Gold Standard for the Global Goals

METHODOLOGY

CARBON SEQUESTRATION THROUGH ACCELERATED CARBONATION OF CONCRETE AGGREGATE[1]

PUBLICATION DATE: **xx.xx.2021**]
VERSION: **v. 1.0**

SUMMARY

This Methodology is prepared for project activities aiming at sequestering CO_2 in demolished concrete (concrete aggregate). Through the applied processes of carbonation, concrete aggregate is exposed to an increased CO_2 concentration and the CO_2 reacts with the cement phase of the concrete aggregate which contains calcium oxides to form stable carbonate minerals. Through the conversion to calcium carbonate ($CaCO_3$), CO_2 is permanently stored. This is a natural process observed during the weathering of concrete structures. The Methodology describes two different processes which use either direct or the indirect mineral carbonation. Direct processes (a) imitate the natural process of weathering of concrete structures, but increase the reaction rate through different factors such as an increased CO_2 concentration or an increased contact surface between the CO_2 and the cement phase. On the other hand, the indirect mineral carbonation process (b) extracts the cement phases by means of a solvent and carbonates it. As a result, calcium carbonate precipitates from the solvent. Both methods ((a) and (b)): 1) permanently store CO_2 as $CaCO_3$; 2) generate negative greenhouse gas emissions if the sequestered CO_2 originated from biogenic waste and if the amount of sequestered CO_2 is bigger than the emissions arising along the value chain of the mineralisation and 3) generate raw materials which are mostly used in the construction industry.

[1] In the future other mineral waste streams can be included.

TABLE OF CONTENTS

DEFINITIONS

For the purpose of this Methodology, the following definitions apply:

Calcination — Highly endothermic process where limestone is converted by thermal decomposition into calcium oxide and carbon dioxide.

Carbonation (Process) — CO_2 reacts with oxides such as calcium oxide or magnesium oxide to form stable carbonates. The carbonation reaction is exothermic.
Carbonation of concrete happens when concrete is in contact with CO_2. The cement phase of the concrete is converted into $CaCO_3$. In doing so, CO_2 is permanently stored.

Carbonation Plant — Plant, where concrete aggregate is being carbonated with a CO_2 rich gas stream at a specific temperature, pressure and optionally with a solvent, in either a direct or indirect manner in order to store CO_2.

Cement — Substance used for construction that hardens and adheres to other materials to bind them together. Cement is a mixture of ground clinker and additives such as gypsum, silica fume, slag, limestone and fly-ash.

Clinker — A homogeneous mixture of raw materials such as limestone, clay soil and iron ore are ground and heated in a kiln to a sintering temperature of approximately 1450°C to produce clinker. The clinker is then ground with additives into cement.

Concrete	Building material made from a mixture of gravel, sand, cement, and water.
Concrete Aggregate	Demolition concrete crushed and sieved to form concrete aggregate with a certain grain size distribution (usually comprising particle sizes from 0 to 32 mm)
Concrete Recycling Facility (CRF)	Facility, where demolished concrete is collected and processed into concrete aggregate. CRF do not produce concrete. They sell the concrete aggregate to road construction companies or to concrete production facilities.
Gravel	Coarse primary aggregates with a grain size bigger than 4 mm and smaller than 32 mm.
Sand	Fine primary aggregates with a grain size smaller than 4 mm.
Carbonated Concrete Aggregate	Concrete aggregate that underwent the carbonation process and sequestered CO_2.
Regenerated Sand	Sand that results from the indirect mineral carbonation of concrete aggregate. In the first step of the process, calcium is extracted from the concrete aggregate using an acidic solution and the regenerated sand is filtered out.
Virgin Concrete	Concrete with a recycled material content below 25 weight %.

1| INTRODUCTION

1.1 | Background

Cement is produced in a rotary kiln at high temperatures of 1'400 to 1'500°C. Limestone ($CaCO_3$) is converted into calcium oxide (CaO) by calcination (i.e., high-temperature burning of the mineral raw material ($CaCO_3$)). As a result, CO_2 is separated and released to the atmosphere.

The following formula describes the chemical process of calcination:

$$CaCO_3 \leftrightarrows CaO + CO_2 \qquad (1.a)$$

When concrete is produced from cement, the calcium oxide present in the cement hardens by adding water via an exothermic reaction to form calcium hydroxide and calcium silicate hydrate (C-S-H).

$$CaO + H_2O \leftrightarrows Ca(OH)_2 \quad (1.b)$$

Once the concrete is hardened, the calcium hydroxide ($Ca(OH)_2$) formed in formula (1.b) can again react with CO_2 to form the calcium carbonate ($CaCO_3$) occurring in formula (1.c), provided that the salt $CaCO_3$ exhibits the lowest solubility of all salts in the H_2O – CO_2 – Ca system. This process is called "carbonation":

$$Ca(OH)_2 + CO_2 \leftrightarrows CaCO_3 + H_2O \quad (1.c)$$

Normally, this happens only on the surface of the hardened concrete components over the typical lifetime of 80 years. An experimental field study conduced at the Federal Swiss Institute of Technology in Zurich came to the conclusion that around 4% of the process emissions are bound over the lifetime of a concrete infrastructure[2].

However, this process can be accelerated and increased with the direct and indirect mineral carbonation. The mineral carbonation processes use higher CO_2 concentrations than average atmospheric values of 400 ppm, humidity, temperature, solvents and optimised particle size of the concrete to accelerate the process of carbonation. This is where the proposed technologies and project activities can be applied.

1.2 | Technologies

In the scope of this Methodology, two technologies are described. However, this methodology may also be applicable for future systems, which fall into the same category and where the presented calculation and measurement methods can be applied.

Direct Mineral Carbonation

This process sequesters carbon in a recycling product – concrete aggregate a material stream containing cement. Through the applied process, concrete aggregate is exposed directly to a gas stream exhibiting an increased CO_2 concentration (>400 ppm) in a reactor system (carbonation plant) at controlled pressure. The calcium hydroxide ($Ca(OH)_2$) and C-S-H, originally contained in the hardened cement paste react with the CO_2 to form chemically stable calcium carbonate ($CaCO_3$). The product of this process is carbonated concrete aggregate.

Indirect Mineral Carbonation

In a first step, the concrete aggregates are suspended in a solvent in the dissolution reactor. The solvent selectively extracts the calcium contained in the hydrated cement

---

[2] Birolini, L. (2019). Co2 capture in concrete recycling residues.Master Thesis, 1–47

phases. In a next step, the inert materials, termed regenerated sand, are filtered out of the slurry and the calcium-enriched solution is fed to the mineralization reactor.

There, the solution is brought into contact with CO_2 which results in the crystallization of $CaCO_3$. Finally, the precipitated $CaCO_3$ is filtered out for further use. The solution is recycled into the dissolution reactor. The solvent lost is compensated with a makeup stream of fresh solvent. The regenerated sand can be used as a replacement for sand in concrete, in road construction or it can be landfilled. There are different potential applications for the produced $CaCO_3$ such as using it as filler material in cement or concrete. Moreover, it can be used in the food industry or as an additive in cleansing material.

Carbonation is an exothermic process and releases heat. The reverse reaction, calcination, requires a lot of energy. Unless the $CaCO_3$ is exposed to temperature above 900°C, the CO_2 is permanently stored in both processes. The source of the CO_2 has to be biogenic waste such as (but not limited to) sewage sludge and animal manure. If the emissions along the value chain of the CO_2 mineralization are smaller than the amount of CO_2 stored, these processes generate negative greenhouse gas emissions . The projects thus act as geological sinks.

