Protocol for Accounting and Reporting of Avoided GHG Emissions through the Value Chain of Cement and Cement-based Products

Ver. 1.0

March 2019

Taiheiyo Cement Corporation

Contents

Preface

In accordance with the international framework adopted at the 21st Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21), countries around the world are making efforts for greenhouse gas reduction. Japan sets a goal of 26.0% reduction by 2030 compared to 2013, and this means that strong actions must be taken in each industry and at a corporate level.

Taiheiyo Cement (hereinafter referred to as "the Company") has been part of these efforts, and as one of its CSR Goals 2025, the Company has set a goal in greenhouse gas (hereinafter "GHG") emissions control and has been working on reduction in GHG emissions intensity through introduction of energy saving equipment and efficiency improvement in kiln operation in cement manufacturing, and active use of waste-derived and biomass-derived energy. As a result, net GHG emissions intensity in cement manufacturing in 2017 was reduced by approximately 8% over the year 2000.

With this in mind, the Company has established an in-house cross-divisional organization and is working for strategic consideration of GHG reduction technologies toward increased innovation in GHG emissions control from a longer-term perspective. The work encompasses considerations into strategies for accomplishing a drastic GHG emissions reduction never achieved in the past, not only with short-term viewpoints but also with visions in longer-term perspectives especially in twenty or thirty years of time. While the strategies for GHG emissions reduction certainly include direct emissions reduction relevant to cement manufacturing, the strategies also explore, from the perspectives of cement value chain, significant potential contributions which the Company's products such as cement products, concrete and others would be able to make on the stage of use by users. This means that in our efforts to GHG emissions reduction, we will tackle direct emissions on one hand and at the same time we will also work on GHG emissions reduction throughout the entire value chain including stages before and after cement manufacturing, namely, avoided emissions.

The Protocol aims at GHG emissions reduction throughout the entire value chain specifically of cement, and provides accounting methodology thereof. The Protocol covers avoided emissions by cement in general but shows a specific case study on accounting methodology of CO_2 uptake which represents a major part in the contribution by cement. Together with this, the Protocol also shows, separately, accounting results obtained by the case study of the amount of CO_2 uptake by cement manufactured by the Company throughout its life cycle, demonstrating that contribution by cement is sizable.

The Protocol is developed, as mentioned above, as a tool for the Company to move toward GHG emissions reduction in terms of avoided emissions from the perspective of long-term global environment. With this Protocol that we have developed, the Company will further promote its GHG emissions reduction in cement and cement products, and at the same time will increase its efforts in development and offering of the products which keep providing incremental contributions throughout the entire value chain.

1 General

1.1 Purposes of the Protocol

Purposes of the Protocol include to provide a framework and methodology for quantification of greenhouse gas (hereinafter referred to as “GHG”) emissions reduced by cement and cement-based products throughout their life cycles and in their value chain, and to promote development of consistent and highly transparent accounting method of the amount of the GHG emissions reduced by such products (hereinafter “avoided GHG emissions”) throughout their life cycles and in their value chain, for increased use of those cement and cement-based products that feature enhanced level of sustainability. There is no intention to use the Protocol for comparative assertion against related products from other companies.

1.2 Scope of the Protocol

The Protocol provides a framework and methodology for quantification of the avoided GHG emissions in the entire value chain when cement and cement-based products are supplied to end users. The protocol looks into the stage where the products are supplied to the end users because making comparisons of intermediate products does not cover the entire product life cycle, and therefore does not give realistic pictures about the avoided GHG emissions.

Avoided GHG emissions in the value chain is generally a result of contributions by all of the related businesses involved in the value chain. However, there is no internationally accepted methods for allocating avoided emissions which are accomplished by respective stakeholders in the value chain. There is also another difficulty that avoided GHG emissions are influenced by complexity of various backgrounds and factors. Based on these, the Protocol only shows basic approaches toward the method of allocating avoided GHG emissions to respective stakeholders in the value chain (see 3.6), but does not give specifics.

1.3 Structure of the Protocol

The Protocol consists of a main part and annexes. The main part includes basic principles regarding accounting of the avoided GHG emissions in the value chain of cement and cement-based products, principles for developing accounting methodologies for avoided GHG emissions, and requirements in regard to evaluating and reporting the results of avoided GHG emissions accounting. The annexes include an accounting methodology for avoided GHG emissions achieved by individual product or solution, and others (Figure 1).

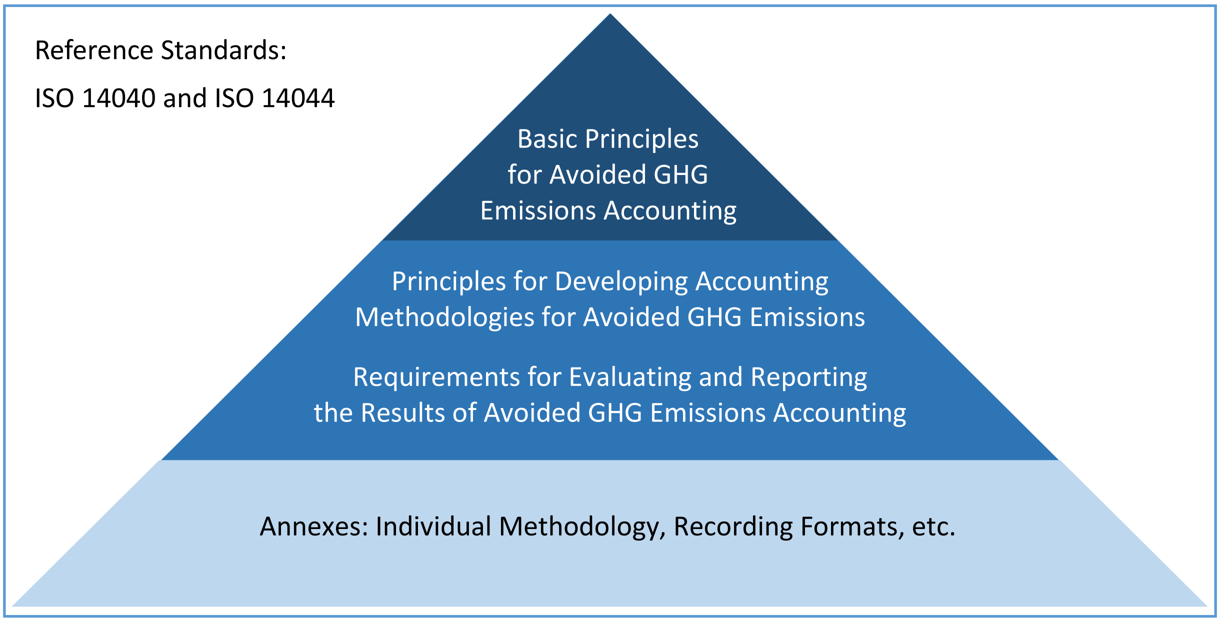

Figure 1: Structure of the Protocol

1.4 Developing Process of the Protocol and Referenced Guidelines and Standards

The first draft of the Protocol was developed in 2018 based on discussions with representatives from various relevant divisions in the Company and other specialists such as consultants, and then the final version was completed after a review by an external certification body.

The first step in developing the Protocol was to determine items to be included and constituent elements based on the following guidelines regarding accounting and reporting of avoided GHG emissions.

<Referenced Guidelines in Determining Items to be Included and Constituent Elements of the Protocol>

- Guidelines for Quantifying GHG emission reductions of goods or services through Global Value Chain (Ministry of Economy, Trade and Industry (METI) of Japan, March 2018)
- Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard (World Business Council for Sustainable Development (WBCSD) and World Resources Institute (WRI), 2011)
- Guidelines--Accounting for and Reporting Greenhouse Gas (GHG) Emissions Avoided along the Value Chain based on Comparative Studies (WBCSD and International Council of Chemical Associations (ICCA), October 2013)
- Accounting and Reporting Protocol for Avoided Greenhouse Gas Emissions along the Value Chain of Cement-based Products (Lafarge Holcim, January 2016)
- ISO 14064-2:2006 (JIS Q14064-2:2011) Greenhouse gases—Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements

The guidelines listed above constantly emphasize the importance of making evaluations from life cycle perspectives of goods or services. Accordingly, the requirements in the Protocol consider the framework, principles and requirements of the following international standards (see Annex B ISO 14044 Reference Table for details).

