Carbon Dioxide Removal by Direct Air Capture

climeworks

climeworks

Methodology Information

Basic Information	
Methodology Name	Carbon Dioxide Removal by Direct Air Capture
Version	2.0
Date of Issue	15.06.2022
Sector	Processes and requirements, for quantifying carbon dioxide removal for the direct air capture component of a capture-transport-storage project.
Author	Friedel Pretorius, Carbon Market Verification Specialist
Owner	Climeworks AG Birchstrasse 155 CH - 8050 Zurich +41 (0)44 533 29 99 contact@climeworks.com
Contact	certification@climeworks.com

Contents

climeworks

Carbon Dioxide Removal by Direct Air Capture Methodology

1. Introduction

This methodology outlines the specific measurement and reporting methodology for the capture component of a capture-transport-storage project and is intended to be used alongside a transportation and in-situ carbon storage methodology to create a complete methodology for the capture-transport-storage project. The Transport and Storage methodologies/y are to be used to provide technology-specific quantification of the emissions and monitoring of transported and injected and released/escaped CO_2.

In unison, the methodologies describe how CO_2 captured from the atmosphere, transported, and stored underground is measured and adjusted for emissions resulting from the project to quantify the net carbon dioxide removal (CDR) resulting from the project. The basic principles of the methodologies are that

- Based on ISO 14064-2:2019 Standards for quantifying greenhouse gas emissions
- Project operational and embodied emissions are subtracted from the stored CO_2 quantities to determine the CDR credited
- Any CO_2 released into the atmosphere after the injection measurement point is subtracted from the CDR credited.
- CDR is accurately accounted for and not double counted
- CO_2 is measured at the injection wellhead of the storage site

The scope of this methodology focuses on the Direct Air Capture (DAC) and post capture treatment components of the overall project but identifies the overarching framework methodology applicable to the overall project and requirements in which the compatible transport and storage methodologies would comply.

In addition to quantifying carbon dioxide removal, the methodology also outlines the monitoring and measurement requirements of the project as well as data management.

1.1 Definitions

Atmospheric carbon dioxide: Carbon dioxide in the atmosphere at respective concentrations (concentration can vary across daytime, month and year. For indicative purposes, the global monthly mean in August 2020 was 409.50 ppm according to NOAA (2020))

Direct Air Capture with solid sorbents: Atmospheric carbon capture with processes relying on solid sorbent (filter) material.

Temperature Vacuum Swing (TVS) adsorption: A cyclic separation process capable of extracting pure CO_2 from atmospheric air, relying on the adsorption of CO_2 on solid sorbent materials and a subsequent desorption under increased temperature and lowered pressure, which regenerates the sorbent material.

Solid Sorbent: A material that is capable of adsorbing CO_2 on its surface. Typically, it consists of a support material that provides a large surface area and an active phase that adsorbs the CO_2 molecules through chemisorption, i.e. a reversible chemical interaction.

Liquefaction Process: The engineered process to change the CO_2 phase from gaseous to liquid CO_2.

Transport Pool: The start of a network, single pipeline or any other transportation mode that is purposefully built, or existing but dedicated/authorized to/for CO_2 transportation.

Last Monitoring Point means the last mass flow measurements in the injection system of the CO_2 stream before it enters the injection well. This measurement point shall be as close as possible to the injection well (at the wellhead or within the injection system).

GHG means greenhouse gases, gases that cause the greenhouse effect, such as CO_2, CH_4, N_2O, CH_4, and N_2O.

In-situ Carbon Mineralization means the reaction of CO_2 with divalent cations (such as Ca^{2+}, Mg^{2+}, and Fe^{2+}) leached from reactive rocks, such as ultramafic, mafic, intermediate, or silicic geological formations to form geologically stable, environmentally benign carbonate minerals in the geological formation, i.e. mineral trapping of CO_2.

Geological Storage Site:

i) A paired geological formation, or a series of such formations, consisting of an injection formation of relatively high porosity and permeability into which carbon dioxide can be injected, coupled with an overlying cap rock formation of low porosity and permeability and sufficient thickness, which can prevent the upward movement of carbon dioxide from the storage formation.

ii) A geological formation that allows for rapid mineralization of CO_2, as described by Matter et al. (2016).