2| SCOPE, APPLICABILTY AND ENTRY INTO FORCE

2.1 | Scope

Technology based sequestration

2.2 | Applicability

This Methodology is applicable for project activities that apply direct or indirect mineral carbonation of demolished concrete at locations where concrete aggregate is available (e.g., (but not limited to) concrete recycling facility (CRF)) or at locations with biogenic CO_2 emissions (e.g., (but not limited to) biogas production). Today, demolition concrete is collected at CRF and crushed into concrete aggregate before it is used to substitute gravel and sand or before it is landfilled. The presented project activities use concrete aggregate as a precursor to sequester CO_2 before it enters downstream processes. CO_2 sequestration can be achieved in the direct or indirect mineral carbonation process. Both processes permanently store CO_2 in concrete aggregate.

This Methodology is applicable under the following conditions:

- Project activity of the direct or indirect mineral carbonation is implemented either at an existing or new source of concrete aggregate which was recycled from demolition concrete or at an existing or new site of DAC or biogenic waste treatment which leads to biogenic CO_2 emissions. Conventionally (but not exclusively), concrete aggregate is collected at CRF, which can be both stationary or mobile.
- The CO_2 shall be sourced through Direct Air Capture (DAC) or originate from biogenic waste, such as (but not limited to) biogenic MSW, fecal sludge or livestock

manure. The CO_2 is released through biomass waste processing (e.g. fermentation) or biomass waste combustion and is subsequently captured to be stored in the concrete aggregate. Suitable sources amongst others are biogas production plants, waste incineration plants, plants combusting biomass for power and heat generation, landfill gas and cement plants co-firing biomass.

- Prior to the implementation of the project activity, the biogenic residual CO2 was produced, but not used for any purpose and the process generating the biogenic residual CO2 undergoes no changes in the capacity as a result of the project activity;
- Biomass treatment plants that process other organic materials than biogenic wastes have to disclose the share of biogenic wastes that was treated at the end of the monitoring period. In case, the biogenic CO2 is sourced from processes which have both fossil and biogenic CO2 emissions, the amount of biogenic emissions shall be determined according to the Monitoring and Reporting regulations of the European Emission Trading scheme or equivalent (EUR-Lex - 02018R2066-20210101 - EN - EUR-Lex (europa.eu)). The amount of stored biogenic CO2 shall not exceed the total biogenic CO2 emission of the respective CO2 source within the same monitoring period.
- If the source(s) of CO_2 used is part of any other carbon program or project, it shall be assured that no double-counting takes place.
- When the carbonation plant is located at the CO_2 source, the off-gas of the respective source shall be used for the carbonation and monitoring of the amount of this off-gas production and consumption shall be possible.
- The concrete with carbonated aggregate must fulfill the same norm as the concrete with non-carbonated aggregate while using the same amount of cement.
- The $CaCO_3$ from the indirect mineral carbonation shall be used in applications and products where the $CaCO_3$ is neither thermally nor chemically decomposed. Using $CaCO_3$ as a filler material for the construction sector is considered as permanent storage of CO_2. For any other application of the $CaCO_3$, the storage of the CO_2 is considered by default non-permanent. Exceptions will be made, if it can be proven that the CO_2 is permanently stored as $CaCO_3$ in the particular product/application and will not be released, i.e., through MSWI at the end of life of the product. The $CaCO_3$ shall not be used in the clinker production, as this would release the CO_2 which was previously stored through carbonation. At the end of the monitoring period, plant operators shall disclose the use of the produced $CaCO_3$.The Methodology is applicable only when baseline scenario (discussed in Section 4 below) is: "Demolition concrete is generated and used or landfilled. CO_2 originating from biogenic waste treatment is emitted to the atmosphere. *As a consequence, no carbonation plant is constructed and operated and no CO_2 is captured and supplied to the CO_2 carbonation plant."*

2.3 | Entry into force - Date to be defined

3| NORMATIVE REFERENCES

This methodology also refers to the latest approved versions of the following CDM and GS4GG tools:

- "Tool to calculate the emission factor for an electricity system";
- "Tool for the demonstration and assessment of additionality";
- "Assessment of the validity of the original/current baseline and to update of the baseline at the renewal of the crediting period";
- "Project and leakage emissions from road transportation of freight";
- "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion";
- Gold Standard for the Global Goals "Safeguarding Principles and Requirements", ver. 1.2, October 2019.

4| BASELINE METHODOLOGY

4.1 | Project boundary

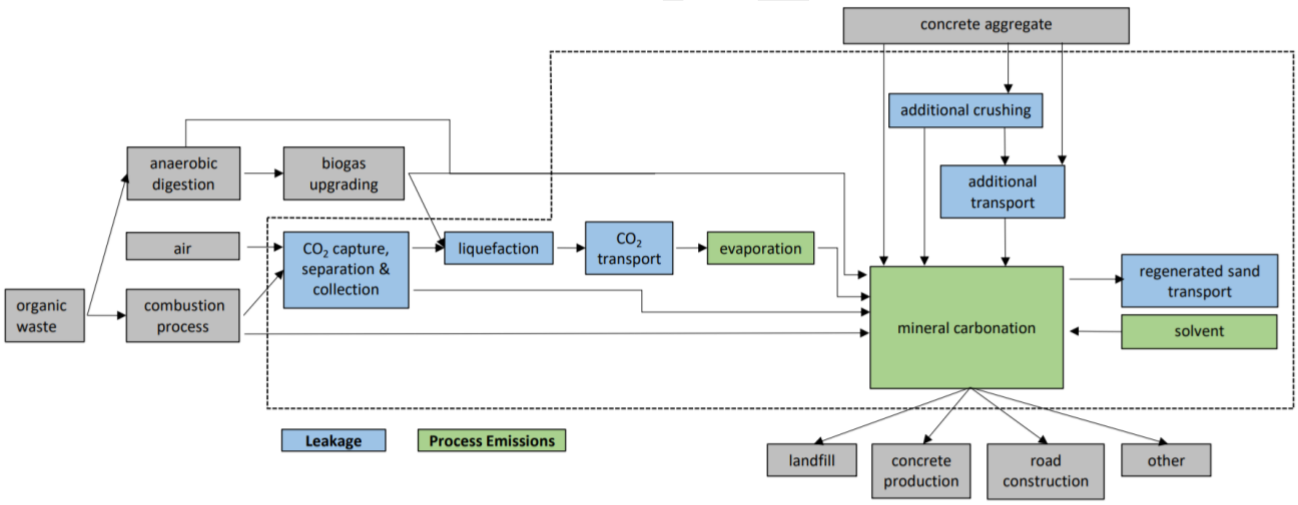

Figure 1: Project boundary

The project emissions include any emissions resulting from onsite power generation or energy sourced from the grid (if applicable) for the purpose of evaporating the liquefied CO_2 and for carbonating the concrete aggregate. The power grid at the location of the carbonation plant will be considered in determining indirect emissions. For the indirect mineral carbonation process, the project boundary further encompasses the emissions resulting from the supply of the solvent. The solvent is usually delivered and not produced on-site.

If a CO2 capture and separation process is needed (i.e., DAC or sometimes for waste incineration plants, landfill gas combustion or plants combusting biomass for power and heat generation) the emissions resulting from the energy consumption of this process

have to be accounted for as leakage. Any transport related emissions for the delivery of liquefied CO_2 to the carbonation plant and emissions related to the production of liquefied CO_2, will be included in the emissions related to the project activity as leakage. In the case, where the carbonation plant is located at the CO_2 source, the off-gas can directly be used. As a result, the CO_2 does not have to be captured, liquefied and transported. However, the leakage should then include the emissions resulting from the transportation of the concrete aggregate from the CRF to the carbonation plant and the transport of the carbonated concrete aggregate or regenerated sand.