<Standards Considered in the Development of the Protocol>

- ISO 14040:2006 (JIS Q14040:2010): Environmental Management—Life Cycle Assessment—Principle and Framework
- ISO 14044:2006 (JIS Q14044:2010): Environmental Management—Life Cycle Assessment—Requirements and Guidelines

The Protocol follows ISO wordings in the use of "shall", "should" and "may". Shall means mandatory, should means recommendation, and may means option depending on situations and necessities.

1.5 Intended Users of the Protocol

While the Protocol is intended for use within the Company, it is applicable to cement products in general since it takes ISO 14040 and ISO 14044, or the two international standards, into account as mentioned above, and nothing prevents any parties in the industry from using the Protocol. The Protocol is expected to play a positive role in promoting contribution to quantification of avoided GHG emissions in the cement industry, promoting product innovation utilizing quantified information about the avoided GHG emissions, and improving reliability in avoided GHG emissions.

1.6 Limitations of the Protocol

Avoided GHG emissions accounting has limitations in its accuracy. A typical example can be trade-offs in terms of environmental impacts which occur in the value chain perspective without being recognized, leading to a biased evaluation of the product. Another example lies in accounting coefficients utilized in avoided GHG emissions accounting. The values of the coefficients are based on current results of studies, and must be replaced by those based on the latest results when avoided GHG emissions accounting is made in the future.

Further, avoided GHG emissions in the value chain are generally a result of contributions by all of the related businesses involved in the value chain. However, there is no internationally accepted methods for allocating avoided emissions which are accomplished by respective stakeholders in the value chain. In addition, avoided GHG emissions can be varied by a complexity of backgrounds and factors. Based on these, the Protocol only shows basic approaches toward the method of allocating avoided GHG emissions related to respective stakeholders in the value chain but does not give specifics. Allocation of avoided GHG emissions to respective stakeholders in the value chain must be based on agreement to be reached in discussion process by parties including the stakeholders in the product life cycle.

2 Terms and Definitions

Definitions of the terms used in the Protocol are as follows:

Term	Definition/Description
Cut-off criteria	Specification of the amount of material or energy flow or the level of environmental significance associated with unit processes or product system to be excluded from a study (JIS Q14044:2010). Criteria for determining a process which will not to be subjected to inventory analysis (example: a process having a minor impact). When setting the criteria, considerations should be made in light of mass, energy and environmental significance.
Completeness check	Process of verifying whether information from the phases of a life cycle assessment is sufficient for reaching conclusions in accordance with the goal and scope definition (JIS Q14044:2010).
Sensitivity check	Process of verifying that the information obtained from a sensitivity analysis is relevant for reaching the conclusions and giving recommendations (JIS Q14044:2010).
Sensitivity analysis	Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study (JIS Q14044:2010).
Reference flow	Measure of the outputs from processes in a given product system required to fulfill the function expressed by the functional unit (JIS Q14044:2010).
Functional unit	Quantified performance of a product system for use as a reference unit (JIS Q14044:2010). (Example: For refrigerators, an amount of space (volume) to be cooled). Comparison throughout life cycle must be made on the basis of an equal functional unit.
Critical review	Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment (JIS Q14044:2010).
System boundary	Set of criteria specifying which unit processes are part of a product system (JIS Q14044:2010).
Consistency check	Process of verifying that the assumptions, methods and data are consistently applied throughout the study and are in accordance with the goal and scope definition performed before conclusions are reached (JIS Q14044:2010).
Unit process	Smallest element considered in the life cycle inventory analysis for which input and output data are quantified (JIS Q14044:2010).
Data validation	Confirmation of evidence that data quality requirements have been fulfilled for the intended application during a process of data collection. Validation may involve establishing mass balances, energy balances and/or comparative analyses of emission factors (JIS Q14044:2010).
Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems (JIS Q14044:2010).

Value chain	An idea of understanding a series of business activities from collection/procurement of raw materials, through manufacturing/processing of products, transport, planning/marketing, sales, and after-sales service, to disposal, as a chain of values rather than a collection of individual processes. When used in the Protocol, the term indicates the above-described series of business activities itself.
Baseline	A scenario/status if the project in question is not implemented.
Life cycle assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (JIS Q14044:2010).
Life cycle inventory analysis (LCI)	Stage of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle (JIS Q14044:2010). In the Protocol, the term indicates, for example, accounting of GHG emissions throughout a life cycle.
Avoided GHG emissions	Quantified contribution to the GHG emission reductions which are estimated throughout the life cycle GHG inventory of environmentally-friendly goods or services in comparison to goods or services that represent what is most likely to occur in the absence of assessed goods or services (baseline scenario) (*Guidelines for Quantifying GHG emission reductions of goods or services through Global Value Chain*, March 2018, METI of Japan).
GHG emissions intensity	GHG emissions per a given reference unit such as an amount of sales and an amount of production (Example: GHG emissions / Amount of sales; GHG emissions / Amount of production).

3 Principles

3.1 Basic Principles for Avoided GHG Emissions Accounting

Avoided GHG emissions accounting shall be based on the five accounting principles (validity (relevance), completeness, consistency, transparency and accuracy) in the *Greenhouse Gas Protocol*. The Protocol takes into consideration, as the sixth principle, “conservativeness” included in ISO 14064-2:2006 (JIS Q14064-2:2011) *Greenhouse gases—Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements*. Further, as the seventh principle, the Protocol takes into consideration “feasibility” included in the *Guidelines--Accounting for and Reporting Greenhouse Gas (GHG) Emissions Avoided along the Value Chain based on Comparative Studies* (October 2013, WBCSD and ICCA). These seven principles serve as guidelines when performing accounting based on the Protocol, including cases where the Protocol does not specify a relevant methodology.

The seven principles are summarized as follows:

Relevance	GHG emissions of a corporate shall be appropriately reflected in the GHG inventory, so as to support decision making needs of the user--both inside and outside of the corporate.
Completeness	All GHG emission sources and activities within the inventory boundary shall be explained and reported. Disclose and justify any specific exclusions.
Consistency	Use consistent methodologies to allow for meaningful tracking of task-fulfilling capability over time. Transparently document any time-series changes to the data, inventory boundary, methods, or any other relevant factors.
Transparency	Address all relevant issues using factual and meticulous methodologies, based on a clear fact-tracking investigations. Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used.
Accuracy	Ensure that the quantification of GHG emissions is systematic, neither over nor under actual emissions as far as can be judged, and that uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable users to make decisions with reasonable assurance as to the integrity of the reported information.
Conservativeness	Use conservative assumptions, values and procedures to ensure that GHG emission reductions or removal enhancements are not over-estimated.
Feasibility	Ensure that the chosen approach can be executed within a reasonable timeframe and at reasonable effort/cost.

Sources: Japanese translation (by Ministry of the Environment and METI of Japan) of the *Technical Guidance for Calculating Scope 3 Emissions - Supplement to the Greenhouse Gas Protocol Corporate Value Chain (Scope 3) Accounting & Reporting Standard* (WBCSD and WRI); ISO 14064-2:2006 (JIS Q14064-2:2011) *Greenhouse gases—Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements*; and *Guidelines--Accounting for and Reporting Greenhouse Gas (GHG) Emissions Avoided along the Value Chain based on Comparative Studies* (October 2013, WBCSD and ICCA).

When accounting avoided GHG emissions, purposes of the accounting should be clearly set first of all. When setting the purposes, clearly describe intended use, reasons for making the accounting, and intended target of communication.

3.2 Application of Life Cycle Approach

As described in 1.4, the Protocol makes use of the framework and principles from two standards regarding LCA, specifically from ISO 14040:2006 (JIS Q14040:2010): *Environmental Management—Life Cycle Assessment—Principle and Framework*; and from ISO 14044:2006 (JIS Q14044:2010): *Environmental Management—Life Cycle Assessment—Requirements and Guidelines*. The framework of LCA helps appropriate grasping of avoided GHG emissions from the viewpoint of product life cycle. LCA consists of four stages, i.e., setting goal and scope of study, inventory analysis, impact evaluation and interpretation.

