: e.g., Verra, Puro.earth, UK Woodland Carbon Code</li> </ul> </li> <li>• Protocols differ in terms of what forest practices are allowed under the protocol, which carbon pools are quantified, how they are quantified, and whether project emissions are included in quantification. The duration of monitoring varies widely between protocols and is typically in the range of 10-30 years. Quantification strongly relies on the assumed baseline, which can be based on historic trends or measurements on a nearby plot. The validity of the baseline is contested in some cases.</li> </ul>

CDR method	Measurement and quantification	Monitoring approaches and technologies	Operationalisation in protocols (see Table 10.2 for number of protocols)
<p>Bioenergy with Carbon Capture and Storage (BECCS)<sup>24-28</sup></p>	<ul style="list-style-type: none"> <li>• The carbon in the biomass used for BECCS is determined by measuring the quantity of biomass supplied to a bioenergy plant, and its C content</li> <li>• Directly measuring the amount of captured CO<sub>2</sub> from biomass combustion and stored in subsurface reservoirs is possible</li> <li>• Changes in pressure, temperature, and composition of a CCS reservoir can be tracked over time</li> <li>• Consideration of feedstock production and provision is key for net negative emissions</li> </ul>	<p>One or more of the following may be used:</p> <ul style="list-style-type: none"> <li>• Geophysical or geochemical monitoring (e.g., using chemical tracers)</li> <li>• Seismic monitoring, e.g., surveys, gravity and geoelectrical approaches</li> <li>• Life-cycle assessments</li> <li>• Biomass certification</li> </ul>	<p>National GHG inventory guidelines for BECCS available, are split across three sectors for reporting under National Greenhouse Gas Inventories:</p> <ul style="list-style-type: none"> <li>• any net changes in land carbon flux over time should be reported under AFOLU</li> <li>• biomass power generation is considered carbon neutral in the energy sector, however transport emissions will be recorded and</li> <li>• captured carbon is recorded under Geological Storage. In each case, reporting happens in the nation where the activity occurs</li> <li>• Some protocols (e.g., voluntary MRV schemes) specifically for BECCS exist, but many CCS protocols can be used to quantify removals from BECCS, although they do not distinguish between the storage of fossil and biogenic CO<sub>2</sub>. Stored CO<sub>2</sub> is typically quantified at the point of injection through direct measurements.</li> <li>• Life-cycle project emissions are often included in the quantification, although some CCS protocols also set the project boundary at the point of capture.</li> </ul>

CDR method	Measurement and quantification	Monitoring approaches and technologies	Operationalisation in protocols (see Table 10.2 for number of protocols)
Biochar <sup>24,29-32</sup>	<ul style="list-style-type: none"> <li>Carbon content of biochar can be measured very accurately, and is consistent if feedstock and pyrolysis parameters are consistent; many voluntary MRV protocols require continuous sampling to achieve this</li> <li>It is possible to quantify carbon removal, but precisely quantifying the fraction that is persistent for &gt; 1000 years is still challenging</li> <li>More precise methods to quantify the persistent fraction of biochar carbon are under development. Currently a high and safe margin of security is applied</li> <li>The carbon in the biomass used for biochar is determined by measuring the quantity of biomass supplied to a production plant, and its C content</li> <li>Calculating the amount of captured CO<sub>2</sub> can be done through the measured carbon of the pyrolysis products (biochar, pyro-oil, and gas)</li> <li>Life-cycle fluxes due to feedstock production and provision are key for net negative emissions calculations</li> </ul>	<p>One or more of the following may be used:</p> <ul style="list-style-type: none"> <li>Proximate analysis (e.g., of biochar sample)</li> <li>Modelling (e.g., tracing carbon pools using exponential decay functions)</li> <li>Life-cycle assessments</li> <li>Biomass certification</li> </ul>	<ul style="list-style-type: none"> <li>National GHG inventory guidelines available for the AFOLU sector, e.g., for estimation of soil carbon stock change from biochar amendments</li> <li>Voluntary, science-based MRV schemes for biochar already exist and are used, for example:             <ul style="list-style-type: none"> <li>The European Biochar Certificate (EBC) and World Biochar Certificate (WBC) C-sink standards certify the sustainability of biomass sourcing (positive list of allowed feedstocks) and the temporary and geological C-sink quantity via material analysis plus a compact LCA where the following information is obtained, reported and included:                 <ul style="list-style-type: none"> <li>biochar properties characterizing C persistence of two pools, the temporary more labile pool and the long-term stable, geological C pool (via the H/Corg ratio)</li> <li>the amount of pyrogenic C within each batch that leaves the pyrolysis premises (gravimetric dry weight of biochar x C concentration)</li> <li>all C expenditures and GHG emissions must be offset (e.g., traces of CH<sub>4</sub> during pyrolysis) along the pathway, from the initial biomass sourcing and transport, to pyrolysis, up to the final C-sink location / installation</li> </ul> </li> </ul> </li> <li>Well-characterized batches of biochar can be tracked using block-chain approaches to the final biochar location / installation</li> <li>The scope of biochar protocols mostly differs in terms of biomass sourcing (e.g., any biomass, positive list of allowed feedstocks, or only waste biomass) and biochar application (e.g., soil or construction). Stored CO<sub>2</sub> is typically quantified based on the production volumes and sampled biochar contents. Stability of biochar is typically modelled. The use of a compact LCA is common, although it differs which project emissions are included in the quantification.</li> </ul>

