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Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries —

Part 3: Cement industry

Émissions de sources fixes — Détermination des émissions de gaz à effet de serre dans les industries énergo-intensives —

Partie 3: Industrie du ciment

Reference number
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Contents

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 1, *Stationary source emissions.*

A list of all parts in the ISO 19694 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

0.1 Overview of cement manufacturing process

Cement manufacture includes three main process steps (see Figure 1):

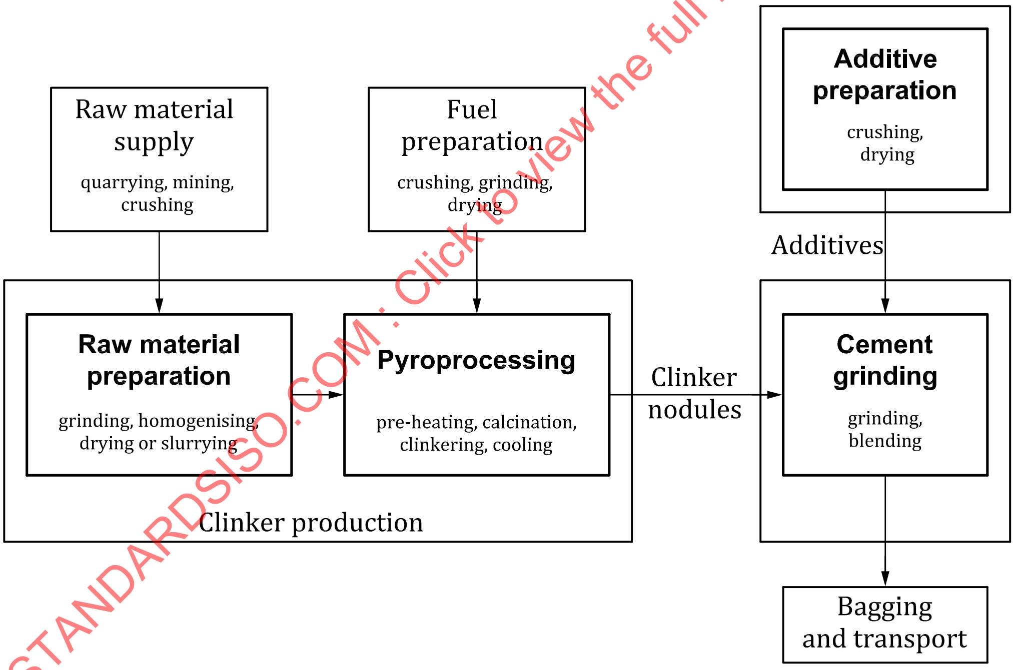
a) preparing of raw materials and fuels;

b) producing clinker, an intermediate, through pyro-processing of raw materials;

c) grinding and blending clinker with other products ("mineral components") to make cement.

There are two main sources of direct CO_2 emissions in the production process: calcination of raw materials in the pyro-processing stage, and combustion of kiln fuels. These two sources are described in more detail below. Other CO_2 sources include direct GHG emissions from non-kiln fuels (e.g. dryers for cement constituents products, room heating, on-site transports and on-site power generation), and indirect GHG emissions from, for example, external power production and transports. Non-CO_2 greenhouse gases covered by the Kyoto Protocol, apart from carbon monoxide (CO) methane (CH_4) and nitrous oxide (N_2O), are not relevant in the cement context in the sense that direct GHG emissions of these gases are negligible.

NOTE The non-CO_2 greenhouse gases covered by the Kyoto Protocol are: methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), partly halogenated fluorohydrogencarbons (HFC) and perfluorated hydrocarbons (PFC).



SOURCE Reference [8], based on Reference [16]. Reproduced with the permission of the authors.

Figure 1 — Process steps in cement manufacture

Table 1 gives an overview of places where materials enter the cement production process.

Table 1 — Overview of input places of materials

Raw meal	**Input place**
Raw materials from natural resources	Raw mill
Alternative raw materials	Raw mill
Raw material flows for clinker production	Input place
Raw meal	Kiln feed
Fuel ashes	Burner or precalciner or fuel dryer
Additional raw materials not part of the kiln feed	Kiln inlet
Fuels flows for clinker and cement production	**Input place**
Fossil fuels	Burner or precalciner or fuel dryer or raw material dryer
Alternative fuels	Burner or precalciner or fuel dryer or raw material dryer
Alternative fossil fuels	Burner or precalciner or fuel dryer or raw material dryer
Mixed fuels	Burner or precalciner or fuel dryer or raw material dryer
Biomass fuels	Burner or precalciner or fuel dryer or raw material dryer
Cement kiln dust	**Output place**
Dust return	Preheater
Filter dust	Precipitator / filter
By pass dust	Bypass filter
Cement constituents-based products	**Output place**
Clinker	Kiln (cooler)
Cement	Cement mill
Blast furnace slag	Cement mill or grinding station
Fly ash	Cement mill or grinding station
Gypsum	Cement mill or grinding station
Cooler dust	Cooler, is normally added to the clinker flow to the clinker silo
Cement kiln dust	Preheater or precipitator or filter or bypass filter
Limestone	Cement mill or grinding station
Burnt shale	Cement mill or grinding station
Pozzolana	Cement mill or grinding station
Silica fume	Cement mill or grinding station

0.2 CO_2 from calcination of raw materials

In the clinker production process, CO_2 is released due to the chemical decomposition of calcium, magnesium and other carbonates (e.g. from limestone) into lime:

$CaCO_3 + \text{heat} \rightarrow CaO + CO_2$

$MgCO_3 + \text{heat} \rightarrow MgO + CO_2$

This process is called “calcining” or “calcination”. It results in direct CO_2 emissions through the kiln stack. When considering CO_2 emissions due to calcination, two components can be distinguished:

- CO_2 from raw materials actually used for clinker production, these raw materials are fully calcined in the clinker production process;

— CO_2 from raw materials leaving the kiln system as partly calcined cement kiln dust (CKD), or as normally fully calcined bypass dust.

CO_2 from actual clinker production is proportional to the lime content of the clinker, which in turn varies little in time or between different cement plants.

NOTE A second, but much smaller factor is the CaO and MgO content of the raw materials and additives used.

As a result, the CO_2 emission factor per tonne of clinker is fairly stable with a default value in this document of 525 kg CO_2/t clinker (IPCC default: 510 kg CO_2/t clinker, CSI default: 525 kg CO_2/t clinker[19]).

The amount of kiln dust leaving the kiln system varies greatly with kiln types and cement quality standards, ranging from practically zero to over one hundred kilograms per tonne of clinker. The associated emissions are likely to be relevant in some countries or installations.

CO_2 emissions from calcination of raw materials can be calculated by two methods which are in principle equivalent: either based on the amount and chemical composition of the products (clinker plus dust leaving the kiln system, output methods B1 and B2), or based on the amount and composition of the raw materials entering the kiln (input methods A1 and A2). See 7.2.1 and 7.2.2 for details.

0.3 CO_2 from organic carbon in raw materials

The raw materials used for clinker production usually contain a small fraction of organic carbon, which can be expressed as TOC content. Organic carbon in the raw meal is converted to CO_2 during pyro-processing. The contribution of this component to the overall CO_2 emissions of a cement plant is typically very small (about 1 % or less). The organic carbon contents of raw materials can, however, vary substantially between locations and between the types of materials used. For example, the resulting emissions can be relevant if a cement company organization consumes large quantities of certain types of fly ash or shale as raw materials entering the kiln.

0.4 CO_2 from fuels for kiln operation

The cement industry traditionally uses various fossil fuels to operate cement kilns, including coal, petroleum coke, fuel oil and natural gas. Fuels derived from waste materials have become important substitutes for conventional fossil fuels. These AFs include fossil fuel-derived fractions such as, for example, waste oil and plastics, as well as biomass-derived fractions such as waste wood and dewatered sludge from wastewater treatment. Furthermore, fuels which contain both fossil and biogenic carbon (mixed fuels), like, for example, (pre-treated) municipal and (pre-treated) industrial wastes (containing plastics, textiles, paper etc.) or waste tyres (containing natural and synthetic rubber), are increasingly used.

Both traditional fossil and alternative fuels result in direct CO_2 emissions through the kiln stack. However, biomass and bioliquids are considered “climate neutral“ in accordance with IPCC definitions. The use of alternative (biomass- or fossil-derived) fuels can, in addition, lead to important emission reductions elsewhere, for instance from waste incineration plants or landfills.

Mineral components are natural and artificial materials with latent hydraulic properties. Examples of MIC include natural pozzolana, blast furnace slag and fly ash. In addition, gypsum is within this document labelled as MIC. MICs are added to clinker to produce blended cement. In some instances, pure MICs are directly added to the concrete by the ready-mix or construction company. Use of MICs leads to an equivalent reduction of direct CO_2 emissions associated with clinker production, both from calcination and fuel combustion. Artificial MICs are waste materials from other production processes such as, for example, steel and coal-fired power production. Related GHG emissions are monitored and reported by the corresponding industry sector. Utilization of these MICs for clinker or cement substitution does not entail additional GHG emissions at the production site. Consequently, these indirect GHG emissions are not included in the cement production inventory.

The basic mass balance methods used in this document are compatible with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories issued by the Intergovernmental Panel on Climate Change (IPCC)[4], and with the revised WRI / WBCSD Greenhouse Gas Protocol[9]. Default emission factors suggested in these documents are used, except where more recent, industry-specific data has become available.

The 2006 IPCC Guidelines[4] introduced a Tier 3 method for reporting CO_2 emissions from the cement production based on the raw material inputs (see Vol. III, Chapter 2.2.1.1, Formula (2).3[4]). However, a large number of raw material inputs and the need to continuously monitor their chemical composition make this approach impractical in many cement plants. The different raw materials are normally homogenized before and during the grinding process in the raw mill. The WRI / WBCSD therefore recommended alternative methods for input-based reporting of CO_2 emissions from raw material calcination in cement plants. They rely on determining the amount of raw meal consumed in the kiln system. In many cement plants, the homogenized mass flow of raw meal is routinely monitored including its chemical analysis for the purpose of process and product quality control. The input methods based on the raw meal consumed are already successfully applied in cement plants in different countries and seem to be more practical than Tier 3 of Reference [4]. They were included in the Cement CO_2 and Energy Protocol Version 3[1] (simple input method A1 and detailed input method A2, 7.2.1). This document provides guidance on how to compare the GHG performance of other companies or plants within a sector level which is different from a methodology of the IPCC National Inventory Guideline.

This document for the cement industry has been based on Reference [1].

Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries —

Part 3:
Cement industry

1 Scope

This document specifies a harmonized methodology for calculating greenhouse gas (GHG) emissions from the cement industry, with a view to reporting these emissions for various purposes and by different basis, such as, plant basis, company basis (by country or by region) or even international group basis. It addresses all the following direct and indirect sources of GHG included:

- Direct GHG emissions [ISO 14064-1:2018, 5.2.4, a)] from sources that are owned or controlled by the organization, such as emissions that result from the following processes:
  - calcinations of carbonates and combustion of organic carbon contained in raw materials;
  - combustion of kiln fuels (fossil kiln fuels, alternative fossil fuels, mixed fuels with biogenic carbon content, biomass and bioliquids) related to either clinker production or drying of raw materials and fuels, or both;
  - combustion of non-kiln fuels (fossil fuels, alternative fossil fuels, mixed fuels with biogenic carbon content, biomass and bioliquids) related to equipment and on-site vehicles, room heating and cooling, drying of MIC (e.g. slag or pozzolana);
  - combustion of fuels for on-site power generation;
  - combustion of carbon contained in wastewater;
- Indirect GHG emissions [ISO 14064-1:2018, 5.2.4, b)] from the generation of purchased electricity consumed in the organization's owned or controlled equipment;
- Other indirect GHG emissions [(ISO 14064-1:2018, 5.2.4, c) to f)] from purchased clinker. Excluded from this document are all other ISO 14064-1:2018, 5.2.4, c) to f) emissions from the cement industry.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12039, *Stationary source emissions —Determination of the mass concentration of carbon monoxide, carbon dioxide and oxygen in flue gas — Performance characteristics of automated measuring systems*

ISO 14064-1:2018, *Greenhouse gases — Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals*

ISO 16911-1, *Stationary source emissions — Manual and automatic determination of velocity and volume flow rate in ducts — Part 1: Manual reference method*

ISO 16911-2, *Stationary source emissions — Manual and automatic determination of velocity and volume flow rate in ducts — Part 2: Automated measuring systems*

ISO 19694-1, *Stationary source emissions — Determination of greenhouse gas emissions in energy-intensive industries — Part 1: General aspects*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 19694-1 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at https://www.electropedia.org/

3.1
additional raw material
ADRM

raw material (3.30) which is fed directly to the calciner or the *kiln inlet* (3.26)

Note 1 to entry: Additional raw materials are not part of the kiln feed.

3.2
alternative fuel
AF

fuel derived from waste materials

Note 1 to entry: AF can be further divided into biogenic, *fossil* (3.18) and mixed alternative fuels.

3.3
automated measuring system
AMS

measuring system permanently installed on site for continuous monitoring of emissions

Note 1 to entry: An AMS is a method which is traceable to a reference method.

Note 2 to entry: Apart from the analyser, an AMS includes facilities for taking samples (e.g. sample probe, sample gas lines, filters, flow meters, regulators, delivery pumps, blowers) and for sample conditioning (e.g. dust filter, water vapour removal devices, converters, diluters). This definition also includes testing and adjusting devices that are required for regular functional checks.

Note 3 to entry: In ISO 14064-1:2018, AMS are called “continuous emission monitoring systems (CEMS)".

3.4
alternative fossil fuel

fossil fuel derived from waste materials without biogenic content and not listed by IPCC

3.5
alternative raw material
ARM

raw material (3.30) for *clinker* (3.13) production derived from artificial resources

3.6
bioliquid

liquid fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass

3.7
bypass dust
BPD
discarded dust from the bypass system dedusting unit of suspension preheater, precalciner and grate preheater kilns, normally consisting of *kiln feed* (3.23) material which is fully calcined or at least calcined to a high degree

3.8
cement
building material made by grinding *clinker* (3.13) together with various *mineral components* (3.26) such as gypsum, limestone, blast furnace slag, coal fly ash and natural volcanic material

Note 1 to entry: This term includes special cements such as the ones based on calcium aluminates.

3.9
cement (equivalent)
calculated cement production value which is determined from *clinker* (3.13) produced on-site in an *integrated cement plant* (3.21) applying the plant-specific clinker/cement-factor

3.10
cement constituent
main and minor additional materials used in *cement* (3.9) plus calcium sulphates and additives in cement

3.11
cement kiln dust
CKD
discarded dust from dry and wet *kiln system* (3.22) dedusting units, consisting of partly calcined *kiln feed* (3.23) material which includes *bypass dust* (3.7) or any other dust flows coming from the *clinker* (3.13) production

3.12
cement constituents-based product
clinker (3.13) produced for *cement* (3.8) making or direct clinker sale, plus *mineral components* (3.26) consumed or processed for sale excluding pre-processed mineral components imported from another cement plant

3.13
clinker
intermediate product in *cement* (3.8) manufacturing and the main substance in cement

Note 1 to entry: clinker is the result of calcination of limestone in the kiln and subsequent reactions caused through burning (see EN 197-1[12]).

3.14
concrete addition
finely divided inorganic material with pozzolanic or latent hydraulic properties or nearly inert, used in concrete in order to improve certain properties or to achieve special properties

3.15
fossil direct GHG emission
total direct emission (3.34) of GHGs within the reporting boundaries excluding GHG emissions from biomass fuels or biogenic carbon content of mixed fuels

3.16
dust return
dust arising during *clinker* (3.13) manufacture that is ultimately returned to the raw mill or *kiln system* (3.22)

Note 1 to entry: This term does not include *bypass dust* (3.7).

Note 2 to entry: See Figure 6 for an example of mass flows in the clinker production process.

3.17
filter dust leaving the kiln system
cement kiln dust (3.11) leaving the *kiln system* (3.22) excluding *bypass dust* (3.7)

3.18
fossil fuel
fuels from fossilized materials listed by IPCC

Note 1 to entry: Examples of fossilized material are coal, oil, and natural gas and peat.

3.19
grinding station
plant for *cement* (3.8) production where cement constituents are ground without having onsite *clinker* (3.13) production

3.20
gross emission
fossil direct GHG emissions (3.15) excluding GHG emissions from on-site power production

3.21
integrated cement plant
plant where *clinker* (3.13) is produced and partly or fully ground to *cement* (3.8)

3.22
kiln system
tubular heating apparatus used in the production of *clinker* (3.13), including preheater and/or pre-calciner

3.23
kiln feed
raw materials (3.30), often processed as *raw meal* (3.31) [including *recirculated dust* (3.33)], which are fed to a preheater or directly into the *kiln system* (3.22)

3.24
kiln fuel
fuel fed to the *kiln system* (3.22) plus fuels that are used for drying or processing of *raw materials* (3.30) for the production of *clinker* (3.13) and their preparation

3.25
kiln inlet
kiln hood or entrance to the tubular heating apparatus for materials

3.26
mineral component
cement constituent (3.10) other than *clinker* (3.13) plus *concrete additions* (3.14) processed in view of changing their properties

3.27
net emission
gross emissions (3.20) excluding fossil GHG emissions from *alternative fuels* (3.2) and comparable benchmark emissions from external heat or energy transfer

3.28
non-kiln fuel
fuels which are not included in the definition of *kiln fuels* (3.24)

3.29
petcoke
petroleum coke
carbon-based solid fuel derived from oil refineries

3.30
raw material
materials used for *raw meal* (3.31) preparation for *clinker* (3.13) production

3.31
raw meal
ground *raw materials* (3.30) for *clinker* (3.13) production

3.32
raw meal consumed
part of the *raw meal* (3.31), which is consumed for *clinker* (3.13) production and the formation of calcined *bypass dust* (3.7)

3.33
recirculated dust
dust flow that is reused as *kiln feed* (3.23)

Note 1 to entry: See Figure 6 for an example of mass flows in the *clinker* (3.13) production process.

3.34
total direct GHG emission
all direct emissions of GHGs within the reporting boundaries including GHG emissions from *raw materials* (3.30) processing, *fossil fuels* (3.18), biomass and biogenic carbon content of mixed fuels, and CO_2 from waste water combustion

4 Symbols and abbreviated terms

For the purposes of this document, the following symbols and abbreviated terms apply.

ADRM	Additional raw material
AF	Alternative fuel
AFR	Alternative fuel and alternative raw material
ARM	Alternative raw material
AMS	Automated measuring system
BioC	Biogenic carbon content
BPD	Bypass dust
cem_{eq}	cement (equivalent)
$cem_{products}$	cement constituents-based product
CKD	Cement kiln dust
cli	clinker
CSI	Cement sustainablity initiative of the WBCSD
EF	Emission factor

FD	Filter dust
GCV	Gross calorific value (synonym for higher heat value, HHV)
GHG	Greenhouse gas
GWP	Global warming potential
HHV	Higher heat value (synonym for gross calorific value, GCV)
IPCC	Intergovernmental panel on climate change
IR	Infrared
KF	Kiln feed
KPI	Key performace indicator
LHV	Lower heat value (synonym for net calorific value, NCV)
LOI	Loss on ignition
MIC	Mineral component
m_N^3	Normal cubic meters (at 1 013 hPa and 0 °C)
NCV	Net calorific value (synonym for lower heat value, LHV)
QXRD	Quantitative X-ray diffractometry
RM	Raw meal
SRM	Standard reference method
TC	Total carbon (the sum of TOC and TIC)
TIC	Total inorganic carbon
TOC	Total organic carbon
UNFCCC	United Nations Framework Convention on Climate Change
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

5 Determination of GHGs

5.1 General

The volume of GHG emissions can be determined by the mass balance method (see 5.4) or by (continuous) stack emission measurements (see 5.3). Further clarification of the different mass flows in the cement production process is given in Annex D.

5.2 Major GHG in cement

For the mass balance, the emissions have been related to carbon assuming that all carbon is converted into CO_2, with exclusion of all other GHG components assuming that these are negligible.

5.3 Determination by stack emission measurements

The GHG emissions of an installation can also be determined by measurement. Emissions from an emission source are determined based on continuous measurement of the concentration of the relevant greenhouse gas in the flue gas and of the flue gas flow. The measurements should include measurements of CH_4 and N_2O as these are assumed to be the only important non-CO_2 GHG emissions. Measurement standards that shall be applied on stack emission measurements are ISO 12039 for measurement of CO, CO_2 and O_2 and ISO 16911-1 and ISO 16911-2 for velocity and volume flow measurement rates. For more details, refer to ISO 16964-1.

5.4 Determination based on mass balance

The GHG emissions of an installation can be determined based on mass balance. Emissions from source streams are calculated from input or production data, obtained by means of measurement systems, and additional parameters from laboratory analyses including calorific factor, carbon content and biomass content. Standard factors can also be used; see Annex B for hints regarding emission factors.

5.5 Gross and net emissions

5.5.1 General

For the purpose of comparison of GHG emissions of plants or installations from different sectors within the energy-intensive industries, it is essential that the boundaries for monitoring and reporting of these emissions are identical on plant level, even when being different in detail for each sector. Within this view the GHG emissions from pure biomass and from the biogenic carbon content of mixed fuels are being recognized as climate change neutral and therefore treated as zero direct GHG emissions.