3.3 Mechanisms of Avoided GHG Emissions

Table 1 shows a summary of categories and mechanisms of avoided GHG emissions of cement and cement-based products from the life cycle viewpoint.

Table 1: Summary of Mechanisms of Avoided GHG Emissions by Cement and Cement-based Products

No.	Large Category	No.	Middle Category	Mechanisms of Avoided GHG Emissions
A	Mining process	1	Raw material mining	• Efficient mining process of raw materials reduces GHG emissions in comparison to conventional mining process.
		2	Preservation of mining sites	• Preservation of mining sites (e.g., tree planting) after completion of mining creates CO_2 absorption effect.
B	Manufacturing process	1	Raw material procurement	• In manufacturing process, procurement of raw materials which have low GHG emissions intensity reduces GHG emissions at the procurement sources.
		2	Transport	• Efficient or innovative transport process reduces GHG emissions.
		3	Manufacturing	• Manufacturing process which has high GHG emissions control effect reduces emissions. • Use of recycled materials and/or recycled thermal energy sources reduces production-induced emissions.
C	Construction process	1	Transport	• Efficient or innovative transport process reduces GHG emissions.
		2	Construction and installation	• In construction and repairing of structures and buildings, active use of materials which enable efficient construction and repair reduces direct and indirect emissions related to the construction. Further, shortened construction period will reduce the amount of related tasks and materials, leading to additional emissions reduction.

No.	Large Category	No.	Middle Category	Mechanisms of Avoided GHG Emissions
D	Use process	1	Use	• During the use stage of buildings or the like, materials which, for example, have superior heat insulation reduce the amount of energy necessary for heating/air conditioning. • During the use stage of cement and cement-based products, CO_2 absorption effect takes place as these products undergo carbonation.
		2	Maintenance, repair, replacement and renovation	• Use of materials and products superior in strength/durability reduces GHG emissions (through extended durable life for example) arising from new construction work of structures and buildings, and from production/use of necessary materials. Decreased frequency in maintenance/repair also reduces GHG emissions relevant to the work and materials. • Active use of materials and diagnostic technologies which enable efficient maintenance and repair reduces need for relevant work and materials, and therefore reduces GHG emissions.
E	Disposal process	1	Demolition and temporary storage	• Efficient demolition process reduces GHG emissions over conventional demolition process. • During the stage of demolition and temporary storage of cement-based products, CO_2 absorption effect takes place as these products undergo carbonation.
		2	Transport	• Efficient or innovative transport process reduces GHG emissions.
		3	Waste treatment	• Efficient and effective waste treatment process reduces GHG emissions over conventional treatment process.
F	Others	1	Reuse and recycling	• Through reuse and recycling, manufacture of new products and GHG emissions caused by the manufacturing process are avoided.

3.4 Trade-off

In general, LCA is effective in understanding trade-offs between various impacts on the environment since it takes various environmental impacts into account throughout the product life cycle. The Protocol makes use of the framework and principles of LCA with special focus on impacts onto climate changes, and more specifically onto GHG emissions and avoided GHG emissions. While it is anticipated that reduction in GHG emissions will basically not cause serious negative impact on other environmental indicators (e.g., discharge of waste, and water resources), it is necessary, when accounting avoided GHG emissions, to see if there is any possible trade-offs in terms of environmental impact. If the accounting detects any possible trade-offs, environmental impacts from them shall also be reported.

3.5 Double Counting

The subject of the Protocol is accounting of avoided GHG emissions from cement and cement-based products throughout their value chain. For this reason, there can be cases where, for example, the amount of GHG emissions reduction in the product manufacturing process is counted in both of the reporting of Scope 1 emissions and the reporting of avoided GHG emissions; namely, double counting can take place between the two. Double counting can also occur when accounting the scope 3 emissions. Since the entire value chain of the product is the subject in both of the accounting of avoided GHG emissions and the accounting of the scope 3 emissions, there can be double counts between the two.

It is necessary to explain all of these double counts in avoided GHG emissions accounting. GHG emissions at the corporate level and avoided GHG emissions at the product level shall be distinguished from each other, and any possible double counts shall be disclosed in reporting of the accounting results.

Still another area of possible double counting is avoided GHG emissions by related business entities in the value chain. A plural number of related parties in the value chain may claim for a certain amount of avoided GHG emissions as their own contribution. Handling methods of these problems are provided in 3.5. Setting rules on how to allocate avoided GHG emissions to the related parties in the value chain is useful to avoid double counting but is not in the scope of the Protocol as stated in 1.6.

Another chance for double counting is when avoided GHG emissions by one product is accounted in plural categories of avoided GHG emissions. Annex A provides a methodology for individual accounting categories of avoided GHG emissions. Avoided GHG emissions of a product shall be evaluated only in one category of avoided GHG emissions.

3.6 Allocation of Avoided GHG Emissions

Avoided GHG emissions of a product are a sum of activities of a plural number of business entities in the value chain (e.g., raw material suppliers, product manufacturer, and users of the product). In most cases the scope lies beyond the range controllable by any single business entity (e.g., product manufacturer). For example, at the use stage of a building, energy saving effect is a sum of activities not only by the product manufacturer but also the owner and users of the buildings.

However, there is no internationally accepted methods which are capable of allocating avoided emissions to each of the business entities in the value chain.

While the Protocol does not show details for methodologies to allocate avoided GHG emissions to individual entities in the value chain, directions thereof are provided in the *Guidelines--Accounting for and Reporting Greenhouse Gas (GHG) Emissions Avoided along the Value Chain based on Comparative Studies* (October 2013, WBCSD and ICCA). The Guidelines provide, as shown in Table 2, contribution levels in value chain avoided emissions and basis in determining the levels. The reporting corporate shall report a total amount of avoided emissions in the entire value chain, and also report about the levels of contribution of the product with respect to the final product in accordance with Table 2. Further, the reporting corporate shall describe specific part that their product plays and how it relates to the avoided GHG emissions of the final product, clearly in a way the readers can comprehend.

Table 2: Contribution Levels in Value Chain Avoided Emissions by Chemical Product

Contribution Level	Relationship between Chemical Product and Final Product
Fundamental	The chemical product is the key element that enables the avoided GHG emissions by the use of the final product.
Extensive	The chemical product is part of the key element and its properties/functions are essential for enabling the avoided GHG emissions by the use of the final product.

Substantial	The chemical product does not contribute directly to the avoided GHG emissions, but it cannot be substituted easily without affecting the avoided emissions by the final products.
Minor	The chemical product does not contribute directly to the avoided GHG emissions, but it is used in the manufacturing process of a fundamentally or extensively contributing product.
Too small to communicate	The chemical product can be substituted without affecting the avoided GHG emissions by the final products.

Source: *Guidelines--Accounting for and Reporting Greenhouse Gas (GHG) Emissions Avoided along the Value Chain based on Comparative Studies* (WBCSD and ICCA, 2013).

3.7 Methodological Framework for Accounting of Avoided GHG Emissions

Based on the mechanisms of avoided GHG emissions (see 3.3), the Protocol provides a methodological framework for avoided GHG emissions accounting as shown in Table 3.