CDR method	Measurement and quantification	Monitoring approaches and technologies	Operationalisation in protocols (see Table 10.2 for number of protocols)
Peatland and coastal wetland* restoration <sup>24,33-36</sup>	<ul style="list-style-type: none"> <li>• Directly measuring the CO<sub>2</sub> flux is possible using eddy covariance or chamber systems, but it is challenging to scale up over space and time to net carbon removal e.g., due to high variability and costs</li> <li>• Chamber measurement requires extrapolation into the restored area, which is usually done using vegetation cover and water table as a proxy</li> <li>• Long-term soil carbon content and change can be measured and monitored to estimate net removal, but large uncertainties remain as it is variable spatially and temporally. It is especially sensitive to changes in water table height due to management (drainage) or climate variability and change</li> <li>• Carbon storage can be assessed via parameters such as bulk density, soil organic carbon content, and sediment composition and extrapolated spatially via parameters such as vegetation</li> <li>• Measurements are often useful to parametrise models that can then be used to estimate carbon changes over space and time</li> <li>• With peatlands, it is important to consider the overall global warming potential (GWP), i.e., climate impacts from non-CO<sub>2</sub> gases (CH<sub>4</sub> and N<sub>2</sub>O)</li> </ul> <p>*Wetlands can be forested, in which case A/R approaches could apply</p>	One or more of the following may be used: <ul style="list-style-type: none"> <li>• Field samples / in-situ data (e.g., soil carbon content, bulk density, soil type)</li> <li>• GHG/carbon dioxide flux measurements, including CH<sub>4</sub> and N<sub>2</sub>O: Eddy covariance, closed chamber approaches</li> <li>• Sediment cores</li> <li>• Remote sensing to identify land cover types and changes (e.g., using machine learning classifiers on images from drone surveys, satellite imagery)</li> <li>• Modelling</li> <li>• Allometric equations</li> <li>• Correlative functions (water table, vegetation, land use as proxies)</li> <li>• Radiometric dating analysis</li> <li>• GEST-method (proxy approach)</li> </ul>	<ul style="list-style-type: none"> <li>• National GHG inventory guidelines available for peatlands (under the term 'organic soils') and wetlands in the 2006 guidelines and the 2019 Supplement on Wetlands. These range from direct measurements of changes in soil carbon, use of emission factors related to changes in land management practices, and modelling.</li> <li>• UK peatland code voluntary standards are based on models that use the condition of the peatland before and after restoration to estimate the emissions reductions.</li> <li>• GEST-method uses vegetation as a proxy for CO<sub>2</sub> emissions; is implemented in the MoorFutures scheme for peatland carbon credits.</li> </ul>