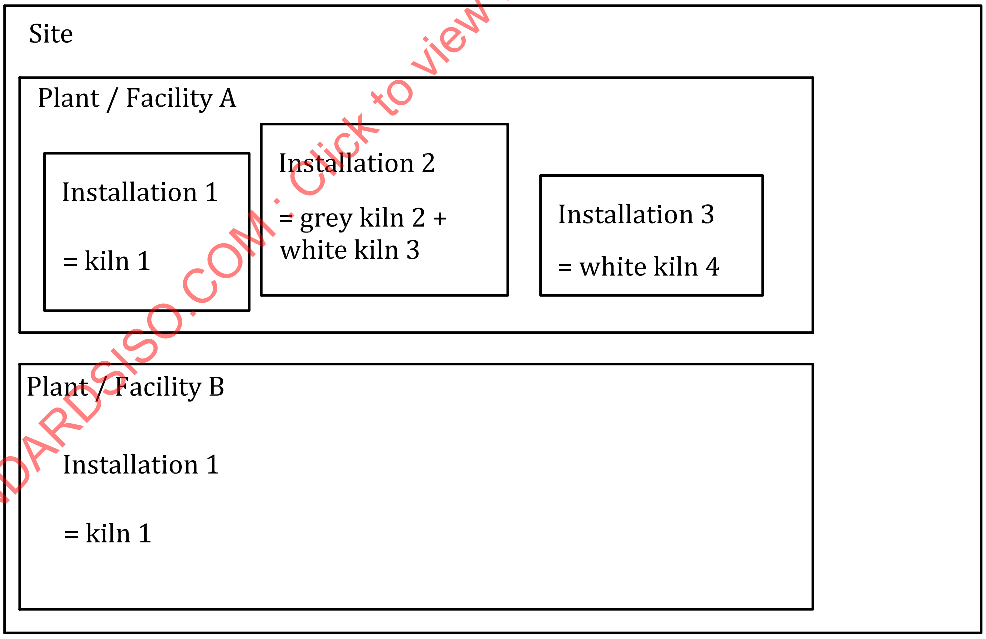


Figure 2 — Site, facility, plant or installation

For a plant this leads to the so-called “fossil direct GHG emissions”, to the value of which can be compared with comparable volumes from sites within different sectors. It is an absolute volume of reported GHGs by a plant, site or organization, see Figure 2 and definitions.

But this volume of “fossil direct GHG emissions” cannot be used for comparison of the performances of installations within the cement industry sector. A site that is producing its own electricity (power) will have higher fossil direct GHG emissions than a nearly identical site which gets the electricity from the external grid as emissions of external electricity production are reported as indirect GHG emissions from imported energy. For comparison reasons, the emissions from on-site power generation have to be excluded from the fossil direct GHG emissions leading to the so-called “gross emissions”.

This concept of gross emissions enables a comparison of GHG emissions on plant, site or organization level.

Table 2 — Direct emissions

Calculation result	Calculation contribution	Description
$E_{\text{fossil,dir}}$ =		Fossil direct GHG emissions
	$E_{\text{total,dir}}$	Total direct GHG emissions
	$-\ E_{\text{bio}}$	Emissions from pure biomass and from the biogenic carbon content of mixed fuels
E_{gross} =		Gross emissions
	$E_{\text{f,dir}}$	Fossil direct GHG emissions
	$-\ E_{\text{ospg}}$	Emissions from on-site power generation

The concept of gross emissions enables comparison of direct GHG emissions on plant level within the cement industry. This concept does not enable fair comparison of performance of plants and installations for their effect on global climate change, because some GHG emissions are excluded – see Tables 2 and 3.

This document offers the incentive of taking advantage of indirect GHG savings from the use of AFR by reporting gross (including alternative fossil fuels) and net (excluding alternative fossil fuels) emissions.

Some waste materials can substitute conventional fossil fuels and minerals in cement production. The recovered wastes are called AFR. As a result, direct CO_2 emissions from conventional fossil fuels are reduced but direct CO_2 emissions from wastes (“waste-to-energy conversion”) occur. The direct CO_2 emissions from waste combustion can be higher or lower than the displaced emission, depending on the emission factors of the fuels involved. Moreover, wastes can be of fossil or biomass origin.

In addition to those direct effects, utilization of AFR results in indirect GHG savings at landfills and incineration plants where these wastes can otherwise be disposed. These savings can partly, fully or more than fully offset the direct CO_2 emissions from waste combustion at the cement plant, depending on local conditions (type of waste, reference disposal path).

Gross emissions are the total direct GHG emissions (excluding on-site power generation) from a cement plant or organization, including GHG from fossil wastes (but excluding CO_2 from biomass wastes, which is treated as a memo item). Advantages from indirect GHG savings reflect the GHG emission reductions achieved at waste disposal sites as a result of AFR utilization. The actual reductions will usually be difficult to determine with precision; hence the countable savings will to some degree have to be agreed upon by convention, rather than based on “precise” GHG impact assessments.

Table 3 — Gross and net emissions

Calculation result	Calculation contribution	Description
E_{net} =		Net emissions
	E_{gross}	Gross emissions
	$-\ E_{\text{AF}}$	Emissions from alternative fossil fuels and non-biogenic content of mixed fuels
	$-\ E_{\text{BM,heat}}$	Comparable benchmark emissions for external heat transfer

Net emissions are the gross emissions minus the advantages for indirect GHG savings. As far as practicable, reported AFR advantages should take into account local circumstances (e.g. national agreements, life cycle analyses of local AFR use). When reporting to third parties, supporting evidence for the savings should be provided and verified as appropriate. As a default, this document assumes indirect savings to be equal to the direct GHG emission from fossil AFR use. This approach is a simplification of the AFR issue. It is however, in the medium-term, the least onerous and most practicable approach, where transparency is achieved through disclosure of gross and net emissions.

5.5.2 Gross emissions

5.5.2.1 General

Table 4 gives the emission sources included within "total direct GHG emissions", Table 5 gives the emission sources to be reported within "fossil direct GHG emissions" and Table 6 gives the emission sources to be reported within "gross emissions".

Table 4 — Emission sources included within "total direct GHG emissions"

Calculation result	Calculation contribution	Description
$E_{\text{total,dir}} =$		Total direct GHG emissions
	$+ E_{\text{rawmaterials}}$	GHG from raw materials
	$+ E_{\text{convfuels}}$	GHG from conventional fossil fuels
	$+ E_{\text{fossilAF}}$	GHG from alternative fossil fuels (fossil wastes)
	$+ E_{\text{fossil,mixedfuels}}$	GHG from fossil carbon of mixed (alternative) fuels covering GHG from kiln fuels and non-kiln fuels including GHG from on-site power generation
	$+ E_{\text{bio}}$	GHG from biomass and biogenic carbon of mixed fuels
	$+ E_{\text{wastewater}}$	GHG from combustion of waste water
Memo item Indirect GHG (from purchased energy and clinker)		

Table 5 — Emission sources to be reported within "fossil direct GHG emissions"

Calculation result	Calculation contribution	Description
$E_{\text{fossil,dir}} =$		Fossil direct GHG emissions
	$+ E_{\text{rawmaterials}}$	GHG from raw materials
	$+ E_{\text{convfuels}}$	GHG from conventional fossil fuels
	$+ E_{\text{fossilAF}}$	GHG from alternative fossil fuels (fossil wastes)
	$+ E_{\text{fossil,mixedfuels}}$	GHG from fossil carbon of mixed fuels covering GHG from kiln fuels and non-kiln fuels including GHG from on-site power generation
	$+ E_{\text{wastewater}}$	GHG from combustion of wastewater
Memo items — GHG from biomass fuels — GHG from biogenic carbon of mixed fuels — Indirect GHG (from purchased power and clinker)		

Table 6 — Emission sources to be reported within "gross emissions"

Calculation result	Calculation contribution	Description
$E_{\text{gross}} =$		Gross emissions
	$+ E_{\text{rawmaterials}}$	GHG from raw materials
	$+ E_{\text{convfuels}}$	GHG from conventional fossil fuels
	$+ E_{\text{fossilAF}}$	GHG from alternative fossil fuels (fossil wastes)
	$+ E_{\text{fossil,mixedfuels}}$	GHG from fossil carbon of mixed fuels covering GHG from kiln fuels and non-kiln fuels (excluding GHG from on-site power generation)
	$+ E_{\text{wastewater}}$	GHG from combustion of wastewater
Memo items — GHG from biomass fuels — GHG from biogenic carbon of mixed (alternative) fuels — GHG from fossil carbon of mixed fuels used for on-site power generation — Indirect GHG (from purchased energy and clinker)		

5.5.2.2 Accounting of CO_2 emissions from the biomass content of fuels

The CO_2 emissions originating from the biogenic carbon content of mixed fuels are not accounted as part of the gross emissions. Biomass CO_2 from these fuels is added up with the CO_2 from pure biomass to give the total biomass CO_2 and reported as memo item. It is subtracted when calculating absolute direct CO_2 emissions.

5.5.2.3 Net emissions and indirect GHG savings related to utilization of wastes as alternative fuels

The cement industry recovers large quantities of waste materials for use as fuel and/or raw material. These recovered wastes are also referred to as AFR. By utilizing AFR, cement companies reduce their consumption of conventional fossil fuels while at the same time helping to avoid conventional disposal of the waste materials by landfill or incineration.

Increased utilization of AFR can have an influence on the direct GHG emissions of a cement organization because the emission factors of the AFR can differ from those of the displaced fuels. Moreover, the carbon contained in the AFR can be of fossil and/or biomass origin. As mentioned above, utilization of AFR by the cement industry typically results in GHG emission reductions at landfills and incineration plants where these wastes would otherwise be disposed. The combination of direct GHG emissions impacts, indirect GHG emission reductions and resource efficiency makes the substitution of AF for conventional fossil fuels an effective way to reduce global GHG emissions (e.g. see References [21], [22], [23] and [24]).