Table 3: Methodological Framework for Accounting of Avoided GHG Emissions

No.	Large Category	No.	Middle Category
A	Mining process	1	Raw material mining
		2	Preservation of mining sites
B	Manufacturing process	1	Raw material procurement
		2	Transport
		3	Manufacturing
C	Construction process	1	Transport
		2	Construction and installation
D	Use process	1	Use
		2	Maintenance, repair, replacement and renovation
E	Disposal process	1	Demolition and temporary storage
		2	Transport
		3	Waste treatment
F	Others	1	Reuse and recycling

4 Accounting of Avoided GHG Emissions

4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions

Methodologies for accounting avoided GHG emissions shall describe all definitions, assumptions and rules necessary for accounting avoided GHG emissions throughout the product life cycle. Consistency should be ensured within the scope of the Protocol throughout all of the avoided GHG emissions accounting methodologies. Table 4 lists the contents which should be included in the accounting methodologies for avoided GHG emissions:

Table 4: Contents which Should be Included in Accounting Methodologies for Avoided GHG Emissions

No.	Major Item	Intermediate Item	Content
1	Name of methodology	N.A.	Write the name of the methodology.
2	Definitions of terms	N.A.	Write the definitions of terms used in the methodology.
3	Levels in the value chain / System boundary / Coverage of accounting and target processes / Mechanisms of avoided GHG emissions	Explanation	Describe the purposes and summary of the methodology.
		Functions and functional units	Describe functions and functional units (see 2. Terms and Definitions).
		System boundary, coverage of accounting, and target processes	Describe system boundary, coverage of accounting and target processes, and rationales and/or basis thereof. Any exclusions shall be accompanied by description on their impacts on the conclusion (e.g., amount of avoided emissions) and reasons for the exclusion.
		Service life / Durable life	Describe service life / durable life of the goods or services in the functional unit, and rationales for the service life / durable life.
		Time and geographical references	Describe the time and geographical area selected as the basis of the study.
		Baseline	Describe information about the baseline (see 2. Terms and Definitions).
		Mechanisms of avoided GHG emissions	Describe mechanisms of how GHG emissions are avoided.
		Flow of unit process, and input and output thereof	Describe the flow of unit process (see 2. Terms and Definitions), and input/output thereof.
4	Accounting method	General information and outline of accounting	Provide general information about avoided GHG emissions accounting methodology, and list databases and others used in the study.

No.	Major Item	Intermediate Item	Content
		Estimations and assumptions	Provide information about estimations and assumptions if included in the accounting methodology.
		Cut-off criteria	Describe cut-off criteria (see 2. Terms and Definitions).
		Allocation	Describe methods of allocation (see 2. Terms and Definitions) if allocation is needed.
		Mathematical formulae	Provide mathematical formulae for avoided GHG emissions accounting based on the appropriate flow of the unit process.
		Data sources	List sources and rationales for coefficients and other values used in the accounting.
		References	List reference documents and other literature used in the development of accounting methodology.
		Others	Describe, for example, further procedures to convert indicators obtained as a result, reference materials selected, and rationales for weighing coefficients and others.

4.2 Accounting of Avoided GHG Emissions

From the avoided GHG emissions accounting methodologies developed on the principles in 4.1, select an appropriate methodology in terms of the avoided emissions accounting category, and perform an accounting by following the selected methodology. Data which are collected for the accounting shall be subjected to data validation in order to ensure that data quality requirements are met for the intended use.

5 Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results

Evaluation shall be performed in consideration of three methods listed in Table 5 in order to establish and enhance credibility and reliability of the results of the avoided GHG emissions accounting.

Table 5: Evaluations to be Performed in the Developing Process of Avoided GHG Emissions Accounting Methodology and the Accounting Process

No.	Major Item	Content
1	Completeness check	Process of verifying whether information from the phases of a life cycle assessment is sufficient for reaching conclusions in accordance with the goal and scope definition (JIS Q14044:2010).
2	Sensitivity analysis / Sensitivity check	Sensitivity analysis: Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study (JIS Q14044:2010). Sensitivity check: Process of verifying that the information obtained from a sensitivity analysis is relevant for reaching the conclusions and giving recommendations. Sensitivity check shall consider the followings (JIS Q14044:2010): • Items predetermined by the goal and scope of the study • Results obtained from all the other stages of the study • Professional judgments and past experiences
3	Consistency check	Process of verifying that the assumptions, methods and data are consistently applied throughout the study and are in accordance with the goal and scope definition performed before conclusions are reached. The following questions shall be addressed in the consistency check (JIS Q14044:2010): • Are differences in data quality along a product system life cycle and between different product systems consistent with the goal and scope of the study? • Have regional and/or temporal differences, if any, been consistently applied? • Have allocation rules and the system boundary been consistently applied to all product systems? • Have the elements of impact assessment been consistently applied?

The avoided GHG emissions accounting methodology and the avoided GHG emissions accounting results shall be subjected to critical review as a principle. Processes of the critical review shall ensure the followings:

- Methods utilized in performing the LCA confirm to JIS Q14044:2010 and the Protocol.
- The methods utilized in performing the LCA are scientifically and technically valid.
- Utilized data are pertinent and reasonable in the light of goal of the study.
- Interpretations reflect the specified limitations and the goal of study.
- The study report has transparency and consistency.

The critical review may be performed by internal or external professionals. In this case, the reviewing professionals shall be independent from the LCA. Further, the review may be made by interested parties. In this case, the reviewer should be selected from external independent professionals. The critical review should be performed by those knowledgeable in LCA, GHG emissions and avoided GHG emissions accounting, and cement-based products. Record shall be made for determinations on the scope and type of the critical review.

If the critical review is not performed, reasons or grounds therefor shall be expressly described.

6 Reporting of Avoided GHG Emissions

Since avoided GHG emissions represent the amount of avoided emissions throughout the entire value chain, it is not possible to subtract the avoided emissions from a corporate level GHG inventory (scope 1, 2 and 3 emissions). Therefore, reporting of avoided GHG emissions shall be made separately from corporate-level external reporting (scope 1, 2 and 3 emissions) which follows, e.g., the *Greenhouse Gas Protocol*. Table 6 lists items required in the reporting.

Table 6: Items Required in Reporting of Avoided GHG Emissions

No.	Major Item	Intermediate Item
1	Outline of GHG avoided emissions	Methods of GHG avoided emissions
2	Levels in the value chain / System boundary / Coverage of accounting and target processes / Mechanisms of avoided GHG emissions	Description
		Functions and functional units
		System boundary, and coverage of accounting and target processes
		Service life / Durable life
		Time and geographical references
		Baseline
		Mechanisms of avoided GHG emissions
		Flow of unit process, and input and output thereof
3	Accounting method	General information and outline of accounting
		Estimations and assumptions
		Cut-off criteria
		Allocation (if allocation was required)
		Mathematical formulae
		Information regarding parameters
		Data sources (sources and rationales for coefficients and others)
		Data quality (Describe handling rules for missing data, if any.)
		Others
4	Evaluation	Completeness check
		Sensitivity check
		Consistency check
5	Life cycle interpretation	The results; assumptions and limitations associated with the interpretation of results, both methodology and data related; data quality assessment; and full transparency in terms of value-choices, rationales and expert judgments

Source: The table was developed with reference to the *Guidelines--Accounting for and Reporting Greenhouse Gas (GHG) Emissions Avoided along the Value Chain based on Comparative Studies* (WBCSD and ICCA, 2013).

References of the Protocol

- Accounting and Reporting Protocol for Avoided Greenhouse Gas Emissions along the Value Chain of Cement-based Products (Lafarge Holcim, January 2016)
- ISO 14040:2006 (JIS Q14040:2010): Environmental Management—Life Cycle Assessment—Principle and Framework
- ISO 14044:2006 (JIS Q14044:2010): Environmental Management—Life Cycle Assessment—Requirements and Guidelines
- ISO 14064-2:2006 (JIS Q14064-2:2011) Greenhouse gases—Part 2: Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements
- Greenhouse Gas Protocol Product Life Cycle Accounting and Reporting Standard (WBCSD and WRI, 2011)
- Guidelines for Quantifying GHG emission reductions of goods or services through Global Value Chain (METI of Japan, March 2018)
- Guidelines--Accounting for and Reporting Greenhouse Gas (GHG) Emissions Avoided along the Value Chain based on Comparative Studies (WBCSD and ICCA, October 2013)

Annex A Individual Methodology

A-1 A methodology for accounting CO_2 uptake by cement [target processes in the value chain: D-1, E-1 and F-1 in Table 1]

1. Name of methodology

Accounting of CO_2 uptake by cement

2. Definitions of terms

Terms	Definitions
Portland cement	Cement manufactured by grinding clinker which mainly consists of hydraulic calcium silicate with addition of an appropriate amount of gypsum. Cement which is generally specified in JIS R5210.
Blended cement	Portland cement pre-mixed with mineral admixture such as ground granulated blast furnace slag.
Clinker	Nodular material produced by burning the raw materials (limestone, clay, silica stone, iron material, etc.) in a rotary kiln at a high temperature around 1,450°C.
Cement-based solidifying material	General term for soil stabilizers consisting mainly of cement which are used to solidify soil for the purpose of improving mechanical and chemical properties of the soil.
Carbonation	Phenomenon in which hardened concrete gradually loses its alkalinity under the effects of atmospheric carbon dioxide and others. Unlike the term "neutralization", the term in this accounting methodology means carbonation of concrete due to the effect of carbon dioxide.
Degree of carbonation	Ratio (in moles) of CaO contained in cement which transforms to $CaCO_3$ due to carbonation (forming $CaCO_3$).
Unit cement content	Amount of cement per 1 m^3 of concrete (kg/m^3).
Equivalent surface area	Surface area of a structure or building specified to determine the volume of concrete carbonated during the use stage, which is calculated by dividing the total volume of concrete used with an average thickness of the members.
Subbase material	Material used for the layer which distributes and transfers the load from asphalt mixture layer or concrete slab to the roadbed. Examples include crushed stone for road construction use produced by breaking rock and recycled crushed stone produced by breaking waste concrete mass and others occurring from demolition of buildings.
Waste concrete mass	Concrete waste in a massive form occurring from demolition or the like of concrete structures and buildings.
Recycled crushed stone	Recycled aggregate obtained by crushing and mechanically stabilizing waste concrete mass or other waste materials.