CDR method	Measurement and quantification	Monitoring approaches and technologies	Operationalisation in protocols (see Table 10.2 for number of protocols)
<p>Soil carbon sequestration in croplands and grasslands<sup>37-40</sup></p>	<ul style="list-style-type: none"> <li>• It is possible to directly measure soil carbon flux, but it is challenging to scale up over space and time to net carbon removal e.g., due to high variability and costs</li> <li>• Long-term soil carbon content and change can be measured and monitored to estimate net removal, but large uncertainties remain as it is highly variable spatially and temporally</li> <li>• Storing carbon in soil largely depends on the region, soil properties, cultivation, chosen practice (or SCS intervention) and climate</li> <li>• The anthropogenic component is difficult to distinguish and baselines/additionality are hard to establish</li> <li>• Soil C is sensitive to management and climate variability and therefore large uncertainties remain around durability</li> <li>• Measurements are often useful to parametrise models that can then be used to estimate carbon changes over space and time</li> </ul>	<p>One or more of the following may be used:</p> <ul style="list-style-type: none"> <li>• Field measurements (e.g., soil carbon content, bulk density, soil type)</li> <li>• GHG/carbon dioxide flux measurements such as eddy covariance, closed chamber approaches</li> <li>• Spectral measurements</li> <li>• Remote sensing (e.g., together with point data or for estimating net primary productivity (NPP) and fractional cover for models)</li> <li>• Modelling</li> <li>• Allometric and correlative relationships (e.g., soil type, vegetation type, land management)</li> </ul>	<ul style="list-style-type: none"> <li>• National GHG inventory guidelines available for the AFOLU sector. These range from direct measurements of changes in soil carbon, use of emission factors related to changes in land management practices, and modelling.</li> <li>• Protocols exist for a variety of practices that quantify SCS. Some protocols can be used to quantify many activities, whereas others are more specific to one activity, such as reducing tillage.</li> <li>• Protocols mostly quantify the storage through sampling of the soil, although sampling practices vary. Some protocols require the inclusion of project emissions, whereas others only quantify the change in carbon pools. Many approaches depend on modelling.</li> <li>• Some approaches do not estimate soil carbon changes, but rather reward activities (e.g., low tillage) such as payments for ecosystem services (UK) or payments in other nature markets.</li> <li>• Quantification strongly relies on the assumed baseline, which can e.g., be based on historic trends or measurements in a nearby plot.</li> </ul>

CDR method	Measurement and quantification	Monitoring approaches and technologies	Operationalisation in protocols (see Table 10.2 for number of protocols)
<p>Ocean fertilisation (OF)<sup>24,41,42</sup></p>	<ul style="list-style-type: none"> <li>• Directly measuring the amount of captured CO<sub>2</sub> is not possible</li> <li>• It is possible to quantify net carbon removal, but large uncertainties remain, e.g., around the efficiency of air-sea gas exchange</li> <li>• Monitoring will likely have to rely on tracking the amount of nutrients added to the ocean and estimating the amount of CO<sub>2</sub> stored by these activities (e.g., taken up by phytoplankton); it will also be necessary to know how much CO<sub>2</sub> gets remineralized in the surface ocean versus gets exported to the deep ocean</li> <li>• Particularly important to monitor side effects in ecosystems (e.g., levels of oxygen and climate-relevant gases, development of toxic algae blooms)</li> </ul>	<p>One or more of the following may be used:</p> <ul style="list-style-type: none"> <li>• Tracing of fertilised patch, e.g., physical and biogeochemical tracers</li> <li>• Neutrally buoyant sediment traps (NBST) and water-column-derived thorium-234 (234Th) method</li> <li>• Autonomous profilers</li> <li>• Autonomous underwater (benthic) vehicles</li> </ul>	<ul style="list-style-type: none"> <li>• National GHG inventory guidelines not available</li> <li>• No MRV protocols were identified in the voluntary market</li> </ul>