Waste treatment or reuse of demolition concrete always require crushing. Since the material enters the process boundaries as concrete aggregate, the emissions resulting from the crushing process are not accounted for. For this reason, emissions from activities related to recycling of demolished concrete, such as: transportation from demolition site to sorting plant, sorting efforts (removal of steel, wood, etc.), transportation from sorting plant to the concrete recycling facility or to the landfill are considered to be outside of project boundary and are not accounted. If the demolition concrete is crushed to smaller grain size distributions than in the baseline scenario to increase the uptake efficiency of the concrete aggregate, the emissions resulting from the fuel or energy consumption needed for this additional crushing effort have to be accounted for in the leakage emissions.

The products of the processes, namely carbonated concrete aggregate or recycled sand and $CaCO_3$ are afterwards used downstream for the production of new concrete and other products.

4.2 | Identification of the baseline scenario

Project participants shall identify the most plausible baseline scenario among all realistic and credible alternatives(s). Steps 2 and/or 3 of the latest approved version of the CDM "Tool for the demonstration and assessment of additionality" shall be used to assess which of these alternatives should be excluded from further consideration (e.g. alternatives where barriers are prohibitive or which are clearly economically unattractive). Where more than one credible and plausible alternative remains, project participants shall, as a conservative assumption, use the alternative baseline scenario that results in the lowest baseline emissions as the most likely baseline scenario.

In doing so, project participants shall consider all realistic and credible scenarios for the treatment of demolition concrete and for the CO_2 originating from biogenic waste treatment, that are consistent with current rules and regulations in the host country or region, including the existing practice of demolition concrete treatment, the proposed project activity, and practices in other CRFs in the region using similar input raw materials, and facing similar economic, market and technical circumstances. The baseline alternatives shall be (but not limited to):

- Landfilling of the demolished concrete without any prior treatment.
- Crushing and sorting out the steel reinforcements bars and other useful materials from demolition concrete at sorting plants with further landfilling of concrete.

- Crushing and sorting out the materials from demolition concrete with further recycling into new concrete (through its crushing into concrete aggregate and use in the preparation of new concrete or use in unbound form, e.g., construction of roads).
- Landfilling of biogenic waste. Combustion of landfill gas without capture and storage of the CO_2 emissions.
- Anaerobic digestion of biogenic waste, cleansing of the biogas through biogas upgrading and releasing of the separated CO_2 into the atmosphere.
- Incineration of biogenic waste without capture and storage of the CO_2 emissions.
- Anaerobic digestion of biogenic waste, cleansing of the biogas through biogas upgrading and storing of the separated biogenic CO_2 in concrete aggregate(proposed project activity which is realized without CDM/GS4GG certification consideration).
- Combustion of landfill gas, capture and separation of the emitted CO_2 with subsequent storage in concrete aggregates (proposed project activity which is realized without CDM/GS4GG certification consideration).
- Incineration of biogenic waste, capture and separation of the emitted CO_2 with subsequent storage in concrete aggregates (proposed project activity which is realized without CDM/GS4GG certification consideration).
- Direct Air Capture with subsequent storage of the CO_2 in concrete aggregates (proposed project activity which is realized without CDM/GS4GG certification consideration).

This Methodology is applicable only in case where it can be proven that alternative "Demolition concrete is generated and used or landfilled. CO_2 originating from biogenic waste treatment is emitted to the atmosphere. *As a consequence, no carbonation plant is constructed and operated and no CO_2 is captured and supplied to the CO_2 carbonation plant."* is the most plausible baseline scenario. Today, the presented base line scenario is the most plausible one, since the carbonation process does not generate any inherent economic value besides negative emissions. If this is not the case, the latest approved version of the CDM "Tool for the demonstration and assessment of additionality" should be applied to determine the baseline scenario.

4.3 | Demonstration of additionality

The additionality of the project activity shall be demonstrated and assessed using the latest version of the CDM "Tool for the demonstration and assessment of additionality" approved by the CDM Executive Board.

In applying the tool, where an investment analysis is used, projects' participants shall apply Option II (investment comparison analysis) or Option III (benchmark analysis). All boxes inside the project boundary in Figure 1: Project boundary lead to either capital and/or operational costs. The sales of CO_2 certificates and of the produced material are the only revenue streams of the project activity.

While calculating the financial indicator for Options II or III, project participants shall consider the following components (but not limited to)in the analysis:

- Additional capital expenditures related to the equipment and machinery needed for the carbonation of concrete aggregate in production e.g., CO_2 supply (separation, capture and collection of CO_2, liquefaction, transport and evaporation), CO_2 carbonation plant, etc.;
- Costs related to operation and maintenance of the carbonation equipment, e.g. electricity, transport fuels, costs of liquefied CO_2 of biogenic waste origin, costs of the solvent, etc.;
- Additional revenues associated with sales of carbonated concrete aggregate or regenerated sand and $CaCO_3$ compared to revenues from sales of conventional concrete aggregate.
- Expenses related to development of in-house capacity and/or research to operate new carbonation technologies;
- If required, other costs related to the marketing of carbonated concrete aggregate, regenerated sand and $CaCO_3$ e.g., market awareness campaigns.

Project participants should demonstrate in an objective manner how the GS4GG/CDM certification alleviates the claimed barriers to the carbonation technologies under the projects' activities, to a level that the projects are not prevented any more from occurring by such barrier. The project participant shall provide transparent and documented evidence as presented above and illustrated in the "Tool for the demonstration and assessment of additionality".

4.4 | Safeguards

Ownership of Carbon rights

The project proponent must clearly communicate to all project participants the entity that is claiming ownership rights of and selling the negative emissions resulting from the project activity. This must be communicated by contract or clear written assertions in the transaction paperwork. If the claimants are not the project technology end users, the end users will need to be informed and notified that they cannot claim for emission reductions from the project.

Data ownership and supply (example)

It is the project developer's responsibility to ensure that all data and monitoring requirements are met. Thus, the plant operator must make all needed data available to the project delevoper. To this end, an agreement is needed between the plant operator and the project developer. The detailed data would be considered confidential, and would only be shared with the validation and verification entities and The Gold Standard Foundation, with the understanding that the information would not be publicly available. Summary statistics used to determine emissions reduction would be published in the verification reports and would be publicly available.

4.5 | Baseline emissions (Project Sinks)

Ex-ante calculation of Baseline Emissions (Project Sinks)

The baseline scenario does not generate any positive nor negative emissions while the presented project sequesters biogenic CO_2 in concrete aggregate through mineral carbonation. By doing so, concrete aggregate serves as permanent sink. Therefore it would be correct to apply the term "Project Sinks" instead of the term "Baseline Emissions".