3. Levels in the value chain / Coverage of accounting and target processes / System boundary

(1) Explanation

The cement after production and sales is mainly used in concrete for buildings and structures. They are demolished after a given use stage and reused as recycled crushed stone for, for example, subbase material and backfilling material (Figure 7.1-1). This methodology aims at CO_2 uptake by cement at these life cycle stages.

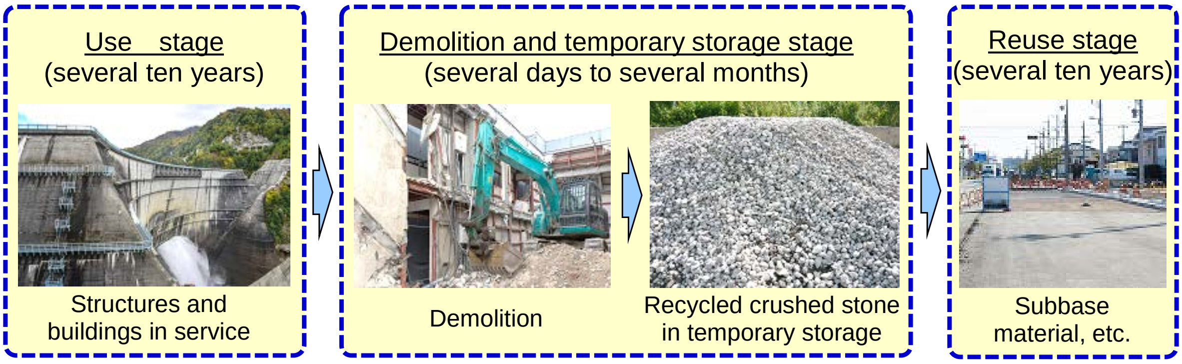

Figure 7.1-1: Life Cycle of Cement Products

Cement and cement-based products produced at cement plants include portland cement, blended cement, clinker and cement-based solidifying material. In this CO_2 uptake accounting methodology (hereinafter "this methodology"), accounting shall be made with proper consideration given to impacts of each product on the CO_2 absorption.

In addition, portland cement is available in several types, including ordinary portland cement, high early strength portland cement and moderate heat portland cement, and there are also various types of blended cement such as portland blast furnace slag cement and portland fly ash cement. Influence of these cement types on CO_2 absorption shall be also taken into account in accounting properly.

Table 7.1-1: Types of Cement and Cement-based Products and CO_2 Uptake Accounting Categories

Types	Categories for CO_2 uptake accounting
Portland cement	
Blended cement	
Clinker	
Cement-based solidifying material	

The period of time shall be properly specified for each stage of use, demolition and temporary storage, and reuse. The period of the use stage is generally a period during which a structure or building is in service after completion of construction. The period of the demolition and temporary storage is a period during which the structure or building is demolished and stored until the recycling stage. The period of the reuse stage is a period during which the demolished concrete is reused as recycled crushed stone for subbase material or other applications.

(2) Explanation about function and functional unit

The function is expressed by the amount of cement produced within one year, used in buildings or structures and, after the use stage, demolished and reused* within the coverage of accounting (specific cement plant(s), inside or outside the country, etc.), or, an appropriate range or functional unit (category or amount of cement, etc.) of the goods/services to be evaluated.

*reused as recycled crushed stone for subbase material or backfilling material

(3) System boundary, coverage of accounting, and target processes

Figure 7.1-2 shows the system boundary, the coverage of accounting, and the target processes. The coverage of accounting covers a series of processes in which cement is used in buildings or structures for a given use stage, demolished and temporarily stored, then reused as recycled crushed stone for subbase material and backfilling material.

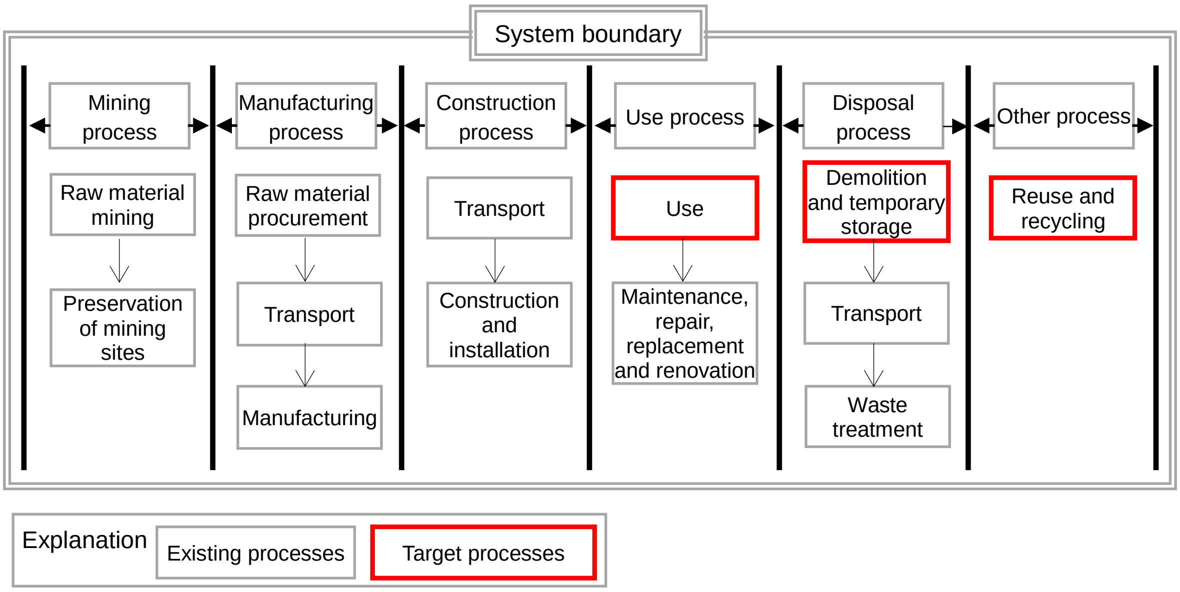

Figure 7.1-2: System Boundary, Coverage of Accounting, and Target Processes

(4) Service life / Durable life

- **Use stage**

Carbonation of concrete depends on the time length of exposure to the atmosphere. The use stage which actually varies by the type of structures and buildings shall be specified based on the principle of conservativeness described in 3.1 Basic Principles for Avoided GHG Emissions Accounting in the main part.

- **Demolition and temporary storage stage**

Generally, concrete structures and buildings are demolished after their use stage on site into waste concrete masses sized several ten centimeters or smaller. They also contain fine particles of several millimeters to powdery sizes. The waste concrete mass is transported to an intermediate processor and refined there into recycled crushed stone through the processes like crushing by crushers and particle size classification using sieves. After a certain period of storage at a storage yard of the intermediate processor, the recycled crushed stone is transported to its destination and reused for subbase material or other applications. The demolished concrete during this period absorbs CO_2 in the atmosphere as it is in a massive or granular to powdery form with small particle sizes and exposed to the external air for a certain period of time.

The demolition and temporary storage period shall be specified based on the principle of conservativeness.