CDR method	Measurement and quantification	Monitoring approaches and technologies	Operationalisation in protocols (see Table 10.2 for number of protocols)
<p>Enhanced rock weathering (ERW)<sup>43-47</sup></p>	<ul style="list-style-type: none"> <li>• Directly measuring the amount of captured CO<sub>2</sub> is possible through the analysis of drainage waters, although difficult if the weathering flux is small compared to the background and/or if field drainage is diffuse (no confined catchment)</li> <li>• How CO<sub>2</sub> is estimated depends on whether sequestration is in aqueous solution and transported from soil to terrestrial waterways (e.g., groundwater) to oceans, which would require inclusion of all carbon reservoirs passed through (e.g., terrestrial and ocean) or solid form (e.g., CO<sub>2</sub> mineralization in soil)</li> <li>• It is possible to quantify net CO<sub>2</sub> removal, but large uncertainties remain, e.g., around the rate of rock weathering and subsequent alkalinity production</li> <li>• There remains uncertainty about how much CO<sub>2</sub> is lost back to the atmosphere during the transit of alkalinity from the soil to the ocean</li> </ul>	<p>One or more of the following may be used:</p> <ul style="list-style-type: none"> <li>• Field/soil samples / in-situ data</li> <li>• Lab-scale or mesocosm experiments</li> <li>• Modelling</li> <li>• Radiocarbon analysis</li> <li>• Geochemical tracers</li> <li>• Tracking of the weathering signal via alkalinity in the soil water (aqueous phase)</li> <li>• Tracking the removal (through dissolution) of minerals from the soil (solid phase)</li> <li>• Comparing surface CO<sub>2</sub> exchange at ERW sites with untreated control sites (gas phase)</li> </ul>	<ul style="list-style-type: none"> <li>• National GHG inventory guidelines not available</li> <li>• MRV protocol development, in particular for enhanced rock weathering in croplands, is occurring in the voluntary market (e.g., Puro.earth, Ithaka Institute Global Rock C-Sink, Isometric).</li> <li>• Some protocols are starting to set our requirements for direct measurements of mineral weathering and carbon storage (e.g., in the field), which have higher accuracy but require more resources; others rely on modelling and simulations, which may have large uncertainties and be difficult to verify.</li> </ul>

CDR method	Measurement and quantification	Monitoring approaches and technologies	Operationalisation in protocols (see Table 10.2 for number of protocols)
Direct air carbon capture and storage (DACCS) <sup>24,48-50</sup>	<ul style="list-style-type: none"> <li>• Directly measuring the amount of captured CO<sub>2</sub> possible</li> <li>• Changes in pressure, temperature, and composition of a CCS reservoir can be tracked over time (i.e., surface system inputs are easily measured, and technology is available to measure subsurface injection of CO<sub>2</sub> in storage reservoirs)</li> <li>• Consideration of the direct and indirect effects from increased demand on renewable energy is key</li> <li>• Permanent carbon removal can be quantified with relatively high confidence, however there are large uncertainties on the side effects from increased demand of renewable energy</li> </ul>	One or more of the following may be used: <ul style="list-style-type: none"> <li>• Measurement technology exists, e.g., meters, in particular for transport and subsurface storage of CO<sub>2</sub> from the industrial CCUS sector</li> <li>• Life-cycle assessments</li> <li>• Geophysical or geochemical monitoring (e.g., using chemical tracers)</li> <li>• Seismic monitoring, e.g., surveys, gravity and geoelectrical approaches</li> <li>• Lessons can be learned from bioenergy sector, e.g., around use of renewable energy certificates</li> </ul>	<ul style="list-style-type: none"> <li>• National GHG inventory guidelines available for Geological Storage. There are no IPCC GHG guidance methodologies for the capture part of DACCS.</li> <li>• Multiple DACCS protocols are currently under development in the voluntary market (e.g., Verra, Nori). Protocols can be specific to the capture part of DACCS or include storage. Stored CO<sub>2</sub> is typically quantified at the point of capture or at the point of injection through direct measurements.</li> </ul>