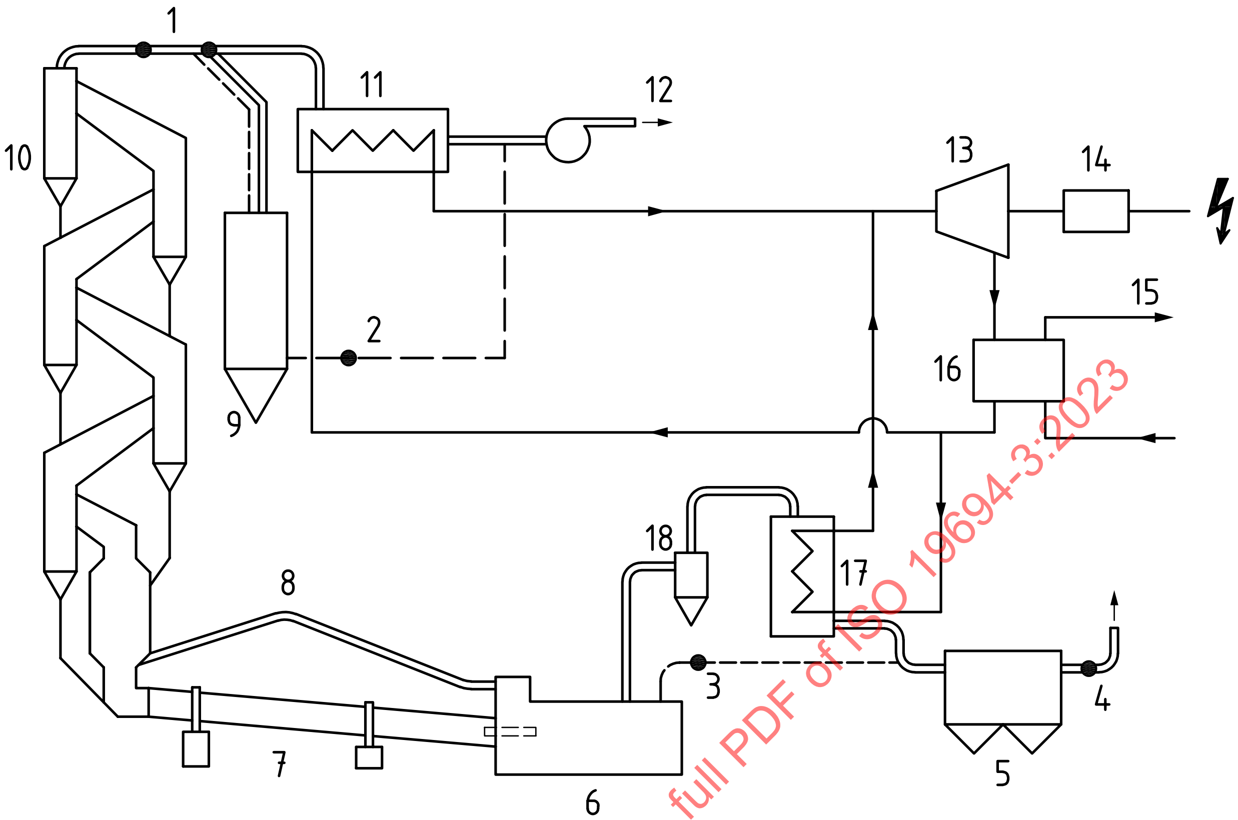
The balance sheet approach described in 5.5.2 ensures completeness, rigor and transparency of reporting. Direct GHG emissions resulting from the combustion of fossil AF shall always be included in the organization's gross emissions, in accordance with 7.6.

With the following concept this document provides a framework for reporting also indirect GHG emission reductions achieved by using alternative fuels. Indirect GHG emission reductions at landfills and incineration plants are accounted by subtracting from the gross emissions the fossil GHG emissions of alternative fuels.

See 10.2 for the reporting requirements with respect to net emissions.

5.5.3 Other indirect GHG emission reductions — Utilization of waste heat

Some cement plants export waste heat to external consumers as a substitute for conventional energy sources. In analogy to the indirect effects related to the use of alternative fuels, a cement organization can account for the indirect GHG emission reductions resulting from such waste heat exports.



Key

1	raw gas from preheater	10	preheater tower
2	bypass of preheater boiler	11	preheater boiler
3	bypass of cooler boiler	12	to raw grinding
4	cooler exhaust air	13	turbine
5	cooler vent filter	14	generator
6	clinker cooler	15	cooking tower
7	rotary kiln	16	condenser
8	tertiary air duct	17	cooler boiler
9	conditioning tower	18	de-duster

Figure 3 — Schematic of application of waste heat recovery and electrical power generation in cement manufacture

Similar advantages can be applied for other forms of waste heat utilization[7]. Thus, this document offers the possibility of reporting voluntarily waste heat utilization within the plant (e.g. for raw material or slag drying or power generation) in order to allow a fair comparison between plants exporting heat and plants using the heat internally. This requires additional calculation taking into account waste energy utilized only for clinker or cement production and the total energy flow in GJ/a can be reported. The reporting is voluntary.

Further, in the case of electrical power generation from waste heat originating from the kiln system (see Figure 3), any additional fuel used in the kiln system is accounted as kiln fuel and consequently emissions are accounted as direct GHG emissions of the kiln system. In order to provide more detailed information, this document distinguishes between waste heat recovery and separate on-site power generation. In any case, when applying in their voluntary reporting, companies should consider whether their actions indeed contribute to a global reduction in GHG emissions, or merely to a shift of emissions between different entities.

6 GHG inventory boundaries

6.1 General

Drawing appropriate boundaries is one of the key tasks in an emissions inventory process.

6.2 Reporting boundaries

Reporting boundaries refer to the types of sources covered by an inventory. A key distinction is between direct and indirect GHG emissions:

a) Direct GHG emissions [ISO 14064-1:2018, 5.2.4 a)] are emissions from sources that are owned or controlled by the reporting organization. For example, emissions from fuel combustion in a cement kiln are direct emissions of the organization owning (or controlling) the kiln. This includes the direct emissions from additional fuel use such as for raw material or fuel drying or for on-site power generation.

b) Indirect GHG emissions [ISO 14064-1:2018, 5.2.4 c) to f)] are emissions that result as a consequence of the activities of the reporting company but occur at sources owned or controlled by another organization. Relevant for this document are energy indirect emissions [ISO 14064-1:2018, 5.2.4 b)] and GHG emissions from imported clinker [ISO 14064-1:2018, 5.2.4 d)].

Clause 7 provides detailed guidance on the different sources of direct emissions occurring in cement plants. Indirect GHG emissions are addressed in Clause 8.

Companies shall use the reporting boundaries outlined in Table 7 for the determination of GHG emissions at the cement plant. Any deviation from these boundaries shall be reported and explained.

Table 7 — Reporting boundaries

Process step	ISO 14064-1:2018, 5.2.4, GHG emissions category	Inclusion in this document
Quarrying of raw materials	a d	yes: for quarries owned, controlled or managed by the organization no: for quarries not owned by the organization
Raw materials transport	a c	yes: for lorries owned by the organization no: for lorries not owned by the organization
Raw materials drying	a	yes
Raw materials grinding	a	yes
Fuel preparation in plant	a	yes
Fuel preparation outside plant	a d	yes: for installations owned by the organization no: for installations not owned by the organization
Fuels for kiln	a	yes
Non-kiln fuels (raw materials, fuel)	a	yes
Mobile transport of fuels	a c	yes: for lorries owned by the organization no: for lorries not owned by the organization
CKD = bypass and/ or filter dust	a	yes
Calcination	a	yes
Imported clinker	d	yes, needs inclusion for cement process KPIs
Imported cement	d	yes, needs inclusion for cement process KPIs
Imported pre-processed MIC	d	yes, needs inclusion for cement process KPIs
Drying of cement constituents	a	yes
Cement grinding	b	yes

Table 7 *(continued)*

Process step	ISO 14064-1:2018, 5.2.4, GHG emissions category	Inclusion in this document
Packaging and dispatch	b	yes
Mobile transport for dispatch	a c	yes: for lorries owned by the organization no: for lorries not owned by the organization
Electricity consumption for whole production process	b	yes
On-site power production	a	yes
Waste heat recovery	a	yes
Room heating and cooling	a	no
Mobile transport in plant	a c	1 - yes: for mobile equipment owned by the organization 3 - no: for mobile equipment not owned by the organization
Stock changes	a, b, c and d	Yes, for calculation / KPIs

6.3 Organizational boundaries

6.3.1 General

Organizational boundaries define which parts of an organization – for example, wholly owned operations, joint ventures and subsidiaries – are covered by an inventory, and how the emissions of these entities are consolidated. This document provides guidance on organizational boundaries.

6.3.2 Installations that are covered

GHG emissions result not only from kiln operations, but also from upstream and downstream processes, particularly from quarry operations and (indirectly) cement grinding. These facilities can be located a considerable distance from each other. In addition, quarries, kilns and grinding stations are sometimes operated by separate legal entities. How should this be accounted for in a legal entity's inventory?

Reporting under this document shall cover the main direct and indirect GHG emissions associated with cement production as required in Clauses 7, 8 and 10. These emissions include also those related to consumption of fuel and electricity in upstream and downstream operations. In particular, cement companies shall include the following types of activities in their reporting to the extent that they control or own the respective installations in accordance with 6.3.3 below:

a) clinker production, including raw material quarrying and preparation;

b) preparation or processing of fuels or alternative raw materials (such as fly ash or blast furnace slag) in own installations;

c) grinding of clinker, additives and concrete additions such as slag, both in integrated cement plants and stand-alone grinding stations;

d) additional fuel use for own power generation.

Separate inventories can be established for individual facilities as appropriate, for instance if they are geographically separated or run by distinct operators. The impacts of such a division will cancel out when emissions are consolidated at organization or group level (see also 6.3.4 regarding organization-internal clinker transfers).

6.3.3 Operational control and ownership criteria

Three methods have been identified for consolidation of GHG emissions of the cement industry for companies with more than one plant.

- Under the equity share approach, an organization consolidates its GHG emissions according to the (pro rata) equity share it holds in each operation, i.e. according to ownership. As an exception, no emissions are consolidated for so-called fixed asset investments where an organization owns only a small part of the total shares of an operation and exerts neither significant influence nor financial control. Other possible exceptions relate to the economic substance of a relationship (see revised WRI/WBCSD Protocol[9] for details).
- Financial control is defined as the ability of an organization to direct the financial and operating policies of an operation with a view to gaining economic benefits from its activities. For example, the financial control usually exists if the organization has the right to the majority benefits of the operation, or if it retains the majority risks and rewards of ownership of the operation's assets. Under this approach, companies consolidate 100 % of the emissions of those operations over which they have financial control. As an exception, consolidation according to equity share is required for joint ventures where partners have joint financial control.
- Operational control is defined as an organization's full authority to introduce and implement its operating policies at an operation. This criterion is usually fulfilled if an organization is the operator of a facility, i.e. if it holds the operating license. Under this approach, companies consolidate 100 % of the emissions of those operations over which they have operational control. As an exception, consolidation according to equity share is required for joint ventures where partners have joint operational control.

Companies should explicitly state in the report, which methodology they apply; see Figure 4.

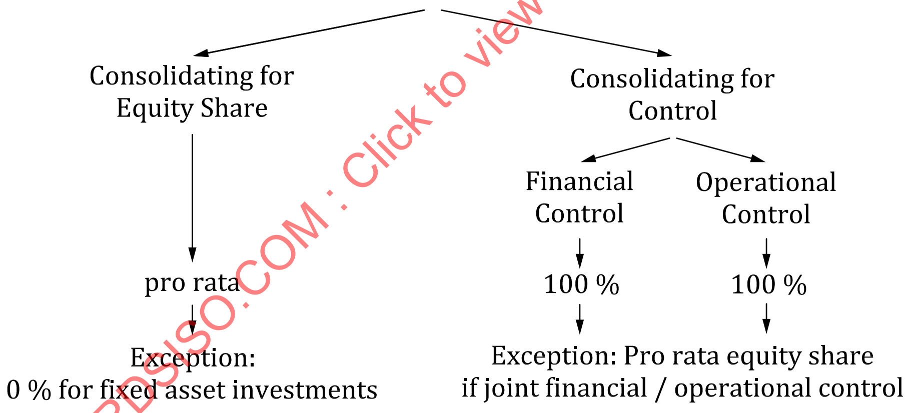


Figure 4 — Options for consolidating emissions

Looking at the characteristics of the cement industry, cement companies shall consolidate primarily according to the operational control criterion, and secondly according to the ownership criterion in case operational control is not clearly assigned to a single legal entity.