- **Reuse stage**

The reuse stage is a period during which the demolished concrete is reused as recycled crushed stone for subbase material or other applications. CO_2 uptake during the reuse stage is considered to be minor because the recycled crushed stone is used under compacted condition in lower layers of the road surface covered with asphalt or concrete upper layers, having practically no contact with the atmosphere. The reuse stage shall be specified based on the principle of conservativeness described in 3.1 Basic Principles for Avoided GHG Emissions Accounting in the main part.

Table 7.1-2: Period of the Life Cycle stage of Concrete

Stage	Use	Demolition and temporary storage	Reuse
Period			

(5) Time and geographical references

As described in 3 (1), this methodology aims at CO_2 uptake by cement at its life cycle stages where cement after production and sales is used in buildings and structures for a given use stage, demolished, and then reused (e.g. subbase material).

There are two approaches for accounting avoided GHG emissions: the flow base approach; and, the stock base approach[1]. The former approach is to calculate cumulative amounts of greenhouse gas emissions avoided by using the assessed goods or services manufactured or sold within a specific assessment period (e.g. for one year), assuming that they are used until the end-of-life (product lifetime). The stock base approach is to calculate amounts of emissions avoided by using (or through other processes of) all the assessed goods or services, including those from past sales, that are in service during a specific assessment period. Either shall be selected in this methodology.

The coverage of accounting shall be specified to determine the CO_2 uptake by cement, for example, within the country, outside the country, or both, to meet the purpose of the study.

(6) Baseline

The baseline is an assumption of a case where materials (e.g. timber) which do not absorb CO_2 are used in buildings and civil engineering structures.

(7) Mechanisms of avoided GHG emissions

Cement consists mainly of four major minerals which are alite ($3CaO \cdot SiO_2$), belite ($2CaO \cdot SiO_2$), calcium aluminate phase ($3CaO \cdot Al_2O_3$) and ferrite phase ($4CaO \cdot Al_2O_3 \cdot Fe_2O_3$). When used in concrete, these minerals react with mixing water (hydration) to produce C-S-H, calcium hydroxide (CH) and calcium aluminate hydrates including ettringite ($3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O$) and monosulfate ($3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O$). The hydrates in the cement paste of concrete comprise roughly 55 to 65% of C-S-H, 15 to 25% of CH and 10 to 15% of calcium aluminate hydrates including ettringite and monosulfate. These cement hydrates can be normally present in stable forms in hardened cement or concrete. However, these minerals containing CaO as a chemical constituent form $CaCO_3$ through carbonation under the presence of water (moisture, etc.) and CO_2 which act as reaction media. The hydrated phases of concrete have a dense and porous structure which allows atmospheric CO_2 to enter through the pores and diffuse inside.

Carbonation is one of the critical deterioration factors for concrete structures, and measures are taken to control carbonation in the material and mix proportion designs as well as during construction and other activities. However, cement in concrete structures generally has a long period of use of more than several ten years. Carbonation occurs and develops to a considerable extent during that period, which results in absorption of CO_2. Concrete after use in structures is demolished and reused. The demolished concrete is in a massive form and has new surface layers which have previously been inside the structures. This causes further carbonation and then absorption of CO_2.

Table 7.1-3 shows the carbonation processes of cement hydrates. It should be noted that the Degree of carbonation depends on the diffusion of CO_2 into the hardened concrete, rather than the progress of the chemical reaction.

Table 7.1-3: Carbonation Processes of Cement Hydrates*

Cement hydrates	Reaction formulae of carbonation
C-S-H	$3CaO \cdot 2SiO_2 \cdot 3H_2O + 3CO_2 \rightarrow 3CaCO_3 + 2SiO_2 + 3H_2O$
CH	$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$
Ettringite	$3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O + 3CO_2$ $\rightarrow 3CaCO_3 + 2Al(OH)_3 + 3CaSO_4 + 29H_2O$
Monosulfate	$3CaO \cdot Al_2O_3 \cdot CaSO_4 \cdot 12H_2O + 3CO_2$ $\rightarrow 3CaCO_3 + 2Al(OH)_3 + CaSO_4 + 9H_2O$

* Since carbonation is a reaction using water as medium, H_2CO_3 can be used in place of CO_2 in the reaction formula.

4. Accounting methods

(1) General information and outline of accounting

CO$_2$ uptake by cement is accounted as a sum of CO$_2$ uptake by cement during its use stage in structure, CO$_2$ uptake by cement during its demolition and temporary storage stage, and CO$_2$ uptake by cement during its reuse stage. The individual CO$_2$ uptake by cement is accounted by multiplying CO$_2$ uptake by cement per 1 m^3 of carbonated zone of concrete (t/m^3) with volume of concrete in the carbonated zone (m^3).

(2) Settings, estimations and assumptions in the accounting method for the common indicator for the use stage and the demolition and temporary storage stage

2-1) Accounting of the CO$_2$ uptake by cement per 1 m^3 of carbonated zone of concrete

This protocol uses the following accounting equations[2] recommended by Danish Technology Institute (DTI).

<Accounting equation>

$$a = \gamma_c \times \frac{C}{1000} \times \frac{CaO}{100} \times \frac{M_{CO_2}}{M_{CaO}}$$

where,

a: CO$_2$ uptake by cement per 1 m^3 of carbonated region of concrete (t/m^3)

γ_c: Degree of carbonation

C: unit cement content in concrete (kg/m^3)

CaO: CaO content in cement (%)

M_{CO_2}: molar mass of CO$_2$ (= 44.0 g/mol)

M_{CaO}: molar mass of CaO (= 56.1 g/mol)

The Degree of carbonation[3] used here is a coefficient to express the ratio of CaO in cement transforming to CaCO$_3$ due to carbonation. The value shall be properly determined based on reliable reference materials and experimental data. It is also necessary to properly set unit cement content in concrete and CaO content in cement. Table 7.1-4 shows examples of chemical compositions of ordinary portland cement and portland blast furnace slag cement type B published by Japan Cement Association.

Table 7.1-4: Examples of Chemical Composition of Cement

Cement types	Chemical composition (%)			
	SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	CaO
Ordinary portland cement	20 to 23	3.8 to 5.8	2.5 to 3.6	63 to 65
Portland blast furnace slag cement (type B)	24 to 27	7.0 to 9.5	1.6 to 2.5	52 to 58

2-2) Accounting of the volume of concrete in the carbonated zone

Volume of concrete in the carbonated zone during the use stage is calculated by multiplying surface area of a concrete structure or building with carbonation depth. Volume of concrete in the carbonated zone during the demolition and temporary storage stage is calculated by multiplying volume of concrete to be reused after demolition with volume of the carbonated zone per unit volume. For the calculation using the former accounting formula, or for the calculation of volume of the carbonated zone per unit volume in the latter case, carbonation depth needs to be determined.

This section describes settings in the calculation method for carbonation depth which is a common indicator for the use stage and the demolition and temporary storage stage. Other indicators for the accounting of carbonated zone of concrete characteristic to the use stage and the demolition and temporary storage stage, respectively, are described in (3) Accounting equations below.

Equations available for accounting the carbonation depth from the surface of a concrete structure or building include the formula presented by Japan Society of Civil Engineers in the *Standard Specifications for Concrete Structures*[4], and the formula proposed by Architectural Institute of Japan in the *Recommendations for Durability Design and Construction Practice of Reinforced Concrete Buildings*[5] which is based on Kishitani's formula[6] with the impacts of materials, mixing and environmental effect standardized based on Shiroyama's[7] and Izumi's[8] Equations (Table 7.1-5). Since carbonation depth can be influenced by some factors including water-to-cement ratio (W/C) of concrete and environmental conditions, it is necessary to define proper values and coefficients for them in the accounting.