Direct Air Capture Operator: a registered Direct Air Capture Operator, as documented by a certified trade registry extract or a similar official document.

Transport Operator: a registered CO_2 Transport Operator, as documented by a certified trade registry extract or a similar official document.

Storage Operator: an authorized geological CO_2 Storage Provider under national laws as documented by a certified trade registry extract or a similar official document stating that the Storage Operator holds a permit under the laws of the project's host country to store CO_2 in the targeted geological Storage Site.

Post Capture Treatment: All processes after adsorption before entrance to transport network, such as liquefaction, pressuring, etc.

Project Proponent(s) means an individual(s) or organization(s) that has overall control and responsibility for the project, or an individual or organization that together with others, each of which is also a project proponent, has overall control or responsibility for the project. The entity(s) that can demonstrate project ownership in respect of the project.

Project Operator(s): One of the above (Direct Air Capture Operator, Transport Operator, Storage Operator) or a combination of two or three of them.

Plant Lifetime: The (estimated) lifetime of the Direct Air Capture and post-capture treatment facilities.

Crediting Period: The period during which the Direct Air Capture project is eligible to achieve removals, the lifespan of the Direct Air Capture Facility.

Monitoring Period: The period evaluated to verify that CDR was produced according in compliance with methodology.

1.2 Applicability Conditions

- This methodology applies to the Capture portion of a Capture, Transport, Storage Project where capture is achieved through direct air capture (DAC) and storage is achieved through geological storage.

- This methodology applies to project and operation activities that meet all the following **project** conditions:
  - CO_2 is measured at the last monitoring point as defined above
  - Net CDR credited shall be evaluated according to Equation 1.
  - Decreasing the global CO_2 concentration by the project activity over its lifetime, on a cradle to grave life cycle assessment (LCA).
  - Do no net harm to environment and society.
  - Transparent and rigorous quantification of the CO_2 removal activity, where every unit of CDR can be uniquely identified traced through the value chain.
  - The project activities shall comply with applicable local environmental, ecological, and social statutory requirements.
  - Installations shall be installed according to national best practices and national statutory requirements.
  - All measurement devices shall be calibrated according to manufacturer recommendations or industry best practices and allow measurements with uncertainty of 5% or better.
  - Access to water shall be according to local permits.

- This methodology applies to project and operation activities that meet all the following **capture** conditions:
  - Capturing atmospheric CO_2 through a TVS adsorption process relying on solid sorbent material.
  - Capturing atmospheric CO_2 for the sole purpose of subsequent in-situ storage or mineralization.
  - Capturing atmospheric CO_2 with a TVS adsorption process where the temperature swing in the desorption step does not exceed 120°C.
  - Delivering atmospheric carbon to the transportation pool at minimally 95% purity if transported in gaseous or liquid state.

- This methodology applies to project and operation activities that meet all the following **transport and storage** conditions:
  - Transfer of the CO_2 by pipeline, dissolved in water or at high purity.

  - Transfer of the CO_2 to a geologic storage site fulfilling the following characteristics:
    - Site criteria: A dedicated geological storage reservoir that fulfils at least one of the following:
      - Approved by national/local authorities.
      - Adhering to site criteria outlined in the EU CCS Directive, in case national/local legislation does not exist.
      - Adhering to site criteria outlined in the Icelandic national transposition of the EU CCS Directive in case of CO_2 storage via rapid mineralization as described by Matter (2016).

    - Behaviour of the injected CO_2 in the proposed geological storage site conditions:
      - Co-injected with water for subsequent rapid mineralization according to Matter et al. (2016), or
      - Supercritical CO_2 injection according to the Special Report on Carbon Dioxide Capture and Storage by the IPCC (2005).

    - Conditions of use to the geological storage site:
      - Where storage of CO_2 is not permissible for the Project Operator directly, it will have an agreement with a CO_2 storage operator for which such storage operation is permissible. In such an agreement, the storage operator agrees to receive and store CO_2 captured and delivered to the storage site.