6.3.4 Internal clinker, cement and MIC transfers

Many cement companies transfer large volumes of clinker, cement and MICs such as slag or fly ash internally, between different plants and grinding stations. These transferred materials are processed further to other products such as low clinker cements and thus have an impact on the clinker/cement factor of the receiving plant. In these cases, the risk of double counting occurs. Companies shall ensure their method of calculation and reporting follows the below methods for plant and organizational level.

On the plant level, internal clinker transfer has to be reported (transfer within the same organization, plus for received and minus for sent clinker). Clinker transferred internally as ingredient of cement has to be reported only if the plant is receiving cement from another plant within the same organization and processes it further to another cement type, which is then reported in that plant. The clinker quantity should be calculated based, for example, on the clinker/cement ratio of the transferred cement. Clinker as ingredient of cement purchased from other companies (external clinker transfer), which is used for blending, should be reported as “purchased clinker”. The total clinker consumed is given in Table 8.

Table 8 — Calculation of total clinker consumed

Calculation result	Calculation contribution	Description
$cli_{\text{cons,total}}$		Total clinker consumed
	$+\ cli_{\text{prod}}$	Clinker production
	$+\ cli_{\text{purch}}$	Clinker purchased
	$-\ cli_{\text{sold}}$	Clinker sold
	$+\ cli_{\text{stock,st}}$	Start of clinker stock
	$-\ cli_{\text{stock,e}}$	End of clinker stock
	$+\ cli_{\text{import,int}}$	Internal clinker import
	$-\ cli_{\text{export,int}}$	Internal clinker export
	$+\ cli_{\text{import},cem}$	Clinker from cement import
$cli_{\text{import},cem} =$		Clinker from cement import
	cem_{import}	Cement import (t)
	$\times\ R_{cli,cem}$	Clinker/cement ratio (%)

On an organization level, internal clinker transfers are added up for checking purposes. It should be zero on an organization level. The clinker from internal cement transfers is reported as a sum of all plants. The total clinker consumed is given in Table 9.

Table 9 — Calculation of total clinker consumed on an organization level

Calculation result	Calculation contribution	Description
$cli_{\text{cons,total,OL}} =$		Total clinker consumed on an organization level
	$+\sum_n cli_{\text{prod},n}$	Clinker production plant A ... plant *n*
	$+\sum_n cli_{\text{purch},n}$	Clinker purchased plant A ... plant *n*
	$-\sum_n cli_{\text{sold},n}$	Clinker sold plant A ... plant *n*
	$+\sum_n cli_{\text{stock,st},n}$	Start of clinker stock plant A ... plant *n*
	$-\sum_n cli_{\text{stock,e},n}$	End of clinker stock plant A ... plant *n*
	$+\sum_n cli_{\text{import,int},n}$	Internal clinker import plant A ... plant *n*
	$-\sum_n cli_{\text{export,int},n}$	Internal clinker export plant A ... plant *n*
	$+\sum_n cli_{\text{import},cem,n}$	Clinker from cement import plant A ... plant *n*
	$-\sum_n cli_{\text{trans},cem,n}$	Clinker from internal cement transfer plant A ... plant *n*
$cli_{\text{cons,total,OL}} =$		Total clinker consumed on an organization level
	$+\sum_n cli_{\text{cons},n}$	Clinker consumed plant A ... plant *n*
	$-\sum_n cli_{\text{trans},cem,n}$	Clinker from internal cement transfer plant A ... plant *n*

Generally, the system for internally clinker transfers can also be applied to internal transferred MIC. The amount of exported MIC should always be shown as a positive value, meaning that the plant is selling/exporting. For the reporting it is not relevant whether sold/exported MICs are used in cement or concrete. However, the amount of consumed pre-processed MIC should not be regarded in the amount of cement constituents-based products in case it is received from another plant (regardless of belonging to the same or another organization).

On an organization level, total MIC transfers are summarized as a sum of all plants.

In conclusion, this document accounts for internal clinker, cement and mineral component transfers. Accounting for internal transfers is required for the analysis of GHG performance indicators at plant level.

7 Direct GHG emissions and their determination

7.1 General

Direct GHG emissions are emissions from sources of the respective plant. In cement plants, direct GHG emissions can result from the following sources:

a) calcination of carbonates, and combustion of organic carbon contained in raw materials;

b) combustion of kiln fuels related to clinker production:

  1) combustion of conventional fossil kiln fuels;

  2) combustion of alternative fossil kiln fuels and mixed fuels with biogenic carbon content;

  3) combustion of biomass and bioliquids (including biomass wastes);

c) combustion of non-kiln fuels:

  1) combustion of conventional fossil fuels;

  2) combustion of alternative fossil fuels and mixed fuels with biogenic carbon content;

  3) combustion of biomass and bioliquids (including biomass wastes);

d) combustion of fuels for on-site power generation;

e) combustion of the carbon contained in wastewater.

Table 10 — CO_2 from raw materials: Methods based in raw material input A1 and A2

Emission components	Parameters	Units	Recommended source of parameters
CO_2 from raw materials: Methods based on raw material input A1 and A2			
Calcination of raw material consumed for clinker production	Raw meal consumed	t	Calculated or measured at plant level
	Kiln feed	t	Calculated or measured at plant level
	CO_2 released from total carbon in raw meal or LOI	mass fraction	Determined at plant level
Dust return correction		mass fraction	Calculated or measured at plant level
Calcination of dust	Dust leaving kiln system excluding bypass dust	t	Measured at plant level
	CO_2 released from total carbon in dust or LOI	mass fraction	Measured at plant level
For detailed input method A2			
Partial calcination of bypass dust	Bypass dust leaving the kiln system	t	Measured at plant level
	CO_2 released from total carbon in bypass dust	mass fraction	Measured at plant level

Table 10 *(continued)*

Emission components	Parameters	Units	Recommended source of parameters
Additional raw materials not included in kiln feed	Additional raw materials	t	Measured at plant level
	CO_2 released from total carbon in additional raw materials	mass fraction	Measured at plant level

Table 11 — Parameters and proposed data sources for the calculation of direct CO_2 emissions and default CO_2 emission factors of fuels

Emission components	Parameters	Units	Recommended source of parameters
CO_2 from raw materials: Methods based on clinker output B1 and B2			
Calcination of raw material consumed for clinker production	Clinker produced	t	Measured at plant level
	Emission factor of clinker	kg CO_2/ t cli	Default equals to 525; or as calculated in detailed output method B2
Calcination of dust	Dust leaving kiln system	t	Measured at plant level
	Emission factor of clinker	kg CO_2/ t cli	Default equals to 525; or as calculated in detailed output method B2
	Calcination degree of dust	calcined fraction	Measured at plant level
Organic carbon in raw materials	Clinker produced	t cli	Measured at plant level
	Raw meal: clinker ratio	t / t cli	Default equals to 1,55; can be adjusted to local situation
	TOC content of raw meal	mass fraction	Default equals to 0,2 %; can be adjusted to local situation
For detailed output method B2			
Calcination of raw material consumed for clinker production	CaO + MgO in clinker	mass fraction	Measured at plant level
Correction of emission factor clinker	CaO + MgO from non-carbonate sources in raw materials	mass fraction	Measured at plant level
	Raw material consumed	t	Measured at plant level
	Ca + Mg silicate sources in raw materials (e.g. as part of clay minerals)	mass fraction	Measured at plant level (e.g. with QXRD with Rietveld refinement)
CO_2 from kiln and non-kiln fuel combustion			
Conventional fossil fuels	Fuel consumption	t	Measured at plant level
	Lower heat value	GJ/ t fuel	Measured at plant level
	Emission factor	t CO_2/ GJ fuel	IPCC/ CSI/ national defaults or measured at plant level
Alternative fossil fuels (fossil AF) and mixed fuels	Fuel consumption	t	Measured at plant level
	Lower heat value	GJ/ t fuel	Measured at plant level
	Emission factor	t CO_2/ GJ fuel	IPCC/ CSI/ national defaults or measured at plant level
	Biogenic carbon content	mass fraction	IPCC/ CSI/ national defaults or measured at plant level
Biomass and bioliquids (biomass AF)	Fuel consumption	t	Measured at plant level
	Lower heat value	GJ/ t fuel	Measured at plant level
	Emission factor	t CO_2/ GJ fuel	IPCC/ CSI/ national defaults or measured at plant level
Wastewater combusted	—	—	Quantification of CO_2 not required

Emission factors, formulae and reporting approaches for these sources are described in the following subclauses of Clause 7.

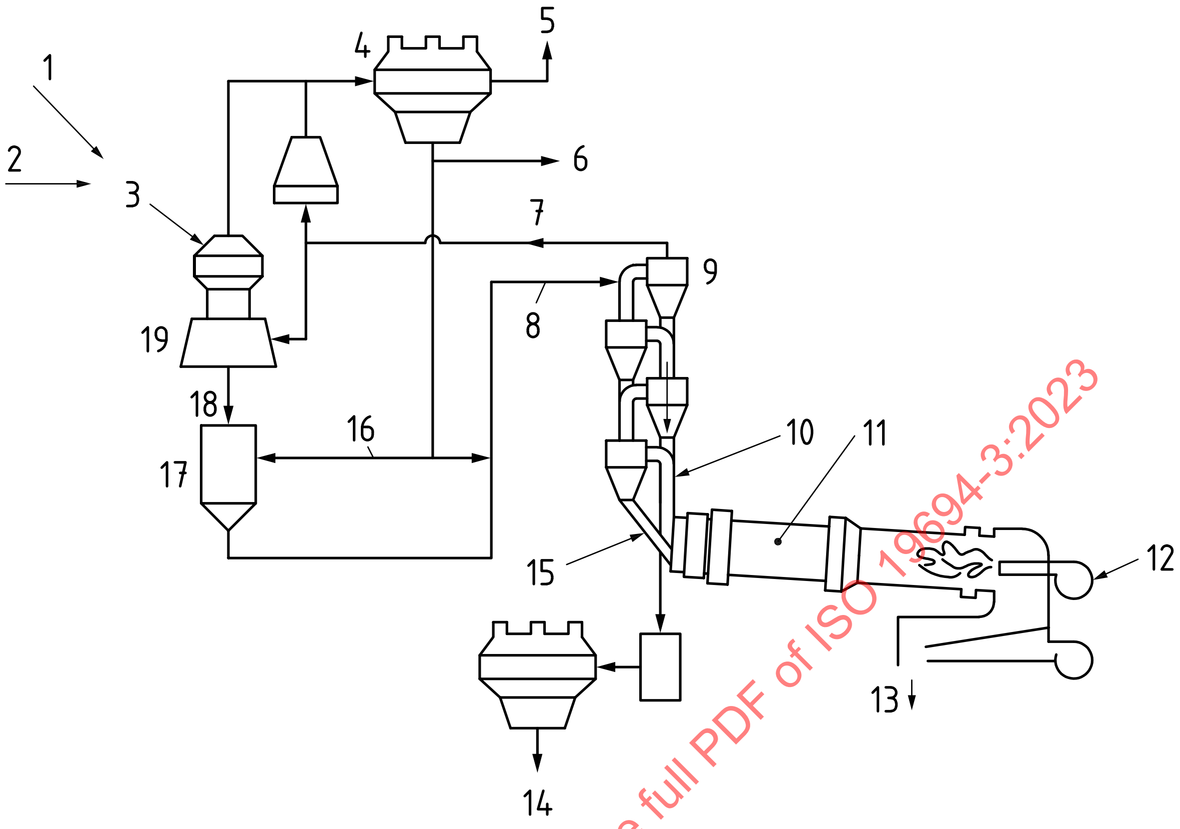
Tables 10 and 11 summarize the parameters involved, and the proposed data sources. Generally, companies are encouraged to measure the required parameters at plant level. Where plant- or organization-specific data are not available, the recommended, international default factors should be used. Other default factors (e.g. national) can be preferred to the international defaults if deemed reliable and more appropriate. The following subclauses provide guidance for choosing between different methods for reporting CO_2 emissions from raw material calcination.