Project Sinks are equivalent to the amount of CO_2 sequestered in carbonated concrete aggregate by applying direct or indirect mineral carbonation with biogenic CO_2 in the project activity. The ex-ante calculation is used to validate the amount of CO_2, measured ex-post, stored in one project sink. For the ex-ante calculation of Project Sinks, the following formula is applied:

$$\mathrm{GSC_y} = \sum_{i=1}^{n} \sum_{d=1}^{\mathrm{m}} \mathrm{MG_{rep,i,d}} * \mathrm{SF}_{i,d} \quad (2)$$

Where:

GSC_y	Gross Sink Capacity in the monitoring period y of the respective project sink (kg CO_2)
$\mathrm{MG_{rep,i,d}}$	$\mathrm{MG_{rep,i,d}}$ corresponds to the representative, cumulative mass of sub fractions *d* and material *i* (kg concrete aggregate) based on historical data or forecast. Material of type *i* can be distinguished in chemical composition. The amount of CO_2 stored depends on the grain size *d* of the material type *i*. To obtain a precise ex-ante estimation of the project sinks, the grain size distribution is split in *m* sub fractions of particles. The grain size distribution of material *i* may be experimentally determined (SN EN 12620) through, e.g., sieving. Alternatively, the data can also be sourced from data sheets from the crusher.
$\mathrm{SF}_{i,d}$	$\mathrm{SF}_{i,d}$ is the sink factor corresponding to the specific amount of CO_2 that can be permanently fixed in the material *i* of grain size *d* (kg CO_2/kg concrete aggregate). The sink factor is a function of the grain size *d* and the quality of the material of type *i*. For this reason, the sink factor $\mathrm{SF_{i,d}}$ for each sub-fraction *d* of the material *i* has to be provided. Sink factors may be determined in lab scale measurements, based on previous measurements at industrial scale or they can be extracted from reports, data sheets or scientific literature. The following sink factors shall be used as default values for concrete aggregate with a low content (<5%) of other inert materials such as clay bricks[3]:

[3] Tiefenthaler et al. (2021).*In press*.

Grain size distribution	0-2 mm	2-4 mm	4-8 mm	8-16 mm	16-22 mm	>22 mm
SF_i	0.035	0.02	0.01	0.0075	0.006	0.005

Ex-post calculation of project sinks

Project Sinks are equivalent to the amount of CO_2 sequestered as $CaCO_3$ by carbonating concrete aggregate with CO_2 in the project activity.

For ex-post calculation of project sinks, the following formulas are applied:

Gross Sink capacity (equivalent to the Project Sinks) is determined by the following formula:

$$PS_y = \sum_{i=1}^{n} \sum_{d=1}^{m} (m_{CO_{2.i.d}}^{in} - m_{CO_{2,i,d}}^{lost}) \quad (3)$$

where:

PS_y — The Project Sink (or Gross Sink Capacity) of the monitoring period y, (kg CO_2) corresponds to the amount of CO_2 fed to the reactor system reduced by the amount of CO_2 leaving the reactor system as a gas

$m_{CO_2,i,d}^{in}$ — Mass of CO_2 which was fed to the carbonation plant in the monitoring period y (kg CO_2) to be stored in material i and grain size d.

$m_{CO_2,i,d}^{lost}$ — $m_{CO_2,i,d}^{lost}$ corresponds to the amount of CO_2 exiting the process without being stored in the monitoring period y (kgCO_2). This value depends on the type of material i, the grain size d as well as on the technology deployed. The amount of CO_2 lost may be calculated in the following manner:

For *Direct Mineral Carbonation:*

1 m^3 reactor volume is filled with $\frac{\rho_{bulk,i,d}}{\rho_{i,d}}$ m^3 of material i and grain size d. $\rho_{bulk,i,d}$ and $\rho_{i,d}$ corresponds to the bulk density and the density of the material i, grain size d. The space in-between the concrete aggregate particles is filled with gas. The gas void fraction ϵ_i per m^3 of reactor volume can be calculated as follows:

$$\epsilon_{i,d} = 1 - \frac{\rho_{bulk,i,d}}{\rho_{i,d}} \quad (3.a)$$

When 1 m^3 of the reactor volume is discharged, the material and $\epsilon_{i,d}$ m^3 gas of a CO_2 molar fraction $y_{i,d}^{CO_2}$ are discharged. In addition to that, if the plant has per design an exiting gas stream, the gas flow rate and composition is quantified with respective devices – to be able to quantify the amount of CO_2 $m_{CO_2,i,d}^{out}$ (kgCO_2) exiting the process in the monitoring period y. Thus, the amount of CO_2 lost in the monitoring period y is:

$$m^{lost}_{CO_2,i,d} = m^{out}_{CO_2,i,d} + \frac{p*M_{CO_2}}{R*T} * \epsilon_{i,d} * \frac{y^{CO_2}_{i,d}}{\rho_{bulk,i,d}} * MG_{y,i,d} \quad (3.b)$$

M_{CO_2} is the molar mass of CO_2 in kg per mole; p to the total pressure in Pascal, R to the ideal gas constant and T to the ambient temperature in Kelvin. $MG_{y,i,d}$ corresponds to the cumulative mass of sub fractions d and material i processed within the monitoring period y (kg concrete aggregate).

Indirect Mineral Carbonation:
The amount of CO_2 lost in a monitoring period is:

$$m^{lost}_{CO_2,i,d} = m^{out}_{CO_2,i,d} \quad (3.c)$$

4.6 | Leakage

- Emissions due to the energy consumption associated with the additional crushing effort to reach higher CO_2 uptake efficiencies of the concrete aggregate.
- Emissions due to electricity and heat demand associated with the capture, separation and collection of the CO_2.
- Emissions due to the energy consumption of the CO_2 tank associated with refrigerating the CO_2.
- Emissions due to electricity consumption associated with the liquefaction of CO_2.
- Emissions associated with the transportation of liquefied CO_2 to the carbonation plant.
- Emissions associated with the transportation of concrete aggregate and regenerated sand.

The leakage emissions are defined as follows:

$$LE_y = LE_{crusher,y} + LE_{capture,y} + LE_{liqu,y} + LE_{ref,CO_2,y} + LE_{tr,CO2,y} + LE_{tr,CA\,,y} + LE_{tr,CCA/sand,y} \quad (4)$$

Where:

LE_y Leakage Emissions in monitoring period y, (kg CO_2-eq.)

$LE_{crusher,y}$ Emissions due to energy consumption associated with the additional crushing effort in monitoring period y.If the demolition concrete is crushed to the same grain size distribution as in the baseline scenario: $LE_{crusher,y} = 0$

$LE_{capture,y}$ Emissions due to electricity and heat consumption associated with the separation, capture and collection of the CO_2 in monitoring period y.

If the carbonation plant is located at the CO_2 source and the CO_2 for the carbonation is directly sourced from the off-gas: $LE_{capture,y} = 0$

$LE_{liqu,y}$ Emissions due to electricity consumption associated with the liquefaction of CO_2 in monitoring period y, (kg CO_2-eq.)

	If the carbonation plant is located at the CO_2 source and the CO_2 for the carbonation is directly sourced from the off-gas: $LE_{liquefaction,y}=0$
$LE_{ref,CO_2,y}$	Emissions due to the refrigerating effort of the CO_2 tank.
	If a vacuum isolated tank is used without the requirement of refrigeration $LE_{ref,CO_2,y} = 0$
$LE_{tr,CO2,y}$	Emissions due to transportation of liquefied CO_2 from liquefying plant to the carbonation plant in monitoring period y, (kg CO_2-eq.)
	If the carbonation plant is located at the CO_2 source and the CO_2 for the carbonation is directly sourced from the off-gas: $LE_{transport,CO2,y}=0$
$LE_{tr,CA,y}$	Emissions due to transportation of concrete aggregate from the CRF to the carbonation plant in monitoring period y, (kg CO_2-eq.). These emissions only have to be considered when the carbonation plant is not located at the CRF. $LE_{tr,CCA/sand,y}$ Emissions from transportation of carbonated concrete aggregate or regenerated sand from the carbonation plant to the location of treatment of the carbonated concrete aggregate or regenerated sand in the monitoring period y, (kg CO_2-eq.). These emissions only have to be considered when the carbonation plant is not located at the CRF.