- The methodology **explicitly excludes**:
  - Forms of geological CO_2 storage other than solubility trapping and in-situ carbon mineralization and excludes pure-phase injections, such as Enhanced Oil Recovery (EOR) and applications in sedimentary basins.

1.3 Scope of Methodology

The scope of this methodology encompasses the Direct Air Capture and CO_2 post-capture treatment steps prior to the transportation, as seen in Figure 1 below. Quantification of the impacts of the CO_2 transport and CO_2 storage steps on the net CDR credited are outlined in separate methodologies/y to be used alongside this one.

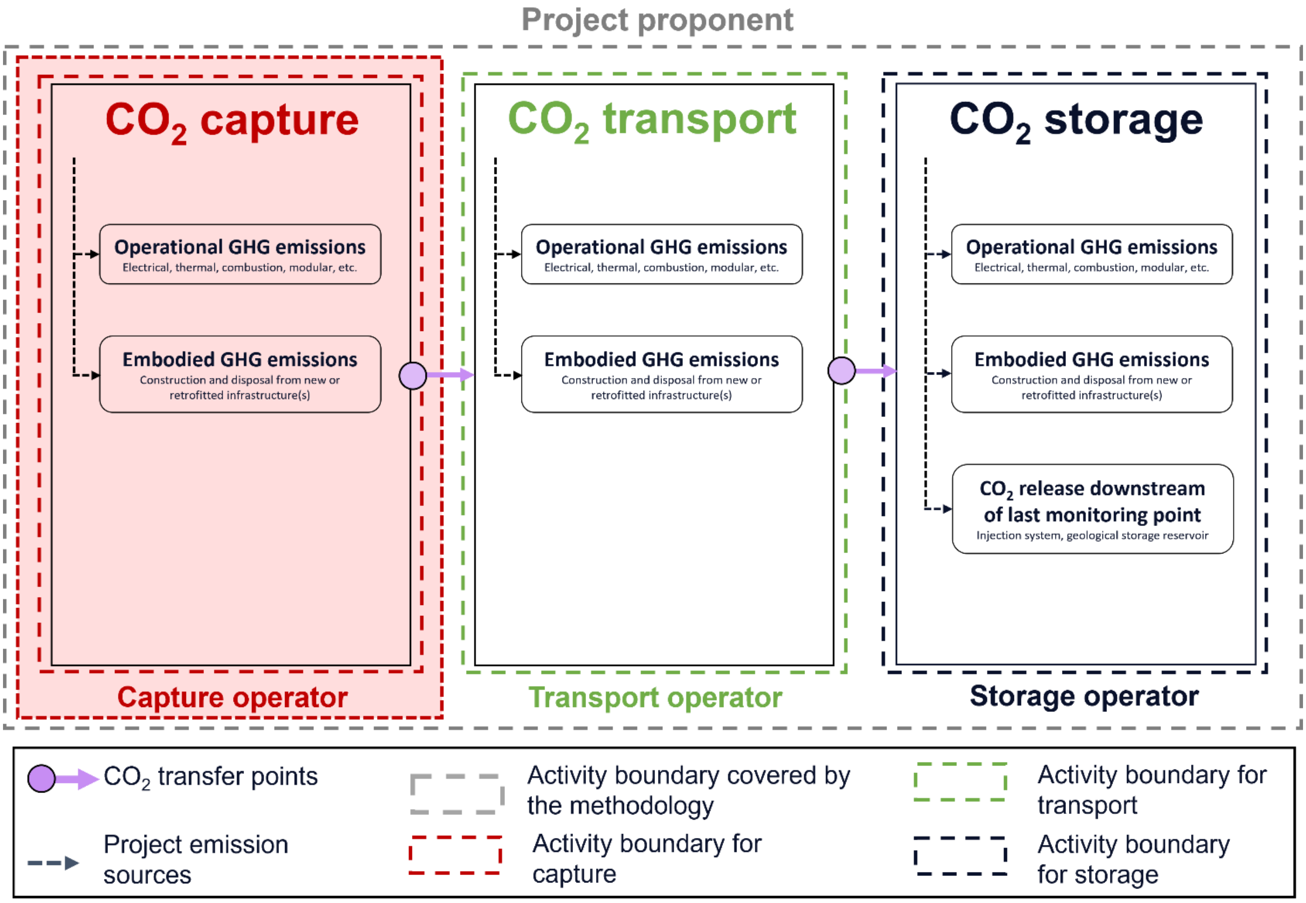

Figure 1 - Project activity boundaries and full chain processes.
(DAC + Mineralization when CO_2 changes its phase into a solid material, as e.g. described by Matter et al. (2016); DAC + Storage where supercritical pure CO_2 phase is injected, as done with conventional CO_2 storage)