7.2 CO_2 from raw material calcinations

7.2.1 General

Calcination is the release of CO_2 from carbonates during pyro-processing of the raw meal. Calcination CO_2 is directly linked with clinker production. In addition, calcination of FD and BPD can be a relevant source of CO_2 where such dust leaves the kiln system for direct sale, addition to cement or other products or for discarding as a waste.

Figure 5 gives an example of relevant mass flows in the clinker production process as they often occur in plants with a cyclone pre-heater.



Key

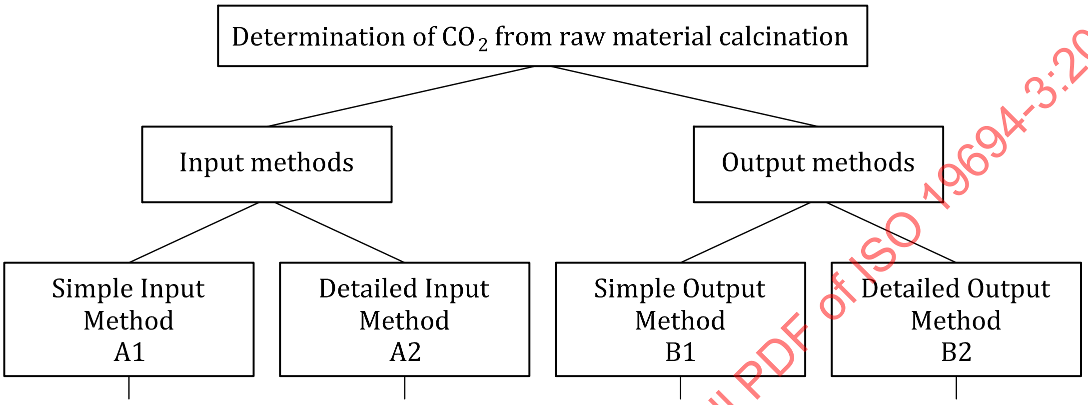
1	limestone CaO_3, $MgCO_3$
2	clay, shale, other CaO, MgO, CaSi
3	raw material
4	dust filter
5	CO_2
6	FD leaving the kiln system
7	dust return
8	KF
9	pre-heater
10	calciner fuel ash
11	kiln
12	fuel ashes
13	cli
14	BPD
15	ADRM
16	recirculated dust
17	silo
18	RM
19	raw mill

Figure 5 — Example of mass flows in the clinker production process in a plant for the production of clinker with cyclone pre-heater and rotary kiln with filter dust, recirculated dust

On the plant level, calcination CO_2 can be calculated in two ways: based on the volume and carbonate content of the raw meal consumed (input method), or based on the volume and composition of clinker produced (output method) plus dust leaving the kiln system. The clinker-based method is often used in Europe. Both input and output based methods are included in the 2006 IPCC Guidelines[4] for National Greenhouse Gas Inventories (output Tier 1 and 2, input Tier 3; see IPCC 2006, Vol. III, 2.2.1.1[4]). Input and output methods are equivalent. This document includes both types of methods. Companies can choose to apply the raw meal-based input method or the clinker-based output method. The choice should be made according to the availability of adequate data and measurements of the mass flows. Furthermore, this document allows for each type applying a simple and a detailed method. The choice between the simple and the detailed method depends on both the intended use of reporting and the availability of data. The detailed reporting methods shall be preferred, if the data required for the more detailed methods can be made available with sufficient accuracy and within the limits of practicability.

In this document, mass flows and parameters of the raw meal, kiln feed, CKD (filter and bypass dust) and clinker refer to a dry state (<1 % of humidity). Normally, the residual moisture of these materials is negligible when measurements are performed in the state as the material or fuel is fed to the process.

The CO_2 emissions from the calcination of relatively small amounts of carbonates in fuel ashes added to the kiln system shall be completely accounted for the reporting of fuel CO_2 emissions. Normally, this is ensured by determining the CO_2 emission factors for fuels based on the TC content of the fuels, which includes both TOC and TIC. Materials with high contents of both TOC and TIC (e.g. municipal sewage sludge) can be regarded as fuel and/or raw material. In any case, the complete CO_2 emissions resulting from their use shall be accounted. Figure 6 summarizes the proposed methodology and the methods for determining the main sources of CO_2 from raw material calcination.



Principle parameter and analysis method	raw meal consumed LOI (weight loss on ignition)	raw meal consumed CO_2 released from TC (e.g. by IR-analysis of gases)	clinker produced default value	clinker produced CaO, MgO analysis (e.g. by XRF)
CO_2 from organic carbon (TOC)	partially included separate analysis for raw materials with high TOC content	included as part of CO_2 released from TC, no separate accounting required	default value	TOC analysis (if relevant) or default value
CO_2 from bypass dust	included complete calcination assumed, no analysis	residual CO_2 released from TC	default value of clinker complete calcination assumed	CaO, MgO analysis or default value of clinker
CO_2 from filter dust	LOI	CO_2 released from TC	default value or analysis	analysis or default value
Additional raw materials fed to calciner or kiln inlet	not covered	CO_2 released from TC accounted separately	included no separate accounting required	Included no separate accounting required

Figure 6 — Overview of methods for the determination of CO_2 emissions from raw material calcination

7.2.2 Input methods A1 and A2

7.2.2.1 General

The input methods are based on determining the amount of raw meal consumed for clinker production from the kiln feed considering a correction for dust return. Both methods (simple input method A1 and detailed input method A2) account for:

- CO_2 emissions from raw material calcination for clinker production;
- CO_2 emissions from calcination of cement kiln dust (CKD equals to filter and/or bypass dust) leaving the kiln system;
- CO_2 emissions from the TOC of raw materials.

7.2.2.2 Raw meal consumed

The amount of raw meal consumed for the production of clinker in the kiln including calcined bypass dust leaving the kiln system is determined from the amount of kiln feed calculated or measured at plant level. The kiln feed weighing is the principal measurement, which determines the final accuracy of reporting according to the input method to the largest extent.

The amount of kiln feed is corrected by subtracting the amount of dust that is returned, for example, from the pre-heater, and which is either recirculated to the kiln feed or to the raw meal silo or discarded as filter dust leaving the kiln system. The concept of the mass flows is illustrated in Figure 6. The correction of the kiln feed by the rate of dust return prevents double counting of recirculated dust. The input methods thus calculate the amount of raw meal that is consumed for the production of clinker and bypass dust leaving the kiln system, where relevant.

The fraction of dust return with reference to the kiln feed shall be determined at plant level. For that purpose, different methods may be applied. Two common methods are either direct measuring (weighing) the amount of dust return or determining the fraction of dust return from a kiln mass balance. In such a balance, the mass inputs from the kiln feed and fuel ashes, and the clinker output, the loss on ignition of the raw meal and dust leaving the kiln system (e.g. as bypass dust) are balanced to yield the mass of dust returned to the dust cycle in a certain period.

In any case, the methods applied for determining the fraction of dust return shall provide sufficient accuracy. When measurements from certain periods of kiln operation are used, these shall be representative of the kiln operation during the period, for which the emission report is prepared. Normally, this requires repeated measurements in order to account for potential changes in the fraction of dust return over time and/or changes with different modes of kiln operation.

The amount of CO_2 emissions from the calcination of the raw meal consumed is calculated by multiplication with the weight fraction of the CO_2 released from TC of uncalcined RM in the detailed input method A2 or in the simple input method A1 its LOI. The corresponding parameter of the raw meal shall be measured regularly at the plant level.

Instead of the raw meal parameter, the respective parameter analysed in samples of the kiln feed may be used when the difference remains insignificant and a regular analysis of the raw meal cannot be achieved. The difference remains small when the dust returned from the pre-heater system shows a very low degree of calcination (as often observed for kiln systems with dry process and cyclone pre-heaters) or if only very small amounts of dust are recycled from the pre-heater to the kiln feed.

— For this parameter substitution in the simple input method A1, the difference of the kiln feed to the raw meal parameter shall not exceed 1 % and the degree of calcination, *d*, in the dust returned from the pre-heater shall not exceed 5 %.

— For the parameter substitution in the detailed input method A2, the difference between both parameters shall be analysed and it shall be demonstrated that the CO_2 emission reporting is complete and no systematic difference exists between the use of parameters determined from raw meal or kiln feed samples, with regard to the limits of accuracy and practicality.

In addition to inorganic carbonates, the raw materials used for clinker production normally contain a small fraction of organic carbon, which is converted to CO_2 during pyro-processing of the raw meal. CO_2 emissions originating from the TOC content shall be included in the parameters used for reporting of CO_2 emissions by the input methods.

— For the detailed input method A2, the measurement of the CO_2 from total carbon should determine the complete CO_2 emissions from the raw meal and any additional raw materials. This means it should encompass CO_2 released from the inorganic carbon content (TIC) and the TOC of the corresponding materials. Such measurements can be performed, for example, by TC analysis or by CO_2 IR-analysis of the gases released from the heated and fully oxidized sample.

— In the simple input method A1, the weight fraction of the LOI accounts for all CO_2 from the calcination of carbonates. CO_2 emissions from the TOC are normally relatively small. They are also accounted by the LOI, but only partially. On the other hand, the mass difference between TOC and the

CO_2 emissions from TOC is often more than fully compensated by small amounts of residual humidity in raw meal samples, which is released as water vapour (H_2O) during heating. This weight loss is also accounted by the LOI. Thus, emission reporting based on the LOI in the simple input method in most cases provides a relatively accurate estimate of the total CO_2 emissions from the calcination and pyro-processing of the raw meal consumed. If raw materials with high organic carbon contents are used, then – instead of the LOI measurements – the CO_2 content including CO_2 emissions from the TOC content shall be used as in the detailed input method A2. This can be necessary, for example, if a plant consumes substantial volumes of shale or fly ash high in TOC content as raw materials entering the kiln. In certain cases, it can make sense to treat the TOC of such materials separately as a “virtual” fuel component. This means that the material will be distinguished (by calculation) in a raw material component (covering the mineral part/carbonates) and a “fuel part” (based on the TOC content).