Table 7.1-5: Examples of Equation for Evaluationg Carbonation Depth

Proposed by	Equation	Parameters
Japan Society of Civil Engineers	$D = (-3.57 + 9.0 \cdot W/(C + kA_d)) \cdot \beta_e \cdot \sqrt{t}$ ...... [1]	*D*: carbonation depth (mm); *k*: constant representing the efficiency of the mineral admixture used (for blast furnace slag: 0.7); A_d: mineral admixture content; β_e: environmental effect coefficient (dry: 1.0)
Architectural Institute of Japan	$D = 1.72 \cdot \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \beta_1 \cdot \beta_2 \cdot \beta_3 \cdot \sqrt{t}$ ...... [2]	*D*: carbonation depth (mm); α_1: coefficient representing the effect of aggregate; α_2: coefficient representing the effect of types of cement; α_3: coefficient representing the effect of W/C; β_1: coefficient representing the effect of ambient temperature; β_2: coefficient representing the effect of humidity/moisture; β_3: CO_2

(3) Accounting Equations

3-1) CO_2 uptake by cement

$$A = A_{sl} + A_{dem} + A_r$$

A: CO_2 uptake by cement (t)
A_{sl}: CO_2 uptake by cement during the use stage (t)
A_{dem}: CO_2 uptake by cement during the demolition and temporary storage stage (t)

A_r: CO_2 uptake by cement during the reuse stage (t)

3-2) CO_2 uptake by cement during the use stage

$$A_{sl} = \sum_i (a_i \times V_{c-sl-i})$$

A_{sl}: CO_2 uptake by cement during the use stage (t)
a_i: CO_2 uptake by cement per 1 m^3 of carbonated zone of concrete under specific conditions (t/m^3)
V_{c-sl-i}: carbonated volume of concrete under specific conditions (m^3)
The specific conditions here are, for example, the classifications of structures and buildings mentioned in a) below.

Hereinafter, a_i and V_{c-sl-i} are generalized and expressed as a and V_{c-sl}, respectively.

$$V_{c-sl} = D \times A_{eq}$$

$$A_{eq} = \frac{V_{con-sl}}{t_{ave}}$$

V_{c-sl}: carbonated volume of concrete during the use stage (m^3)
D: carbonation depth (mm)
A_{eq}: equivalent surface area of a structure or building (m^2)
V_{con-sl}: amount of concrete during the use stage (m^3)
t_{ave}: average thickness of members of a structure or building (m)

$$a = \gamma_c \times \frac{C}{1000} \times \frac{CaO}{100} \times \frac{M_{CO_2}}{M_{CaO}}$$

a: CO_2 uptake by cement per 1 m^3 of carbonated zone of concrete (t/m^3)
γ_c: Degree of carbonation
C: unit cement content in concrete (kg/m^3)
CaO: CaO content in cement (%)
M_{CO_2}: molar mass of CO_2 (g/mol) [44.0 g/mol]
M_{CaO}: molar mass of CaO (g/mol) [56.1 g/mol]

a) Classifications of structures and buildings

Carbonation of concrete occurs as a result of reaction with carbon dioxide present in the atmosphere. It is also known that progress of carbonation is very minor in underground or underwater structures and buildings where contact with carbon dioxide is limited. In order to consider these influences, it is necessary to properly classify the environment to which each structure or building is exposed.

b) Setting of equivalent surface area of structures and buildings

Surface area of each concrete structure or building exposed to atmospheric CO_2 shall be properly defined. For the exposed surface area, equivalent surface area (A_{eq}) obtained by dividing the amount of concrete used in the structure or building in service with average thickness of members can be used.

3-3) CO_2 uptake by cement during the demolition and temporary storage stage

Concrete during the demolition stage is present in a form of waste concrete mass to recycled crushed stone. The state of concrete during demolition period shall be expressed either by appropriate measurement values or by proper modeling. Recycling rate of the demolished concrete shall be considered in accounting of the CO_2 uptake.

$$A_{dem} = \sum_i (a_i \times V_{c-dem-i})$$

A_{dem}: CO_2 uptake by cement during the demolition and temporary storage stage (t)
a_i: CO_2 uptake by cement per 1 m^3 of carbonated zone of concrete under specific conditions (cement types, etc.) (t/m^3)
$V_{c-dem-i}$: carbonated volume of concrete under specific conditions (cement types, etc.) (m^3)

Hereinafter, a_i and $V_{c\text{-}dem\text{-}i}$ are generalized and expressed as a and $V_{c\text{-}dem}$, respectively.

$$a = \gamma_c \times \frac{C}{1000} \times \frac{CaO}{100} \times \frac{M_{CO_2}}{M_{CaO}}$$

a: CO_2 uptake by cement per 1 m^3 of carbonated zone of concrete (t/m^3)
γ_c: Degree of carbonation
C: unit cement content in concrete (kg/m^3)
CaO: CaO content in cement (%)
M_{CO_2}: molar mass of CO_2 (g/mol) [44.0 g/mol]
M_{CaO}: molar mass of CaO (g/mol) [56.1 g/mol]

$$V_{c-dem} = Nr \times V_{con-dem}$$

V_{c-dem}: carbonated volume of concrete during the demolition and temporary storage stage (m^3)
Nr: volume of the carbonated zone per unit volume (1 m^3) of waste concrete mass or recycled crushed stone (m^3/m^3)
$V_{con-dem}$: volume of concrete during the demolition and temporary storage stage (m^3)

$$Nr = \sum_i \left(Nr_{di} \times \frac{p_{di}}{100} \right)$$

Nr_{di}: volume of the carbonated zone per unit volume (1 m^3) of waste concrete mass or recycled crushed stone of particle size di (m^3/m^3)
p_{di}: distributional frequency of particle size d_i in waste concrete mass or recycled crushed stone (%)

$$Nr_{di} = 1 - \left(\frac{(di/2) - D}{(di/2)}\right)^3$$

where Nr_{di} = 1 when $D > (d_i/2)$

Nr_{di}: volume of the carbonated zone per unit volume (1 m^3) of waste concrete mass or recycled crushed stone of particle size di (m^3/m^3)
di: particle size of waste concrete mass or recycled crushed stone (mm)
D: carbonation depth (mm)

$$V_{con-dem} = \frac{R_{con}}{100} \times V_{con-sl}$$

$V_{con-dem}$: volume of concrete during the demolition and temporary storage stage (m^3)
NOTE: Use a directly measured value, if available.
R_{con}: recycling rate of waste concrete mass (%)
V_{con-sl}: amount of concrete during the use stage (m^3)

3-4) CO_2 uptake by cement during the reuse stage

Concrete during the reuse stage is used mainly as subbase material for road construction. The state of concrete and environmental conditions shall be properly considered in accounting of the CO_2 uptake by concrete during the reuse stage.

$$A_r = \sum_i (a_i \times V_{c-r-i})$$

A_r: CO_2 uptake by cement during the reuse stage (t)
a_i: CO_2 uptake by cement per 1 m^3 of carbonated zone of concrete under specific conditions (cement types, etc.) (t/m^3)
V_{c-r-i}: carbonated volume of concrete under specific conditions (cement types, etc.) (m^3)

Hereinafter, a_i and V_{c-r-i} are generalized and expressed as a and V_{c-r}, respectively.

$$a = \gamma_c \times \frac{C}{1000} \times \frac{CaO}{100} \times \frac{M_{CO_2}}{M_{CaO}}$$

a: CO_2 uptake by cement per 1 m^3 of carbonated zone of concrete (t/m^3)
γ_c: Degree of carbonation
C: unit cement content of concrete (kg/m^3)
CaO: CaO content of cement (%)
M_{CO_2}: molar mass of CO_2 (g/mol) [44.0 g/mol]
M_{CaO}: molar mass of CaO (g/mol) [56.1 g/mol]

$$V_{c-r} = Nr \times V_{con-r}$$

V_{c-r}: carbonated volume of concrete during the reuse stage (m^3)
Nr: volume of the carbonated zone per unit volume (1 m^3) of subbase material (m^3/m^3)
V_{con-r}: volume of concrete during the reuse stage (m^3)

$$Nr = \sum_i \left(Nr_{di} \times \frac{p_{di}}{100} \right)$$

Nr_{di}: volume of the carbonated zone per unit volume (1 m^3) of subbase material of particle size *di* (m^3/m^3)
p_{di}: distributional frequency of particle size d_i in subbase material (%)

(4) Data sources (Sources and rationales for coefficients and others)

Described in (2) and (3) above.

(5) Cut-off criteria

CO_2 uptake of a process may be excluded from the accounting if its impact is minor (less than 3%) to the total CO_2 uptake of the target life cycle processes (use, demolition and temporary storage, and reuse).