The Greenhouse Gases (GHGs) included in the project and operation boundaries are according to Table 1 below.

Table 1: Sources and GHGs

	Emission Source	Gas	Included	Justification / Explanation
Baseline	No other activity in the absence of the project and operation activity	n/a	n/a	n/a
Project activity	Electricity usage (DAC facility)	CO_2	Yes	CO_2 is major emission from source
		CH_4	Yes	Included for completeness
		N_2O	Yes	Included for completeness
	Thermal energy usage (DAC facility)	CO_2	Yes	CO_2 is major emission from source
		CH_4	Yes	Included for completeness
		N_2O	Yes	Included for completeness
	Other process inputs incl. disposal	CO_2	Yes	Major emission from source
		CH_4	Yes	Included for completeness
		N_2O	Yes	Included for completeness
	Vented and fugitive emissions (DAC facility)	CO_2	Yes	Major emission from source
		CH_4	No	Assumed negligible
		N_2O	No	Assumed negligible
	Embedded GHGs in construction and disposal	CO_2	Yes	Major emission from source
		CH_4	No	Assumed negligible
		N_2O	No	Assumed negligible

1.4 Additionality

Additionality can be demonstrated with the currently active UNFCCC CDM (Clean Development Mechanism) "Tool for the demonstration and assessment of additionality". According to this assessment, several barriers make for proof of additionality. Inter alia:

- The described project activity has so far been validated in pilot operations.
- Additionality can also be demonstrated through a barrier analysis:
  - Economic barriers: GHG removals from the air are the projects' main purpose and main source of revenues. Without certification and revenues through certificate sales, economic barriers prevent project implementation.
  - Financing barriers: Large upfront costs for DAC plant construction. Similar activities have only been implemented with grants or other non-commercial finance terms.

2. Emissions Calculations

2.1 Baseline Emissions

The baseline emissions without the project are zero as the project has no purpose other than the CO_2 removal.

2.2 Calculation of CDR credited during monitoring period

The net CDR ($mCO_{2,credited,y}$) is reported for the given monitoring period as the total amount of CO_2 injected in the geological storage reservoir ($mCO_{2,\text{injected},y}$) minus; the CO_2 released ($mCO_{2,\text{released},y}$), emissions from operation ($mCO_{2eq,\text{project},\text{operation},y}$), and the embodied emissions ($mCO_{2eq,\text{project},\text{embodied},y}$) from construction and disposal of the project as scheduled in the instalment plan (see section 2.6). This concept is illustrated in Equation 1. Each term in Equation 1 is explained in a subsection where additional parameters are defined.

Equation 1 indicates that the CDR reported during the monitoring period includes the deduction of embodied emissions, operatorial emissions, and CO_2 released during the transport and storage steps of the project. The methodology for calculating these values from other project steps is dictated by the complimentary methodology. Although these parameters are outside of the scope of this methodology, Equation 2 mentions them to make clear that net CDR is not to be calculated without the deduction of all project emissions and releases.