7.2.2.3 Filter dust leaving the kiln system

Filter dust leaving the kiln system refers to all dust that is not recycled to become part of the kiln feed again. For example, it can be sold directly, added to cement or other products, or discarded as a waste. The definition of filter dust leaving the kiln system excludes bypass dust, which is treated separately in the detailed input method A2 [see Formulae (1) and (2)]. The amount of filter dust leaving the kiln system is subtracted as part of the dust return from the measured kiln feed according to the concept of determining the raw meal consumed. Consequently, emissions from the calcination of filter dust leaving the kiln system shall be considered separately. In the dry process, filter dust is often uncalcined. However, partially calcined filter dust is often extracted in plants with semi-dry, semi-wet and wet processes. The CO_2 emissions from its calcination need to be accounted. The CO_2 emissions from calcination of raw meal that will form bypass dust are already accounted as calcination CO_2 originating from the raw meal consumed.

CO_2 from filter dust leaving the kiln system shall be calculated based on the relevant volumes of dust and either the carbonate CO_2 content or the LOI of filter dust measured at plant level. From the carbonate CO_2 content or LOI of filter dust and uncalcined RM the CO_2 emission factor EF_{FD} is calculated according to the following Formulae (1) and (2):

$$EF_{\mathrm{FD}} = \frac{f\mathrm{CO}_{2,\mathrm{RM}} \times d}{1 - f\mathrm{CO}_{2,\mathrm{RM}} \times d} \tag{1}$$

$$d = 1 - \frac{f\,\mathrm{CO}_{2,\mathrm{FD}} \times \left(1 - f\mathrm{CO}_{2,\mathrm{RM}}\right)}{\left(1 - f\mathrm{CO}_{2,\mathrm{FD}}\right) \times f\mathrm{CO}_{2,\mathrm{RM}}} \tag{2}$$

where

EF_{FD} is the emission factor of partially calcined filter dust (t CO_2/t FD);

$f\mathrm{CO}_{2,\mathrm{RM}}$ is the weight fraction of carbonate CO_2 in the raw meal (t CO_2 /t RM);

d is the FD calcination rate (released CO_2 expressed as a fraction of the total carbonate CO_2 in the raw meal);

$f\mathrm{CO}_{2,\mathrm{FD}}$ is the weight fraction of carbonate CO_2 in the FD (t CO_2 /t FD).

The variables $f\mathrm{CO}_{2\ \mathrm{RM}}$ and $f\mathrm{CO}_{2\ \mathrm{FD}}$ are replaced by LOI_{RM} and LOI_{FD} respectively in the simple input method A1, i.e. the weight fractions of the loss on ignition. The calcination rate d of the FD shall preferably be based on plant-specific data. In the absence of such data, a default value of 0 shall be used for dry process kilns because FD is usually not, or only to a negligible degree, calcined in this process. In other processes (half dry, half wet or wet) calcination rates can be significant. In the absence of data, a default value of 1 shall be used for these kiln types. This value is conservative, i.e. in most cases it will lead to an overstatement of FD-related emissions. Formula (1) for the input method is based on raw meal analysis, while EF_{FD} according to the output method is based upon the CO_2 emission factor of clinker [see Formula (11)]. Both calculation methods should lead to the same result.

In the absence of plant-specific data on dust volumes, the IPCC default for CO_2 from discarded dust (2 % of clinker CO_2) shall be used. It should be noted, however, that this default is clearly too low in cases where relevant quantities of dust leave the kiln system. Therefore, using plant- or organization- specific data are clearly preferable.

7.2.2.4 Partial calcination of bypass dust (detailed input method A2)

Normally, BPD extracted from the kiln system is fully calcined. This assumption is made in the simple input method A1. However, in certain types of installations, bypass dust is only partially calcined. Depending on the amount of BPD extraction and its degree of calcination, this can be relevant for the accuracy of reporting emissions from raw material calcination. In such cases, the detailed input method A2 should be preferred and the amount of BPD leaving the kiln system and the carbonate CO_2 content of the BPD shall be measured at the plant level. The amount of residual CO_2 in the mass flow of BPD leaving the kiln system [see Formula (3)], shall then be subtracted from the amount of CO_2 from the calcination of raw meal consumed. This is a correction for the uncalcined fraction of BPD [see Formula (4)].

$$CO_{2,BPD\ \text{not emitted}} = BPD \times CO_{2,BPD,\text{residual}} \tag{3}$$

$$CO_{2,RM} = CO_{2,RM\text{consumed}} - CO_{2,BPD\ \text{not emitted}} \tag{4}$$

where

$CO_{2,BPD\ \text{not emitted}}$	is the amount of CO_2 that is remaining in BPD and is therefore not emitted (t CO_2);
BPD	is the amount of BPD leaving the kiln system (t);
$CO_{2,BPD,\text{residual}}$	is the analysed content of residual CO_2 in BPD (t CO_2/t BPD);
$CO_{2,RM}$	is the CO_2 effectively emitted from raw materials (t CO_2);
$CO_{2,RM\text{consumed}}$	is the amount of CO_2 potentially emitted from the consumed raw meal (t CO_2), with $CO_{2,RM\text{consumed}} = RM_{\text{consumed}} \times CO_{2,RM}$ where RM_{consumed} is the amount of consumed raw meal (t); $CO_{2,RM}$ is the analysed CO_2 released from total carbon in raw meal (t CO_2 /t RM).

7.2.2.5 Additional raw materials not included in kiln feed

Options for considering additional raw materials are provided in the detailed input method A2. In case of raw material, additions which are not included in the kiln feed, for example, directly to the rotary kiln inlet, the simple input method cannot be used. For each type of material, its quantity and CO_2 content including CO_2 emissions from the TOC shall be measured at plant level. Only if the same material is additionally reported as fuel with an emission factor based on a relatively high TOC content, then the reporting of CO_2 emissions as additional raw material shall be restricted to its TIC content, see 7.2.1.

The formula for the simple input method A1 is given in Formula (5):

$$CO_{2,RM} = KF \times (1 - DRC) \times LOI_{RM} + FD_{\text{leaving kiln system}} \times EF_{FD} \tag{5}$$

where

$CO_{2,RM}$	is the total CO_2 from raw material (t CO_2/yr);
KF	is the amount of kiln feed measured at plant level (t/yr);

DRC	is the fraction of returned dust with reference to the kiln feed (–);
LOI_{RM}	is the weight fraction of the loss on ignition of raw meal (–);
$FD_{\text{leaving kiln system}}$	is the amount of filter dust leaving the kiln system (t/yr);
EF_{FD}	is the CO_2 emission factor of partially calcined filter dust (t CO_2/t FD); BPD leaving kiln system is the amount of bypass dust leaving the kiln system (t/yr).

The formula for the detailed input method A2 is given in Formula (6):

$$CO_{2,RM} = KF \times (1 - DRC) \times fCO_{2,RM,TC} + FD_{\text{leaving kiln system}} \times EF_{FD} - BPD_{\text{leaving kiln system}} \times fCO_{2,BPD,TC} + \Sigma_i \left(ADRM_i \times fCO_{2,ADRM,TC,i} \right) \tag{6}$$

where

$CO_{2,RM}$	is the total CO_2 from raw material (t CO_2/yr);
KF	is the amount of kiln feed measured at plant level (t/yr);
DRC	is the fraction of returned dust with reference to the kiln feed (–);
LOI_{RM}	is the weight fraction of the loss on ignition of raw meal (–);
$fCO_{2\ RM,TC}$	is the weight fraction of CO_2 content in the raw meal here including CO_2 emissions from TOC (t CO_2 /t RM);
$FD_{\text{leaving kiln system}}$	is the amount of filter dust leaving the kiln system (t/yr);
EF_{FD}	is the CO_2 emission factor of partially calcined filter dust (t CO_2/t FD); BPD leaving kiln system is the amount of bypass dust leaving the kiln system (t/yr);
$fCO_{2,BPD,TC}$	is the weight fraction of CO_2 released from TC in the bypass dust (t CO_2 /t BPD);
$ADRM_i$	is the amount of additional raw material i (t/yr), which is not part of the kiln feed;
$fCO_{2,ADRM,TC,i}$	is the weight fraction of CO_2 released from TC in the additional raw material i (t CO_2 /t ADRM).

In special cases an adjustment of the concept of the input methods can be necessary, in order to reflect certain material flows in a plant and to ensure their correct accounting. The adjustments shall be explained and accompanied by an overview of all relevant material flows. Furthermore, it shall be demonstrated, that CO_2 emissions from the complete and partial calcination of raw materials and from the organic carbon content of raw materials are completely and more accurately accounted by the adjusted method.

7.2.3 Output methods B1 and B2

7.2.3.1 General

To apply the clinker-based output methods, companies shall use their plant-specific data, as given in 7.2.3.2, 7.2.3.3 and 7.2.3.4.

7.2.3.2 Clinker

Calcination CO_2 shall be calculated based on the volume of clinker produced and an emission factor per tonne of clinker.

The volume of clinker produced can be determined either from

— a mass balance for clinker (backwards calculated from cement dispatch) as given in Formula (7)

$$cli_{\mathrm{prod}} = cem_{\mathrm{disp}} - cem_{\mathrm{stock,st}} + cem_{\mathrm{stock,e}} - cem_{\mathrm{const,ex,cli}} + cli_{\mathrm{disp}} - cli_{\mathrm{supp}} + cli_{\mathrm{stock,e}} - cli_{\mathrm{stock,st}} - cem_{\mathrm{supp}} \quad (7)$$

where

cli_{prod}	is the clinker production (t);
cem_{disp}	is the cement dispatch (t);
$cem_{\mathrm{stock,st}}$	is the cement stock at beginning (t);
$cem_{\mathrm{stock,e}}$	is the cement stock at the end (t);
$cem_{\mathrm{const,ex,cli}}$	is the consumed cement constituents other than clinker (t);
cli_{disp}	is the clinker dispatch (t);
cli_{supp}	is the clinker supplied (t);
$cli_{\mathrm{stock,st}}$	is the clinker stock at beginning (t);
$cli_{\mathrm{stock,e}}$	is the clinker stock at the end (t);
cem_{supp}	is the cement supplied (t); or

— direct weighing after kiln.

The emission factor shall be determined based on the measured CaO and MgO contents of the clinker, and corrected if relevant quantities of CaO and MgO in the clinker stem from non-carbonate sources. This can be the case, for example, if calcium silicates or fly ashes are used as raw materials entering the kiln.

The determination of the emission factor for clinker shall be clearly documented. The detailed method refers to the CaO and MgO analysis of the clinker and a correction for non-carbonate sources of these oxides.