(6) Allocation

Not applicable in this methodology.

(7) Others

Not applicable in this methodology.

References of Annex A

[1] Ministry of Economy, Trade and Industry of Japan (2018), Guidelines for Quantifying GHG emission reductions of goods or services through Global Value Chain, pp. 13.

[2] K. O. Kjellsen, M. Guimaraes and Å. Nilsson (2005), The CO_2 Balance of Concrete in a Life Cycle Perspective, Danish Technology Institute.

[3] Japan Society of Civil Engineers (2012), Concrete Library 134: Toward CO_2 Reduction in Repair, Demolition and Reuse of Concrete Structures, pp. 92. (in Japanese)

[4] Japan Society of Civil Engineers (2018), Standard Specifications for Concrete Structures 2017: Design, pp. 153-156. (in Japanese)

[5] Architectural Institute of Japan (2016), Recommendations for Durability Design and Construction Practice of Reinforced Concrete Buildings. (in Japanese)

[6] Koichi Kishitani (1963), Durability of Reinforced Concrete, Kajima Institute Publishing Co., Ltd. (in Japanese)

[7] Architectural Institute of Japan (1976), Recommendation for Practice of Mix Design of Concrete and Quality Control in Concrete Work. (in Japanese)

[8] Itoshi Izumi (1994), Durability Problems of Concrete Structures and Countermeasures: Carbonation, Concrete journal, Vol. 32, No. 2, pp. 72-83. (in Japanese)

Annex B ISO 14044 Reference Table

ISO 14044 requirements	Reference sections in the Protocol
4 Methodological framework for life cycle assessment (LCA)	—
4.1 General requirements	1.1 Purposes of the Protocol 1.2 Scope of the Protocol 1.4 Developing Process of the Protocol and Referenced Guidelines and Standards 3.2 Application of Life Cycle Approach 4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.2 Goal and scope definition	—
4.2.1 General	1.1 Purposes of the Protocol 1.2 Scope of the Protocol
4.2.2 Goal of the study	1.1 Purposes of the Protocol 3.1 Basic Principles for Avoided GHG Emissions Accounting 6. Reporting of Avoided GHG Emissions
4.2.3 Scope of the study	—
4.2.3.1 General	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.2.3.2 Function and functional unit	4.1 Principles for developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.2.3.3 System boundary	—
4.2.3.3.1	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.2.3.3.2	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
4.2.3.3.3	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
a) Mass	2. Terms and Definitions

ISO 14044 requirements	Reference sections in the Protocol
b) Energy c) Environmental significance	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.2.3.4 LCIA methodology and types of impacts	—
4.2.3.5 Types and sources of data	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.2.3.6 Data quality requirements	—
4.2.3.6.1	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.2.3.6.2 a) Time-related coverage b) Geographical coverage c) Technology coverage d) Precision e) Completeness f) Representativeness g) Consistency h) Reproducibility i) Sources of the data j) Uncertainty of the information	Related descriptions are given in the following sections but not exhaustive to cover the requirements on the left. 4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.2.3.6.3	6. Reporting of Avoided GHG Emissions Related descriptions are also given in the following section but not exhaustive to cover the requirements on the left. 5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results
4.2.3.7 Comparisons between systems	—
4.2.3.8 Critical review considerations	5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results
4.3 Life cycle inventory analysis (LCI)	—
4.3.1 General	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.3.2 Collecting data	—
4.3.2.1	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions

ISO 14044 requirements	Reference sections in the Protocol
	4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.3.2.2	Related descriptions are given in the following sections but not exhaustive to cover the requirements on the left. 4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.3.2.3	—
4.3.3 Calculating data	—
4.3.3.1 General	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.3.3.2 Validation of data	2. Terms and Definitions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.3.3.3 Relating data to unit process and functional unit	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
4.3.3.4 Refining the system boundary	5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
4.3.4 Allocation	—
4.3.4.1 General	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
4.3.4.2 Allocation procedure	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 6. Reporting of Avoided GHG Emissions
a) Step 1	—
b) Step 2	—
c) Step 3	—
4.3.4.3 Allocation procedures for reuse and recycling	—
4.3.4.3.1	—
4.3.4.3.2	—

ISO 14044 requirements	Reference sections in the Protocol
4.3.4.3.3	—
a)	—
b)	—
4.3.4.3.4	—
4.4 Life cycle impact assessment (LCIA)	—
4.4.1 General	3.1 Basic Principles for Avoided GHG Emissions Accounting 3.2 Application of Life Cycle Approach 3.3 Mechanisms of Avoided GHG Emissions 3.4 Trade-off 3.5 Double Counting 3.6 Allocation of Avoided GHG Emissions 3.7 Methodological Framework for Accounting of Avoided GHG Emissions 4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
a)	—
b)	—
c)	—
4.4.2 Mandatory elements of life cycle impact assessment (LCIA)	—
4.4.2.1 General	—
4.4.2.2 Selection of impact categories, category indicators and characterization models	—
4.4.2.2.1	—
4.4.2.2.2	—
4.4.2.2.3	—
a)	—
b)	—
c)	—
d)	—
e)	—
f)	—
g)	—
4.4.2.2.4	—
a)	—
b)	—
4.4.2.3 Assignment of LCI results to the selected impact categories (classification)	—
a)	—
b)	—
4.4.2.4 Calculation of category indicator results (characterization)	—
4.4.2.5 Resulting data after characterization	—

ISO 14044 requirements	Reference sections in the Protocol
4.4.3 Optional elements of LCIA	—
4.4.3.1 General	—
a) Normalization	—
b) Grouping	—
c) Weighting	—
d) Data quality analysis	—
4.4.3.2 Normalization	—
4.4.3.2.1	—
4.4.3.2.2	—
4.4.3.3 Grouping	—
4.4.3.4 Weighting	—
4.4.3.4.1	—
4.4.3.4.2	—
4.4.3.4.3	—
4.4.4 Additional LCIA data quality analysis	—
4.4.4.1	—
4.4.4.2 a) b) c)	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
4.4.5 LCIA intended to be used in comparative assertions intended to be disclosed to the public	—
4.5 Life cycle interpretation	—
4.5.1 General	—
4.5.1.1	4.1 Principles for Developing Accounting Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
4.5.1.2	5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
4.5.2 Identification of significant issues	—
4.5.2.1	—
4.5.2.2	—
4.5.2.3	—
a)	—
b)	—
c)	—
d)	—
4.5.3 Evaluation	—
4.5.3.1 General	4.1 Principles for Developing Accounting

ISO 14044 requirements	Reference sections in the Protocol
	Methodologies for Avoided GHG Emissions 4.2 Accounting of Avoided GHG Emissions 5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
4.5.3.2 Completeness check	5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
4.5.3.3 Sensitivity check	5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
4.5.3.4 Consistency check	5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results
a)	
b)	
c)	
d)	
4.5.4 Conclusions, limitations and recommendations	6. Reporting of Avoided GHG Emissions
a)	
b)	
c)	
d)	
5 Reporting	—
5.1 General requirements and considerations	—
5.1.1	6. Reporting of Avoided GHG Emissions
5.1.2	
a)	
b)	
c)	
d)	
e)	
5.1.3	—
5.2 Additional requirements and guidance for third-party reports	6. Reporting of Avoided GHG Emissions
a) General aspects	
b) Goal of the study	
c) Scope of the study	
d) Life cycle inventory analysis (LCI)	
e) Life cycle impact assessment (LCIA), where applicable	
f) Life cycle interpretation	
g) Critical review, where applicable	5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions
5.3 Further reporting requirements for comparative	—

ISO 14044 requirements	Reference sections in the Protocol
assertion intended to be disclosed to the public	
5.3.1	1.1 Purposes of the Protocol
a)	—
b)	—
c)	—
d)	—
e)	—
f)	—
g)	—
h)	—
i)	—
5.3.2	—
a)	—
b)	—
c)	—
d)	—
e)	—
6 Critical review	—
6.1 General	1.1 Purposes of the Protocol 5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results
6.2 Critical review by internal or external expert	5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results
6.3 Critical review by panel of interested parties	5. Evaluation of the Avoided GHG Emissions Accounting Methodology and Accounting Results 6. Reporting of Avoided GHG Emissions