Let it also be noted that as carbon removals are based on a measurement of the CO_2 stream that is immediately upstream of the storage site, fugitive and vented emissions from the DAC and post-capture treatment facilities and transport are implicitly included in the emission reduction calculation. Since the atmospheric origin of the CO_2 captured by projects under this methodology makes for an impossibility to increase atmospheric CO_2 concentrations by fugitive or vented emissions, it will not lead to an increase of project emissions but rather to a decrease of credited removals.

$$mCO_{2,credited,y} = mCO_{2,\text{injected},y} - mCO_{2,\text{released},y} - mCO_{2eq,\text{project,operation},y} - mCO_{2eq,\text{project,embodied},y}$$ Calculation of CO_2 credited during monitoring period (y): Equation. 1			
where			
$mCO_{2,credited,y}$	=	total amount of CO_2 credited in own accounting or sold/transacted to third parties in period *y*.	tonne (tCO_2)
$mCO_{2,\text{injected},y}$	=	total amount of CO_2 injected in the geological storage in period y, determined at the last monitoring point.	tonne (tCO_2)
$mCO_{2,\text{released},y}$	=	total amount of CO_2 released downstream of the last monitoring point at the storage site in period *y*. **(determined according to Storage Methodology)**	tonne (tCO_2)
$mCO_{2eq,\text{project,operation},y}$	=	total GHG emissions due to project operations of the CDR value chain (DAC, Transport, and Storage) in period *y*.	tonne (tCO_2)
$mCO_{2eq,\text{project,embodied},y}$	=	total GHG emissions due to construction and disposal of the CDR value chain (DAC, Transport, and Storage) scheduled for monitoring period *y*.	tonne (tCO_2)
y	=	monitoring period during which credits are produced	days

2.3 Calculation of Total CO_2 injected during monitoring period

Equation 2 summarizes the calculation for the total mass of CO_2 injected for the project during the monitoring period (y) as the summation of injected CO_2 at all wells (*i*).

Equation 2 shows that the total mass of CO_2 injected ($mCO_{2,i,y}$) into the geological storage reservoir at each well is determined from the mass flow rate ($\dot{m}_{injected}$), measured at the last measurement point of the injection system, multiplied by the weight fraction ($x_{CO2,i}$) of the injection stream.

$$mCO_{2,injected,y} = \sum_i mCO_{2,i,y}$$ Calculation of Total CO_2 injected during monitoring period: Equation. 2			
$$mCO_{2,i,y} = \int_0^y \dot{m}_{CO2,i} \cdot x_{CO2,i} dt$$ Calculation of Total CO_2 injected at injection well (*i*): Equation. 3			
where			
$mCO_{2,i,y}$	=	Mass of CO_2 injected at each injection well in period y, determined at the last monitoring point.	tonne (tCO_2)
$\dot{m}_{CO2,i}$	=	The mass flowrate of the CO_2 stream at the injection well, metered continuously	tonne/sec (t/s)
$x_{CO2,i}$	=	The CO_2 weight fraction of the injection stream entering the injection well.	W_{CO2}/ W_{stream} (unitless)
dt	=	Numerical integration over the period *y*.	seconds (s)
i	=	Injection well(s).	unitless

<u>Measurement Methodology</u>

Mass flowrate of CO_2 injected ($\dot{m}_{CO2,i}$) at each injection well in period (y) shall be measured at the injection well to ensure that any CO_2 purged or released (also known as vented or fugitive emission) upstream from the injection well is excluded from the metered quantity.

The weight fraction of CO_2 in this stream ($x_{CO2,i}$) is to be determined by measurement of the stream or specification. The project must demonstrate that the measurement or specification of this value follows industry standards, is reliable, and is accurate.

2.4 Calculation of total CO_2 Released During Release Events

Release events that occur downstream from the measurement at the storage site shall be discussed and quantified according to the storage methodology. Fugitive and vented emissions in the DAC phase are not calculated as they are inherently included with CO_2 measurement occurring downstream at injection.

2.5 Calculation of GHG Emissions from Project Operation

Equation 4 describes the quantification of GHG emissions resulting from operating the project. Operational emissions are calculated for each project phase (capture, transport, storage) as the sum of all emitting activities in that phase calculated as the product of the intensity of the activity and its emission factor (EF). Project operational emissions are then calculated as the sum of operational emissions across all project phases (capture, transport, storage).