Determination of Leakage due to the energy consumption associated with the additional crushing effort of the RCA

$$LE_{crusher,y} = EC_{crushing,y} * EF_{el} + \sum FC_{crusher,i,y} * NCV_i * EF_{fuel,i} \quad (5)$$

Where:

$EC_{crusher,y}$	Electricity Consumption of the crusher for the additional crushing effort in monitoring period y (MWh)
EF_{el}	Emission factor of the consumed electricity (kg CO_2-eq./MWh)
$FC_{crusher,i,y}$	Consumption of fuel type i in year y used for operation of the crusher for the additional crushing effort
NCV_i	Net calorific value of fuel type i (GJ/t)
$EF_{fuel,i}$	Emission factor of fuel type i (kgCO_2/GJ)

Determination of Leakage due to the energy consumption for the capture, separation and collection of CO_2

$$LE_{capture,y} = EC_{capture,y} * EF_{el} + \sum FC_{capture,i,y} * NCV_i * EF_{fuel,i} \quad (6)$$

Where:

$EC_{capture,y}$	Electricity consumption of the CO_2 capture, separation and collection process in monitoring period y (MWh)
EF_{el}	Emission factor of the consumed electricity (kg CO_2-eq./MWh)
$FC_{capture,i,y}$	Consumption of fossil fuel(s) i for on-site power and heat generation for the capture, separation and collection process in monitoring period y.
NCV_i	Net calorific value of fuel type i (GJ/t)
$EF_{fuel,i}$	Emission factor of fuel type i (kgCO_2/GJ)

Determination of Leakage due to energy consumption associated with the liquefaction of CO_2

Emissions from consumption of energy, associated with the liquefaction of CO_2 are determined by the following formula:

$$LE_{liqu,y} = EC_{liquefaction,y} * EF_{el} + \sum FC_{liquefaction,i,y} * NCV_i * EF_{fuel,i} \quad (7)$$

Where:

$EC_{carbonation,Y}$	Electricity Consumption of liquefaction plant in monitoring period y (MWh)
EF_{el}	Emission factor of the consumed electricity (kg CO_2-eq/MWh)
$FC_{liquefaction,i,y}$	Consumption of fuel type i in year y used for operation of the liquefaction plant (e.g. diesel generation for on site electricity consumption) (t)
NCV_i	Net calorific value of fuel type i (MJ/t)
$EF_{fuel,i}$	Emission factor of fuel type i (kgCO_2/MJ)

Determination of leakage due to refrigerating effort of the CO_2 tank

$$LE_{ref,CO_2,y} = EC_{ref,CO_2,y} * EF_{el} + \sum FC_{ref,CO_2,i,y} * NCV_i * EF_{fuel,i}$$

$EC_{ref,CO_2,y}$	Electricity Consumption of CO_2 tank in monitoring period y (MWh)
EF_{el}	Emission factor of the consumed electricity (kg CO_2-eq/MWh)
$FC_{ref,CO_2,i,y}$	Consumption of fuel type i in year y used for the refrigerating effort of CO_2 tank
NCV_i	Net calorific value of fuel type i (MJ/t)
$EF_{fuel,i}$	Emission factor of fuel type i (kgCO_2/MJ)

Determination of leakage due to transportation of liquefied CO_2, concrete aggregate and regenerated sand

Emissions from transportation of liquefied CO_2, concrete aggregate or regenerated sand shall be determined using the CDM tool "Project and Leakage Emissions from Transportation of Freight". Preferably Option A shall be applied (Monitoring of the fuel consumption of the vehicles used for the transportation of freight under the project activity). Based on the amount of fuel consumed by the vehicles, project emissions are determined using the latest version of the "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion".

Alternatively,Option B of the latest version of CDM tool "Project and Leakage Emissions from Transportation of Freight" shall be applied, which looks like the following:

Emissions from transportation of CO_2 are calculated as follows:

$$LE_{tr,CO2,y} = \sum D_{CO2,f,y} * FR_{CO2,f,y} * EF_{tr,f} \qquad (8)$$

Where:

$LE_{tr,CO2,y}$	Emissions due to transportation of liquefied CO_2 from the CO_2 source to the carbonation plant in the monitoring period y, (kg CO_2-eq.)
$D_{CO2,f,y}$	Round trip distance between the CO_2 source and the carbonation plant of freight transportation activity f in monitoring period y (km)
$FR_{CO2,f,y}$	Total mass of freight transported in freight transportation activity f in monitoring period y (tons)
$EF_{tr,f}$	Default CO_2 emission factor for freight transportation activity f (kg CO_2-eq./t km). This emission factor may also be taken from acknowledged data sources.
f	Freight transportation activities conducted in the project activity in monitored period y

Emissions from transportation of concrete aggregate from the CRF to the carbonation plant:

$$LE_{tr,CA,y} = \sum D_{CA,e,y} * FR_{CA,e,y} * EF_{Tr,e} \qquad (9)$$

Where:

$LE_{tr,CA,y}$	Emissions from transportation of concrete aggregate from the CRF to the carbonation plant in the monitoring period y, (kg CO_2-eq.)
$D_{CA,e,y}$	Round trip distance between CRF and carbonation plant of freight transportation activity e in monitoring period y (km)

$FR_{CA,e,y}$ Total mass of freight transported in freight transportation activity e in monitoring period y (tons)

$EF_{tr,e}$ Default CO_2 emission factor for freight transportation activity e (kg CO_2-eq./t km). This emission factor may also be taken from acknowledged data sources.

e Freight transportation activities conducted in the project activity in monitored period y

Emissions from transportation of carbonated concrete aggregate or regenerated sand from the carbonation plant to the location of downstream use (e.g. concrete producer). This equation is only needed if the carbonated concrete aggregate or the regenerated sand do not go back to the CRF. If they are returned to the CRF, the calculated emissions of equation 9 can be multiplied by a factor of two to account for the transport's emissions of the carbonated concrete aggregate or regenerated sand.

$$LE_{tr,CCA/sand,y} = \sum(D_{CCA/sand,g,y} - D_{sand,baseline}) * FR_{CCA/sand,g,y} * EF_{Tr,g} \quad (10)$$

Where:

$LE_{tr,CCA/sand,y}$ Emissions from transportation of carbonated concrete aggregate or regenerated sand from the carbonation plant to the location of downstream use in the monitoring period y, (kg CO_2-eq.)

$D_{CCA/sand,g,y}$ Round trip distance between carbonation plant and location of downstream use of carbonated concrete aggregate or regenerated sand of freight transportation activity g in monitoring period y (km)

$D_{sand,baseline}$ Average round trip distance between CRF and downstream use of concrete aggregate (e.g. concrete production facility) in baseline scenario.

$FR_{CCA/sand,g,y}$ Total mass of freight transported in freight transportation activity g in monitoring period y (tons)

$EF_{tr,g}$ Default CO_2 emission factor for freight transportation activity g (kg CO_2-eq./t km). This emission factor may also be taken from acknowledged data sources.

g Freight transportation activities conducted in the project activity in monitored period y

4.7 | Project emissions

Project emissions are associated with activities related to the operation of carbonation plant for CO_2 treatment:

$$PE_y = PE_{carbonation,y} + PE_{evaporation,y} + PE_{solvent,y} \quad (11)$$

Where:

PE_y	Project emissions in the monitoring period y, (kg CO_2-eq.)
$PE_{carbonation,y}$	Project emissions due to operation of the carbonation plant in the monitoring period y, (kg CO_2-eq.)
$PE_{evaporation,y}$	Emissions from consumption of energy, associated with the evaporation of CO_2 in the monitoring period y (kg CO_2-eq.) If the carbonation plant is located at the CO_2 source and the CO_2 for the carbonation is directly sourced from the off-gas $PE_{evaporation,y} = 0$
$PE_{solvent,y}$	Emissions associated to the supply of solvent (kg CO_2-eq.). Solvent is required only for the indirect mineral carbonation process. $PE_{solvent,y} = 0$ for the direct mineral carbonation process