CDR method	Measurement and quantification	Monitoring approaches and technologies	Operationalisation in protocols (see Table 10.2 for number of protocols)
<p>Ocean alkalinity enhancement (OAE)<sup>41,51-54</sup></p>	<ul style="list-style-type: none"> <li>Observational methods alone are insufficient to quantify carbon removed by OAE; require combination with numerical simulations</li> <li>Directly measuring the amount of captured CO<sub>2</sub> is possible for approaches that use equilibrated alkalised solutions, and difficult for unequilibrated alkalised solutions</li> <li>Alkaline materials added to the ocean may be able to be measured, tracked, and used to estimate the amount of carbon stored; however, for mineral OAE uncertainties remain e.g., settling speed of particles</li> <li>For electrochemical OAE, it is possible to quantify net carbon removal, but large uncertainties remain, e.g., around the efficiency of air-sea gas exchange</li> <li>CO<sub>2</sub> emissions from related mining activities are easy to monitor (e.g., emissions from mining and rock distribution activities, amount and quality of rock spread out).</li> <li>More measurements / data is needed for models on: ocean current; air-sea gas exchange; temperature and salinity; carbonate chemistry parameters</li> </ul>	<p>One or more of the following may be used:</p> <ul style="list-style-type: none"> <li>Numerical simulations / modelling (e.g., ocean biogeochemical, fit-for-purpose models)</li> <li>Life-cycle assessments</li> <li>Field measurements</li> <li>Autonomous sensors</li> </ul>	<ul style="list-style-type: none"> <li>National GHG inventory guidelines not available.</li> <li>The last year has seen first releases of MRV protocols in the voluntary market (e.g., Running Tide, Planetary), with protocol developers outlining plans for continued research to advance science-based quantification and reduce uncertainties around net carbon removal.</li> </ul>

## Table C. Literature evaluating aspects of the CDR MRV system

Publication	Type of publication	CDR method(s)	Evaluation criteria
Badgley et al., 2022 <sup>55</sup>	Evaluation of credits	Improved forest management	Net negativity
Bednar et al., 2023 <sup>56</sup>	Evaluation of standards	General	Governance level, scope and eligibility, durability and crediting periods, durability, reversal management, and carbon leakage provisions
BeZero Carbon, 2023 <sup>57</sup>	Evaluation of credits	General	Ex and post ante; additionality, non-permanence, carbon accounting, information availability, project execution, governance, over-crediting, leakage, policy.
Broekhoff et al., 2019 <sup>58</sup>	Evaluation of standard guidelines	General	Additionality, avoiding overestimation, permanence, exclusive claims, avoiding harm.
Calyx, n.d. <sup>59</sup>	Evaluation of credits	General	Governance, rules and procedures, stakeholder engagement, transparency, validation and verification, registry, additionality, permanence, overlapping claims, methodology-related risks, and project level assessment.
Carbon180, 2022 <sup>60</sup>	Guidelines for standard development	General	Measurement, monitoring, reporting, verification.
Carbon Direct and Microsoft, 2023 <sup>61</sup>	Guidelines for project development	General and forestry, mangrove restoration, IFM, SCS, ERW, mineralization, biomass-based pathways, DAC	Harms and benefits, environmental justice, additionality and baselines, carbon accounting and monitoring, durability, leakage.
Coffield et al., 2022 <sup>62</sup>	Evaluation of credits	Improved forest management	Additionality
Criscuoli et al., 2023 <sup>63</sup>	Evaluation of methodologies	SCS	Eligibility criteria, baseline, additionality, soil carbon accounting method, permanence, risk of reversal, risk of leakage, other carbon pools, other GHG emissions, other monitored soil qualities, frequency of monitoring and verification, crediting period, number of projects, issued credits and market accessibility