The emission factor shall be literature-derived values and represents the total GHG impacts of the activity represented as carbon dioxide equivalent (CO_{2eq}).

$$mCO_{2eq,\text{project},\text{operation},y} = \sum_{p} mCO_{2eq,p,operation,y}$$

where

$$mCO_{2eq,p,operation,y} = \sum_{z} (I_{z,p,y} \cdot ef_{z,p,y})$$

=

$$mCO_{2eq,\text{project},\text{operation},y} = \sum_{p} \sum_{z} (I_{z,p,y} \cdot ef_{z,p,y})$$

GHG Emissions from Project Operation: Equation. 4

where			
$mCO_{2eq,p,operation,y}$	=	Operational GHG's for project phase (p) during monitoring period (y)	tonne (tCO_2)
p	=	Process Steps, these include the capture, transport, and storage steps.	unitless
z	=	Process Input	unitless
$I_{z,p,y}$	=	Intensity of consumption of a process input.	Quantity (qty)
$ef_{z,p,y}$	=	Emission factor or emission rate of a given pollutant relative to the intensity of a specific process input	tonne/quantity (tCO_2 / qty)

Measurement Methodology

The measurement methodology for operational emissions described here pertain to the capture scope. Operational emissions for the transport and storage shall be calculated according to the respective methodologies/y.

The operational capture emissions are the sum of the emissions linked to the capture operations.

Emission factors for process inputs shall be literature or data derived. Inputs shall be metered and/or quantified by their supplier.

The sorbent emissions can be determined for the monitoring period based on a replacement rate of sorbent multiplied by the emissions factor. This replacement rate can be determined based on operational data for a use case comparable to the project. The emissions estimate can be determined ex-ante based on average sorbent emissions data and shall also account for the specific embedded sorbent emissions in both sorbent production and recycling/disposal.

In addition to the method described above, the project shall also track the actual quantity of sorbent used and the specific sorbent batch emission factors over the project life. Over the life of the project, all actual emissions must agree with the total emissions determined during the monitoring period either through adjusting the emission factor(s) and replacement rate fixed values, or by reconciling the difference between reported and actual emissions in the Monitoring Report. The project must show that all sorbent emissions have been accounted for at the end of the project life.

2.6 Calculation of Embodied GHG Emissions from Construction and Disposal

GHG emissions associated with the construction and disposal of facilities are to be quantified on the basis of case specific assessments of the facilities constructed and can be based on the following:

- academic literature (if the academic assessment is done for a corresponding facility of similar size, capacity and estimated plant lifetime), or
- plant specific LCA study, contracted from an independent third party, or based on Project Operator's calculations according to international standards.

In all cases, the minimal scope of the assessment of construction emissions shall be the cradle to grave GHG emissions from materials used, including embodied emissions. Construction emissions can be calculated according to an assessment before the start of operations and should be for a specific plant. Construction emissions only need to be accounted for once. If a plant gets reused or if its operational lifetime is expanded beyond what was assumed in the ex-ante estimate, the accounting for construction emissions shall cease to zero once the entire amount has cumulatively been accounted for (i.e. similar to full depreciation of the value of a good at the end of its planned lifetime in financial accounting).

Embodied emissions are to be totalled across project phases as shown in Equation 5 and shall be scheduled to be deducted from injected CO_2 quantities during the project life. The project may decide the schedule and division of the emissions as long as a minimum of 50% of the embodied emissions are scheduled within the first 50% of the project lifespan and all embodied emissions are scheduled for within the project lifespan.

$$mCO_{2eq,\text{project,embodied},y} = \sum_{p} mCO_{2eq,p,emboddied,y}$$

Equation. 5

where			
$mCO_{2eq,p,emboddied,y}$	=	Embodied GHG emissions due to construction and disposal of phase (p) facilities as scheduled for monitoring period (y)	tonne (tCO_2)

Measurement Methodology

Emissions from the construction and disposal shall be calculated following ISO 14064-2:2019 standard and the project's operational data. The analysis shall include all embodied emissions related to the construction and disposal of the project facilities. GHG embodied emissions shall be reported in carbon dioxide equivalent units.

3. Monitoring

Figure 2 identifies the operational inputs and output parameters of the DAC component in a capture-transport-storage process. The input parameters will vary slightly between different projects, but should include:

- Energy requirements (heat, electricity, etc.)
- Sorbent material
- Other process inputs (water, etc.)