Project emissions due to the energy consumption of the carbonation plant are determined with the following formula:

$$PE_{carbonation,y} = EC_{carbonation,y} * EF_{el} + \sum FC_{carbonation,i,y} * NCV_i * EF_{fuel,i} \quad (12)$$

Where:

$EC_{carbonation,Y}$	Electricity Consumption of carbonation plant in monitoring period y (MWh)
EF_{el}	Emission factor of the consumed electricity (kg CO_2-eq./MWh)
$FC_{carbonation,i,y}$	Consumption of fuel type i in year y used for operation of carbonation reactor (e.g. diesel generation for on site electricity consumption) (t)
NCV_i	Net calorific value of fuel type i (MJ/t)
$EF_{fuel,i}$	Emission factor of fuel type i (kgCO_2/MJ)

Emissions from consumption of energy, associated with the evaporation of CO_2 are determined by the following formula:

$$PE_{evaporation} = EC_{evaporation,y} * EF_{el} + \sum FC_{evaporation,i,y} * NCV_i * EF_{fuel,i} \quad (13)$$

Where:

$EC_{evaporation,y}$	Electricity Consumption of CO_2 reboiler in monitoring period y (MWh)
EF_{el}	Emission factor of the consumed electricity (kg CO_2-eq./MWh)
$FC_{evaporation,i,y}$	Consumption of fuel type i in year y used for operation of reboiler (e.g. diesel generation for on site electricity consumption) (t)
NCV_i	Net calorific value of fuel type i (MJ/t)

$EF_{fuel,i}$	Emission factor of fuel type i ($kgCO_2/MJ$)

Emissions associated to the production and supply of the solvent used for the indirect mineral carbonation process are determined by the following formula:

$$PE_{solvent,y} = SC_y * EF_{solvent} \quad (14)$$

Where:

SC_y	Solvent Consumption of the indirect mineral carbonation process, ($kg_{solvent}$)
$EF_{solvent}$	Emission factor of the solvent supply. A default value shall be used for the $EF_{solvent}$ which considers the whole life cycle of the solvent and can be looked-up in databases such as ecoinvent. (kg CO_2-eq./kg solvent)

Project emissions related to leakage of CO_2 from the carbonation reactor during the carbonation process

A certain amount of CO_2 is lost during the carbonation process and escapes through the exit stream to the atmosphere. As the Methodology is only applicable for CO_2 originating from biogenic waste treatment, these CO_2 emissions are considered as neutral and are not accounted in the calculation of the total Project Emissions. However, the CO_2 leakage increases the CO_2 emissions of the CO_2 supply chain (liquefaction, transport, evaporation), which is accounted for in the methodology.

4.8 | Emission reductions

The emission reductions are calculated as follows:

$$ER_y = PS_y - PE_y - LE_y \quad (15)$$

Where:

ER_y	kg CO_2-eq. removed in the monitoring period *y* due to project activity
PS_y	Project sinks in the monitoring period *y* (kg CO_2-eq.)
PE_y	Project emissions in the monitoring period *y* (kg CO_2-eq.)
LE_y	Leakage emissions in the monitoring period *y* (kg CO_2-eq.)

4.9 | CO_2 Emissions from Biogenic Waste

In case, the biogenic CO_2 is sourced from processes which have both fossil and biogenic CO_2 emissions, the amount of biogenic emissions shall be determined according to the Monitoring and Reporting regulations of the European Emission Trading scheme or equivalent (EUR-Lex - 02018R2066-20210101 - EN - EUR-Lex (europa.eu)). The amount of stored biogenic CO_2 shall not exceed the total biogenic CO_2 emission of the respective CO_2 source within the same monitoring period.

The default emission factors for combustion of the biomass shall be retrieved from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories or equivalent.

4.10 | Survey and Sampling requirements

This Methodology does not envisage Survey and Samplings activities for determination of baseline, neither for calculation of emission reductions.

4.11 | Safeguarding requirements

This Methodology shall be applied in conjunction the latest Gold Standard for the Globe Goals "Safeguarding Principles and Requirements" when developing the proposed project activity as GS4GG Project.

5| MONITORING METHODOLOGY

5.1 | Data and parameters not monitored

In addition to the data and parameters listed below, the guidance on all tools to which this methodology refers applies. Thus, it is recommended also to refer to specific guidelines and tools applied in Methodology, as not all parameters may be listed in this section.

Data / Parameter:	$MG_{rep,i,d}$
Data unit:	kg
Description:	Representative, cumulative mass of sub fractions d and material i before treatment (kg concrete aggregate)
Source of data:	Based on historical production of concrete aggregate or forecast
Any comment:	

<table>
<tr><td>Data / Parameter:</td><td>$SF_{i,d}$</td></tr>
<tr><td>Data unit:</td><td>kg CO_2-eq./kg material</td></tr>
<tr><td>Description:</td><td>Sink factor as a function of the type of material i and grain size distribution d – defines approx. amount of CO_2 that can be sequestered by material of type i per unit mass of input material</td></tr>
<tr><td>Source of data:</td><td>Determined in experiments, based on previous industrial tests or sourced from reports or scientific literature. Default values for concrete aggregate (>95 purity), are listed in the table below:
<table>
<tr><td>Grain size distribution</td><td>0-2 mm</td><td>2-4 mm</td><td>4-8 mm</td><td>8-16 mm</td><td>16-22 mm</td><td>>22 mm</td></tr>
<tr><td>SF_i</td><td>0.035</td><td>0.02</td><td>0.01</td><td>0.0075</td><td>0.006</td><td>0.005</td></tr>
</table></td></tr>
<tr><td>Any comment:</td><td></td></tr>
</table>

Data / Parameter:	P
Data unit:	Pascal
Description:	Average local ambient pressure
Source of data:	-
Any comment:	Averaged annual pressure measured close by at e.g. a weather station. Default: 101’325 Pa (standard pressure) The average annual pressure shall be verified with measurements in the vicinity of the carbonation plant.

Data / Parameter:	T
Data unit:	Kelvin
Description:	Average annual ambient temperature of the project location
Source of data:	-
Any comment:	The average annual ambient temperature shall be verified with measurements in the vicinity of the carbonation plant.

Data / Parameter:	M_{CO2}
Data unit:	Kg/mol
Description:	Molar Mass of CO2
Source of data:	-
Any comment:	0.044 kg/mol

Data / Parameter:	$EF_{tr,f}$
Data unit:	kg CO_2-eq./t km
Description:	Default CO_2 emission factor for freight transportation activity f
Source of data:	CDM tool "Project and Leakage Emissions from Transportation of Freight" (TOOL 12): Section 5.3, Table 1, page 7 (of 9). The emission factor can also be sourced from other widely acknowledged data bases (e.g. Ecoinvent, version 3.6 – allocation cut-off, dataset: market for *transport, freight, lorry >32 metric ton, EURO 6 RER*))
Any comment:	-

Data / Parameter:	$EF_{tr,e}$
Data unit:	kg CO_2-eq./t km
Description:	Default CO_2 emission factor for freight transportation activity e
Source of data:	CDM tool "Project and Leakage Emissions from Transportation of Freight" (TOOL 12): Section 5.3, Table 1, page 7 (of 9). The emission factor can also be sourced from other widely acknowledged data bases (e.g. Ecoinvent, version 3.6 – allocation cut-off, dataset: market for *transport, freight, lorry >32 metric ton, EURO 6 RER*)
Any comment:	-

Data / Parameter:	$EF_{tr,g}$
Data unit:	kg CO_2-eq./t km
Description:	Default CO_2 emission factor for freight transportation activity g
Source of data:	CDM tool "Project and Leakage Emissions from Transportation of Freight" (TOOL 12): Section 5.3, Table 1, page 7 (of 9). The emission factor can also be sourced from other widely acknowledged data bases (e.g. Ecoinvent, version 3.6 – allocation cut-off, dataset: market for *transport, freight, lorry >32 metric ton, EURO 6 RER*)
Any comment:	-

Data / Parameter:	EF_{el}
Data unit:	kg CO_2-eq./MWh

Description:	Emission factor of national/regional power grid in the host country.
Source of data:	To be determined applying CDM TOOL 07 "Tool to calculate the emission factor for an electricity system" for the Project whole crediting period. The emission factor can also be sourced from other widely acknowledged data bases (e.g. Ecoinvent, version 3.6 – allocation cut-off, dataset: market for electricity, medium voltage, CH)
Any comment:	The value of grid emission factor shall be renewed every time, when the Project crediting period is renewed.