Publication	Type of publication	CDR method(s)	Evaluation criteria
DEHSt, 2014 <sup>64</sup>	Evaluation of standards	General	Sustainable development
EDF, WWF, and Oko-Institute, 2020 <sup>65</sup>	Evaluation of methodologies and credits	General and biomass-based pathways	Additionality, vulnerability, robust quantification, robust registry, avoiding double issuance, avoiding double use, avoiding double claims, significance of non-permanence, robustness of the program approach to address non-permanence, enhancing adoption of low carbon technology, overall program governance, transparency, auditing, environmental and social safeguards, sustainable development impacts, contributions to improving adaption and resilience, host country commitment to the Paris Agreement, stringency and coverage of host country NDC, ability of host country to meet NDC.
Frontier, n.d. <sup>66</sup>	Guidelines for project development	Long-duration CDR	Durability, cost, capacity, net negativity, additionality, verifiability, safety and legality.
Haya et al., 2023 <sup>67</sup>	Evaluation of methodologies	Improved forest management	Additionality, baselines, leakage, durability, and forest carbon accounting
Howes et al., 2023 <sup>68</sup>	Evaluation of methodologies	DACCS, BECCS, Biochar, EW, Ocean, Building materials	Suitability, assurance, safeguards, credibility, governance
ICAO, 2019 <sup>69</sup>	Accreditation of credits	General	Program governance (methodology development, scope, retirement and issuance procedures, identification and tracking, legal nature and transfer of units, validation and verification procedures, program governance, transparency and public participation, safeguard systems. sustainable development criteria, avoidance of double counting), carbon offset credit integrity (additionality, baseline, quantification, monitoring, reporting and verification, transparency in custody chain, permanence, leakage, avoiding double counting, no net harm).
ICROA, 2024 <sup>70</sup>	Accreditation of standards	General	Independence, governance, registry, validation and verification, carbon crediting principles, environmental and social impacts, stakeholder consideration, scale.
ICVCM, 2023 <sup>71</sup>	Accreditation of standards	General	Governance, emissions impacts, sustainable development benefits.

Publication	Type of publication	CDR method(s)	Evaluation criteria
Kollmus et al., 2008 <sup>72</sup>	Evaluation of standards and credits	General and biological sequestration	Additionality, baseline, project types, crediting periods, co-benefit requirements, project auditing, registries, project locations.
McDonald et al., 2021 <sup>73</sup>	Evaluation of standards	General	Additionality, baseline, leakage, system boundaries, uncertainty, permanence, sustainability, co-benefits, negative externalities, verification, validation, payment timing.
Michaelowa et al., 2019 <sup>74</sup>	Evaluation of standards	General	Governance, accounting, scope, eligibility, environmental integrity, MRV, sustainable development, link to other policies
Oldfield et al., 2021 <sup>39</sup>	Evaluation of methodologies	SCS	Additionality, leakage, reversal, permanence
Plastina, 2021 <sup>75</sup>	Evaluation of standards	SCS	Ecosystem covered, geographical range, eligible crops, covered new practices, minimum acreage enrolment, minimum contract length, payment currency, payment per practice and credits, payment schedule, required data sharing, credit generation and verification, storage and retainment of credits, soil tests required, out of pocket program costs, breach of contract, agronomic assistance, stacking payments, market launch date.
Renoster, 2024 <sup>76</sup>	Evaluation of credits	Forestry	Additionality, baseline, leakage, verification, permanence.
Richards et al., 2012a, 2012b <sup>77,78</sup>	Evaluation of methodologies	Forestry	Additionality, baselines, permanence, leakage, assessment, wood products, validation and verification
Sapkota and White, 2020 <sup>79</sup>	Evaluation of methodologies	Coastal wetland	Scope, applicability, project activities identification, additionality, baseline, net GHG emission reduction, risk and uncertainty, emission reduction tons, monitoring plans
Schneider et al., 2015 <sup>11</sup>	Evaluation of standards	General	Double counting
Shell, 2021 <sup>80</sup> .	Guidelines for project development	Forestry	Baseline setting, permanence, leakage, additionality, quantification, safeguards, benefit sharing.
Shopify, 2022 <sup>81</sup>	Guidelines for credit purchasing	General	Net negativity, verifiability, additionality, safety and environmental justice, cost, durability, capacity.
Sylvera, 2023 <sup>82</sup>	Evaluation of credits	General	Carbon accounting, additionality, permanence, co-benefits.
Zelikova et al., 2021 <sup>83</sup>	Evaluation of methodologies	SCS	Rigour, additionality, durability, safeguards
Zou et al., 2014 <sup>84</sup>	Evaluation of methodologies	Forestry	Additionality and baseline, leakage, permanence, carbon pools

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