Depending on the project, the quality (weight fraction) of the CO_2 stream may be measured in the capture or transport component of the project.

In addition to operational parameters, the DAC component of the project shall monitor the embodied emissions from construction and disposal of the site.

Outputs from the DAC component of the project include CO_2 captured and transported and fugitive emissions. The CO_2 stream shall be monitored in the storage phase of the project at injection, thereby inherently including losses from fugitive and vented emissions during the capture phase.

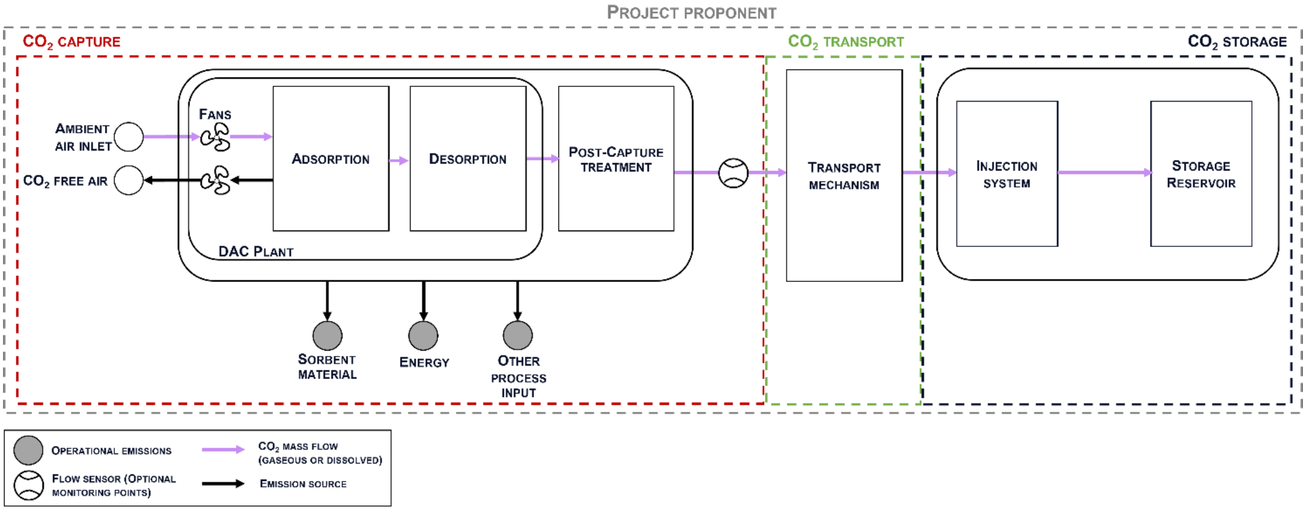

Figure 2 - High-level calculation parameters overview

3.1 Monitored Parameters

The following section outlines the parameters that should be monitored for the capture component of the Project. Equations 1-5 identify how these parameters are used in Project calculations. Parameters mentioned in Equations 1-5 but not listed below are to be monitored in the transport or storage steps of the project according to their applicable methodologies.

Parameter	$x_{CO2,i}$
Parameter Type	measured or fixed
Data unit	W_{CO2}/ W_{stream} (unitless)
Description	The CO_2 weight fraction of the CO_2 stream entering the injection well.
Equations	Equation 3
Source of data	One of the following options shall be chosen: a) On-site measurement b) Periodic sampling and on-or-off-site laboratory analysis if a) is technically not feasible or incurs unreasonable cost c) Manufacturer specification of the process equipment generating this CO_2 stream if it has a constant CO_2 weight fraction.
Calculation method/ equations	NA
Description of Measurement methods and procedures to be applied	Depending on choice of source of data: a) Continuous measurement in the injection system b) Sampling in the injection system and laboratory analysis twice a year c) Fixed at the time of validation.
Frequency of monitoring	Depending on choice of source of data: a) At least monthly b) At least twice a year c) Fixed value, confirmed at least twice a year (see QA/QC)
QA/QC procedures to be applied	Depending on choice of source of data: a) Recalibration according to manufacturer's specifications. If not available, according to industry best practice. b) Laboratory analysis of samples twice a year using a method resulting in the highest feasible accuracy without incurring unreasonable cost. c) Analysis of samples in accredited laboratory twice a year.
Justification of choice of data source	NA
Purpose of Data	CO_2 injection
Comments	