Data / Parameter:	$EF_{solvent}$
Data unit:	kg CO2-eq./kg solvent
Description:	Emission factor of solvent used for the indirect mineral carbonation process
Source of data:	The emission factor can be sourced from widely acknowledged data bases (e.g. Ecoinvent)
Any comment:	-

Data / Parameter:	NCV_i
Data unit:	kWh/t
Description:	Net calorific value of fuel type i, used for the operation of carbonation plant or reboiler (e.g. diesel generation for on-site electricity consumption)
Source of data:	Most recent version of IPCC Guidelines for National Greenhouse Gas Inventories
Any comment:	Net calorific value of fossil fuel shall be revised every time when the project crediting period is renewed.

Data / Parameter:	$EF_{fuel,i}$
Data unit:	kg CO_2-eq./GJ
Description:	Emission factor of fuel type i used for operation of carbonation plant or reboiler (e.g. diesel generation for on-site electricity consumption)
Source of data:	Most recent version of IPCC Guidelines for National Greenhouse Gas Inventories
Any comment:	Emission factor of fuel type shall be revised every time when the project crediting period is renewed.

Data / Parameter:	$D_{sand,baseline}$
Data unit:	km
Description:	Average round trip distance between CRF and location of downstream use of concrete aggregate in baseline scenario.
Source of data:	Historical records of transportation company/Facility or maps
Any comment:	Only has to be considered when the carbonation plant is not located at the CRF.

5.2 | Data and parameters monitored

All data collected as part of monitoring should be archived electronically and be kept at least for 2 years after the end of the last crediting period. All the data should be monitored if not indicated otherwise in the tables below. All measurements should be conducted with calibrated measurement equipment according to relevant industry standards.

In addition, the monitoring provisions in the tools referred to in this methodology apply.

Data / Parameter:	$MG_{y,i,d}$
Data unit:	kg
Description:	Mass of the concrete aggregate type i of a grain size distribution d in monitoring period y.
Source of data:	On-site measurements.
Monitoring frequency:	Continuously, aggregated to the total amount per monitoring period
QA/QC procedures:	-
Any comment:	

Data / Parameter:	$m_{CO_2,i,d}^{in}$
Data unit:	$kgCO_2$
Description:	mass of CO_2 which was fed to the reactor system in within the monitoring period y
Source of data:	On-site measurements.
Monitoring frequency:	Continuously, during carbonation unit operation. Aggregated to the total amount per monitoring period
QA/QC procedures:	Measured results shall be cross checked with the amount of the Liquefied CO_2 purchased (invoices/Liquefied CO_2 trucks weight measurement records)
Any comment:	The gas flow rate is measured through a calibrated mass flow meter. In case the gas is not pure CO_2 (CO_2 concentration below 98%), the composition may be measured with a corresponding device. To minimize the gas loss to the atmosphere, the saturation of the material i and grain size d with respect to the CO_2 uptake is measured directly or indirectly with a sensor and the gas flow rate is adjusted correspondingly.

Data / Parameter:	$m_{CO_2,i,d}^{out}$
Data unit:	$kgCO_2$
Description:	mass of CO_2 which is exiting the reactor system in the exiting gas stream in the monitoring period y
Source of data:	On-site measurements.
Monitoring frequency:	Continuously, during plant operation. Aggregated to the total amount per monitoring period
QA/QC procedures:	Measured results shall be cross checked with previously obtain results of other project sinks

Any comment:	The plant shall be equipped with a device measuring the flow rate and composition of the exiting gas stream. These two numbers allow to determine the amount of CO_2 $m_{CO_2,i,d}^{out}$ (kg CO_2) exiting the process in the monitoring period y.

Data / Parameter:	$\rho_{bulk,i,d}$
Data unit:	kg/m^3
Description:	Bulk density of material of type i
Source of data:	On-site measurements.
Monitoring frequency:	Measured once at the beginning of the project
QA/QC procedures:	Options to determine $\rho_{bulk,i,d}$ (in order of preference): 1) Measured once according to the norm SN EN 1097-3 (or equivalent) 2) Reports, data sheets or scientific literature 3) Default value: 1500 kg/m3
Any comment:	

Data / Parameter:	$\rho_{i,d}$
Data unit:	kg/m^3
Description:	Density of material of type i
Source of data:	On-site measurements.
Monitoring frequency:	Measured once at the beginning of the project
QA/QC procedures:	Options to determine $\rho_{i,d}$ (in order of preference): 1) Measured once according to the norm SN EN 1097-6 (or equivalent) 2) Reports, data sheets or scientific literature 3) Default value: 2400 kg/m3
Any comment:	

Data / Parameter:	$y_{CO_2,i,d}$
Data unit:	Mole CO_2 /mole gas
Description:	CO_2 concentration in the void fraction between the particles of concrete aggregate during material discharge
Source of data:	On-site measurements.
Monitoring frequency:	Measured in industrial operation on a recurring basis
QA/QC procedures:	Options to determine $y_{CO_2,i,d}$: A dedicated CO_2 concentration sensor measures the CO_2 concentration in the gas phase between the particles, as they are discharged from the system. This concentration is monitored over a few process cycles and shall be recalibrated regularly.
Any comment:	This value has to be validated on a recurring basis

Data / Parameter:	$D_{CO2,f,y}$
Data unit:	km
Description:	Round trip distance between liquefaction plant and CRF for each freight (Delivery) of liquefied CO_2
Source of data:	Records of transportation company/Facility or maps
Monitoring frequency:	For each truck, delivered liquefied CO_2 to CRF
QA/QC procedures:	-
Any comment:	-

Data / Parameter:	$FR_{CO2,f,y}$
Data unit:	Tonne
Description:	Total mass of freight (Liquefied CO_2) transported in each freight transportation activity f in the monitoring period y
Source of data:	Records of transportation company/Facility
Monitoring frequency:	For each truck, delivered liquefied CO_2 to CRF
QA/QC procedures:	Measured mass of delivered liquefied CO_2 shall be cross-checked with the invoiced amounts.
Any comment:	

Data / Parameter:	$D_{CA,e,y}$
Data unit:	km
Description:	Round trip distance between CRF and carbonation plant
Source of data:	Records of transportation company/Facility or maps
Monitoring frequency:	For each truck
QA/QC procedures:	-
Any comment:	Only has to be considered when the carbonation plant is not located at the CRF.

Data / Parameter:	$FR_{CA,e,y}$
Data unit:	Tonne
Description:	Total mass of freight (concrete aggregate (CA)) transported in each freight transportation activity e in the monitoring period y
Source of data:	Records of transportation company/Facility
Monitoring frequency:	For each truck, delivered concrete aggregate from CRF to the carbonation plant.
QA/QC procedures:	-
Any comment:	Only has to be considered when the carbonation plant is not located at the CRF.