climeworks

Parameter	$I_{z,capturey}$	
Parameter Type	measured	
Data unit **(Units provided for possible inputs)**	Operational Electricity used	MWh
	Operational heat used	MWh
	Quantity sorbent used	tonne (t/y)
	Quantity water used	tonne (t_{water})
Description	Intensity of consumption of a process input.	
Equations	Equation 4	
Source of data	Assessed at project level	
Calculation method/ equations	NA	
Description of Measurement methods and procedures to be applied	Assessed at project level	
Frequency of monitoring	Assessed at project level	
QA/QC procedures to be applied	NA	
Justification of choice of data source	NA	
Purpose of Data	Operational emissions	
Comments		

Parameter	$ef_{z,capture,y}$	
Parameter Type	fixed	
Data unit	Emission factor of electricity	tCO_2/MWh
(Units provided for possible inputs)	Emissions factor for heat	tCO_2/MWh
	Emissions factor for sorbent	$tCO_2/ t_{sorbent}$
	Emissions factor for water	tCO_2/ t_{water}
Description	Emission factor or emission rate of a given pollutant relative to the intensity of a specific process input.	
Equations	Equation 4	
Source of data	Assessed at project level	
Calculation method/ equations	NA	
Description of Measurement methods and procedures to be applied	NA	
Frequency of monitoring	NA	
QA/QC procedures to be applied	NA	
Justification of choice of data source	Values are to be taken from national or international standards, supported by literature, or supported by extensive data.	
Purpose of Data	Operational emissions	
Comments		

Parameter	$mCO_{2eq,capture,emboddied,y}$
Parameter Type	fixed
Data unit	tonne (tCO_2)
Description	Emissions due to construction and disposal for each process p attributed to the operational phase in period y.
Equations	Equation 5
Source of data	Cradle to grave based life cycle assessment (LCA)
Calculation method/ equations	NA
Description of Measurement methods and procedures to be applied	NA
Frequency of monitoring	NA
QA/QC procedures to be applied	NA
Justification of choice of data source	On a cradle to grave basis for all emission sources. International standards for conducting an LCA shall be respected. Only valid if the academic assessment is done for a corresponding facility of similar size, capacity, and estimated plant lifetime or can be scaled to the project specific installations in line with international standards of conducting an LCA
Purpose of Data	Embodied emissions
Comments	

4. References Information

- CCS Directive
- GS Principles and Requirements
- LUF Risks & Capacities guideline
- ACR methodology
- CARB Carbon Capture and Sequestration Protocol under the Low Carbon Fuel Standard
- CDM AM0063: Recovery of CO_2 from tail gas in industrial facilities to substitute the use of fossil fuels for production of CO_2
- CDM Durban Decision with CCS Req. 2011
- SOC Framework
- EU carbon dioxide removal credits regulatory framework planning
- EU Commission Implementation Regulation 2018/2066

5. Bibliography

IPCC. (2005). IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change [Metz, B., O. Davidson, H.C. de Coninck, M. Loos, and L.A. Meyers (eds.)]. Cambridge: Cambridge University Press.

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Rport of the Intergovernmental Panel on Climate Change. Geneva, Switzerland: IPCC. Retrieved from https://www.ipcc.ch/report/ar5/syr/

IPCC. (2018). Global warming of 1.5°C. Retrieved from https://www.ipcc.ch/sr15/

Matter, J., Stute , M., Snaebjörnsdottir , S., Oelkers, E., Gislason, S., Aradottir, E., . . . Broecker, W. (2016, June 10). Rapid carbon mineralization for permanent disposal of anthropogenic carbon dioxide emissions. Science, 352(6291), pp. 1312-1314. doi:DOI: 10.1126/science.aad8132

National Oceanic & Atmospheric Administration. (2020, 12 07). Global Monitoring Laboratory. Retrieved from Atmospheric CO_2 concentrations: https://www.esrl.noaa.gov/gmd/ccgg/trends/