Data / Parameter:	$D_{CCA/sand,g,y}$
Data unit:	km

Description:	Round trip distance between carbonation plant and location of downstream use of the carbonated concrete aggregate or regenerated sand.
Source of data:	Records of transportation company/Facility or maps
Monitoring frequency:	For each truck
QA/QC procedures:	-
Any comment:	Only has to be considered when the carbonation plant is not located at the CRF.

Data / Parameter:	$FR_{CCA/sand,g,y}$
Data unit:	Tonne
Description:	Total mass of freight (carbonated concrete aggregate or regenerated sand) transported in each freight transportation activity g in the monitoring period y
Source of data:	Records of transportation company/Facility
Monitoring frequency:	For each truck, delivered carbonated concrete aggregate or regenerated sand from carbonation plant to the location of downstream use
QA/QC procedures:	-
Any comment:	Only has to be considered when the carbonation plant is not located at the CRF.

Data / Parameter:	$EC_{carbonation,y}$
Data unit:	MWh/kgCO_2
Description:	Electricity Consumption of CO_2 carbonation process in monitoring period y
Source of data:	Electric meter on-site
Monitoring frequency:	Continuously over the monitoring period y
QA/QC procedures:	-
Any comment:	For determination of ex-ante emission reductions, the specific electricity consumption of the carbonation plant shall be used.

Data / Parameter:	$FC_{carbonation,i,y}$
Data unit:	Tonne
Description:	Consumption of fossil fuel(s) i for on-site power generation for carbonation process in monitoring period y
Source of data:	On site measurements
Monitoring frequency:	Continuously
QA/QC procedures:	To be cross-checked with fuel purchase invoices.
Any comment:	-

Data / Parameter:	$FC_{evaporation,i,y}$
Data unit:	Tonne

Description:	Consumption of fossil fuel(s) i for on-site power or heat generation for evaporation process in monitoring period y
Source of data:	On site measurements
Monitoring frequency:	Continuously
QA/QC procedures:	To be cross-checked with fuel purchase invoices.
Any comment:	-

Data / Parameter:	$EC_{evaporation,y}$
Data unit:	MWh/kg CO_2
Description:	Electricity Consumption of CO_2 evaporation process in monitoring period y
Source of data:	Electric meter on-site
Monitoring frequency:	Continuously over the monitoring period y
QA/QC procedures:	For determination of ex-ante emission reductions, the specific electricity consumption of the reboiler shall be used which is listed in the fact sheet of the reboiler.
Any comment:	-

Data / Parameter:	$FC_{crusher,i,y}$
Data unit:	Tonne
Description:	Consumption of fossil fuel(s) i for on-site power generation for additional crushing process in monitoring period y
Source of data:	On site measurements
Monitoring frequency:	Continuously
QA/QC procedures:	To be cross-checked with fuel purchase invoices.
Any comment:	-

Data / Parameter:	$EC_{crusher,y}$
Data unit:	MWh/kgCO_2
Description:	Electricity Consumption of additional crushing process in monitoring period y
Source of data:	Electric meter on-site
Monitoring frequency:	Continuously over the monitoring period y
QA/QC procedures:	For determination of ex-ante emission reductions, the specific electricity consumption of the crusher shall be used
Any comment:	-

Data / Parameter:	$FC_{capture,i,y}$
Data unit:	Tonne

Description:	Consumption of fossil fuel(s) i for on-site power and heat generation for the capture, separation and collection process in monitoring period y
Source of data:	On site measurements
Monitoring frequency:	Continuously
QA/QC procedures:	To be cross-checked with fuel purchase invoices.
Any comment:	-

Data / Parameter:	$EC_{capture,y}$
Data unit:	$MWh/kgCO_2$
Description:	Electricity Consumption of capture, separation and collection process in monitoring period y
Source of data:	Electric meter on-site
Monitoring frequency:	Continuously over the monitoring period y
QA/QC procedures:	For determination of ex-ante emission reductions, the specific electricity consumption of the capture, separation and collection process shall be used
Any comment:	-

Data / Parameter:	$FC_{liquefaction,i,y}$
Data unit:	Tonne
Description:	Consumption of fossil fuel(s) i for on-site power generation for the liquefaction in monitoring period y
Source of data:	On site measurements
Monitoring frequency:	Continuously
QA/QC procedures:	To be cross-checked with fuel purchase invoices.
Any comment:	-

Data / Parameter:	$EC_{liquefaction,y}$
Data unit:	$MWh/kgCO_2$
Description:	Electricity Consumption of liquefaction process in monitoring period y
Source of data:	Electric meter on-site
Monitoring frequency:	Continuously over the monitoring period y
QA/QC procedures:	For determination of ex-ante emission reductions, the specific electricity consumption of the liquefaction shall be used
Any comment:	-

Data / Parameter:	$FC_{ref,CO_2,i,y}$
Data unit:	Tonne
Description:	Consumption of fuel type i in year y used for the refrigerating effort of the CO_2 tank
Source of data:	On site measurements
Monitoring frequency:	Continuously
QA/QC procedures:	To be cross-checked with fuel purchase invoices.
Any comment:	-

Data / Parameter:	$EC_{ref,CO_2,y}$
Data unit:	$MWh/kgCO_2$
Description:	Electricity Consumption of CO_2 tank in monitoring period y (MWh)
Source of data:	Electric meter
Monitoring frequency:	Continuously over the monitoring period y
QA/QC procedures:	For determination of ex-ante emission reductions, the specific electricity consumption of the CO_2 tank shall be used
Any comment:	-

Data / Parameter:	$SC_{solvent,y}$
Data unit:	$kg_{solvent}$
Description:	Solvent Consumption of the indirect mineral carbonation process
Source of data:	On-site measurements.
Monitoring frequency:	Continuously
QA/QC procedures:	Cross check with transport bills
Any comment:	

Data / Parameter:	$CO_{2,biogenic}$
Data unit:	Tonne
Description:	Amount of CO_2 that originated from biogenic waste or DAC.
Source of data:	Invoices, certificates of origin, Monitoring and Reporting regulations of the European Emission Trading scheme or equivalent (EUR-Lex - 02018R2066-20210101 - EN - EUR-Lex (europa.eu)
Monitoring frequency:	For all the CO_2 which is used for the carbonation process.
QA/QC procedures:	
Any comment:	Methodology only applicable, when the sequestered CO_2 originated from biogenic waste or DAC. If this is not the case, CO_2 removal cannot be claimed under this methodology.

Data / Parameter:	$Sink_{CaCO3}$
Data unit:	Tonne
Description:	Amount of $CaCO_3$ used as filler material in the construction sector or in other applications that ensure the permanent storage of CO_2
Source of data:	Invoices, records
Monitoring frequency:	For all the $CaCO_3$ produced with the indirect mineral carbonation process in the monitoring period y
QA/QC procedures:	
Any comment:	If there is no verification of the type of application of the $CaCO_3$, the storage of the CO_2 is assumed to be non-permanent by default and no VERs are issued for the sequestered CO_2

6| APPLICATION TO PROGRAMME OF ACTIVITIES

The proposed project activity can be implemented as single stand lone project as well as a program of activities. In the latter case, it is recommended that the technology provider(s) will act as Coordinating and Managing Entity (CME). For inclusion of each new VPA to the PoA, the applicability, additionality, and other requirements provided in this Methodology shall be met.

7| LIST OF REFERENCES

Tiefenthaler, J., Braune, L., Bauer, C., Sacchi, R. and Mazzotti, M. (in press). Technological Demonstration and Life Cycle Assessment of a Negative Emission Value Chain in the Swiss Concrete Sector