In the absence of better data, a default of 0,525 t CO_2/t clinker shall be used (simple output method B1). This value is comparable to the IPCC default (0,510 t CO_2/t) corrected for typical MgO contents in clinker. See 7.3 for details on the default emission factor [see Formula (8)].

$$EF_{cli} = fCaO_{cli} \times 0{,}785 + fMgO_{cli} \times 1{,}092 \quad (8)$$

where

EF_{cli}	is the CO_2 emission factor of clinker (t CO_2/t clinker);
$fCaO_{cli}$	is the CaO content of clinker (%);
$fMgO_{cli}$	is the MgO content of clinker (%).

Significant contents of non-carbonate CaO and MgO (e.g. from precalcined raw materials) can be subtracted.

7.2.3.3 Dust

CO_2 from bypass dust or filter dust leaving the kiln system shall be calculated based on the relevant volumes of dust and an emission factor. The calculation shall account for the complete volumes of dust leaving the kiln system, irrespective of whether the dust is sold directly, added to cement, or discarded as a waste.

Bypass dust is usually fully calcined. Therefore, emissions related to bypass dust shall be calculated using the emission factor for clinker (simple output method B1) as given in Formula (9):

$$CO_{2\ BPD} = BPD \times EF_{cli} \tag{9}$$

where

$CO_{2,BPD}$	is the amount of CO_2 emitted from BPD (t CO_2);
BPD	is the amount of BPD leaving the kiln system (t BPD);
EF_{cli}	is the plant specific emission factor of clinker (t CO_2/t clinker).

If more information is available, the emission factor of BPD can be estimated from the calcination rate of BPD according to Formula (11) (suggested for FD emissions).

Alternatively, the CO_2 emission factor of bypass dust (EF_{BPD}) can be determined from CaO, MgO and remaining carbonate CO_2 analysed in BPD samples (detailed output method B2). These parameters are directly related to the mass of BPD. This method gives more precise results, especially in the case of components such as alkaline chlorides and sulphates being enriched in the BPD compared to the composition of clinker or partially calcined raw meal.

$$EF_{BPD} = CO_{2,CaO} + CO_{2,MgO} - fCO_{2,BPD} = \left(CO_{2,CaO} + CO_{2,MgO}\right) \times d \tag{10}$$

where

EF_{BPD}	is the CO_2 emission factor of partially calcined bypass dust (t CO_2/t BPD);
$CO_{2,CaO}$	is the stoichiometric amount of CO_2 related to the content of calcium oxide in bypass dust (t CO_2/t BPD), with $CO_{2\ CaO} = \frac{CaO_{BPD}}{100} \times 0{,}785$;
$CO_{2,MgO}$	is the stoichiometric amount of CO_2 related to the content of magnesium oxide in bypass dust (t CO_2/t BPD), with $CO_{2,MgO} = \frac{MgO_{BPD}}{100} \times 1{,}092$;
$fCO_{2,BPD}$	is the weight fraction of carbonate CO_2 content in the bypass dust (t CO_2/t BPD);
d	is the BPD calcination rate (released CO_2 expressed as a fraction of the total carbonate CO_2 in fully uncalcined bypass dust).

The calculation of the CO_2 emission factor of BPD (EF_{BPD}) according to Formula (10) follows the same method as normally applied for determination of the emission factor of clinker (EF_{cli}). However, by using parameters from bypass dust and its specific mass reference, it considers

a) a reduction of the mass fraction of CaO and MgO in bypass dust (in comparison to calcined raw meal or clinker) due to enrichment of alkaline chlorides and sulphates, and

b) its partial calcination (degree of calcination, d): filter dust, as opposed to bypass dust, is usually not fully calcined.

The emission factor for filter dust shall be determined based on the emission factor for clinker and the calcination rate of the filter dust.

$$EF_{FD} = \frac{\frac{EF_{cli}}{1 + EF_{cli}} \times d}{1 - \frac{EF_{cli}}{1 + EF_{cli}} \times d} \tag{11}$$

where

EF_{FD} is the emission factor of partially calcined filter dust (t CO_2/t FD);

EF_{cli} is the plant specific emission factor of clinker (t CO_2/t clinker);

d is the FD calcination rate (released CO_2 expressed as a fraction of the total carbonate CO_2 in the raw meal), see Formula (2).

See Clause B.2 for the details about deriving the calculation formula, which is Formula (11).

The calcination rate of the FD, d, shall preferably be based on plant-specific data. In the absence of such data, a default value of 0 shall be used for dry process kilns because FD is usually not or only to a negligible degree calcined in this process. In other processes (half dry, half wet or wet), calcination rates can be significant. In the absence of data, a default value of 1 shall be used for these kiln types. This value is conservative, i.e. it will in most cases lead to an overstatement of FD-related emissions. Input method A2 is based on raw meal analysis, while output method B2 is based upon the CO_2 emission factor of clinker. Both mass balance methods should lead to the same result. See 7.3 to 7.6 for details on calculating the calcination rate, d, and Formulae (1) and (2).

In the absence of plant-specific data on dust volumes, the IPCC default for CO_2 from discarded dust (2 % of clinker CO_2, see 7.3) shall be used. It should be noted, however, that this default is clearly too low in cases where relevant quantities of dust leave the kiln system. Therefore, using plant- or organization-specific data are clearly preferable.

7.2.3.4 CO_2 from organic carbon in raw materials

In addition to inorganic carbonates, the raw materials used for clinker production usually contain a small fraction of organic carbon which is mostly converted to CO_2 during pyro-processing of the raw meal. The TOC contents of raw materials can vary substantially between locations, and between the types of materials used.

Data compiled by the CSI indicate that a typical value for TOC in the raw meal is about 0,1 % to 0,3 % (dry weight). This corresponds to CO_2 emissions of about 10 kg/t clinker, representing about 1 % of the typical combined CO_2 emissions from raw material calcination and kiln fuel combustion.

NOTE 1,55 t RM/t cli × 2 kg C/t RM × 3,664 kg CO_2/kg C = 11 kg CO_2 /t cli, under the assumption that all organic carbon is converted to CO_2. The latter is conservative since a part of the organic carbon is usually emitted as VOC or CO. The TOC content of 2 kg/t raw meal was determined based on 43 measurements compiled.

CO_2 emissions from organic carbon in raw materials shall be quantified and reported to ensure completeness of the inventory (see Clause 10 on materiality thresholds). However, since their contribution to overall emissions is small, a simple calculation needs to be implemented which multiplies clinker production with the following default values:

- default raw meal to clinker ratio: 1,55;
- default TOC content of raw meal: 2 kg/t raw meal (dry weight, corresponding to 0,2 %). This default factor for the TOC content has been checked by collecting and analysing more than 100 analyses from different raw materials from cement plants all over the world. Based on the analysis of the data, the value of the default factor of 0,2 % is confirmed.

Companies are not required to analyse these emissions any further unless they have indications that organic carbon is more relevant. This can be the case, for example, if an organization consumes substantial volumes of shale or fly ash high in TOC content as raw materials entering the kiln. Furthermore, please note that any volumes of dust leaving the kiln system are not automatically reflected in this default calculation.

Companies producing substantial quantities of dust should apply their plant-specific raw meal to clinker ratios if they wish to analyse their TOC-related emissions in more detail. Plant-specific raw meal to clinker ratios should exclude the ash content of the fuels used, to avoid double-counting. For example, if fly ash with a high carbon content is accounted for as a fuel (i.e. by assigning it a heating value and CO_2 emission factor), its ash content should not be included in the raw meal to clinker ratio for the purpose of calculating emissions from TOC in raw meal.

The formula for the output methods B1 and B2 is given in Formula (12):

$$CO_{2,RM} = cli_{\mathrm{prod}} \times EF_{cli} + BPD_{\text{leaving kiln system}} \times EF_{BPD} + FD_{\text{leaving kiln system}} \times EF_{\mathrm{FD}} + RM_{\mathrm{cons}} \times fTOC_{RM} \times 3{,}664 \tag{12}$$

where

$CO_{2,RM}$	is the total CO_2 from raw material (t CO_2/yr);
cli_{prod}	is the clinker production measured at plant level (t/yr);
EF_{cli}	is the CO_2 emission factor of clinker (kg CO_2/t clinker); simple output method B1: default value = 0,525 t CO_2/t clinker; detailed output method B2: determination according to 7.3;
$BPD_{\text{leaving kiln system}}$	is the amount of bypass dust leaving the kiln system (t/yr);
EF_{BPD}	is either EF_{cli} estimated from its calcination rate or determined from analysis;
$FD_{\text{leaving kiln system}}$	is the amount of filter dust leaving the kiln system (t/yr);
EF_{FD}	is the CO_2 emission factor of partially calcined filter dust determined according to Formula (11) (t CO_2/t FD);
RM_{cons}	is the amount of raw meal consumed for clinker production and bypass dust (t/yr);
$fTOC_{RM}$	is the weight fraction of TOC in the raw meal (–); default value = 0,002 = 0,2 %;
3,664	is the stoichiometric proportion of CO_2 released per unit of C.

The raw meal consumed is calculated in Formula (13):

$$RM_{\mathrm{cons}} = cli_{\mathrm{prod}} \times R_{RM,cli} \tag{13}$$

where

cli_{prod}	is the clinker production measured at plant level (t/yr);
RM_{cons}	is the amount of raw meal consumed for clinker production and bypass dust (t/yr);
$R_{RM,cli}$	is the raw meal clinker mass ratio (raw meal consumed per clinker production, (-), the addition of fuel ashes and dust leaving the kiln system shall be accounted for its determination; default value equals to 1,55.

7.3 Reporting of CO_2 emissions from raw material calcination based on clinker output: Summary of IPCC[4] and CSI recommendations, and default emission factor for clinker

IPCC[4] recommends calculating calcination CO_2 based on the CaO content of the clinker produced (0,785 t CO_2/t CaO, multiplied with the CaO content in clinker). A default CaO content in clinker of 65 % is recommended, corresponding to 510 kg CO_2/t clinker.

CO_2 from discarded kiln dust, according to IPCC, should be calculated separately, taking into account its degree of calcination. Where more precise data are not available, IPCC recommends accounting for discarded dust by adding 2 % to clinker CO_2 by default, acknowledging that emissions can range much higher in some instances[25]. IPCC does not distinguish between bypass dust and filter dust.

Furthermore, the IPCC default value neglects CO_2 from decomposition of magnesium carbonates (MgO content in clinker is usually about 2 %)[1].

This document recommends determining the emission factors for clinker calcination on a plant-specific basis. To this end, an auxiliary worksheet for the detailed output method B2 has been included in the spreadsheet of the CSI protocol[1], which can account for the specific CaO and MgO content of a plant's clinker as well as non-carbonate sources of CaO and MgO such as calcium silicates, or fly ash added to raw meal. In the absence of plant-specific data, this document recommends using the simple output method B1 with a default emission factor of 525 kg CO_2/t clinker, corresponding to the IPCC default corrected for Mg carbonates.

The CO_2 emission factor for clinker determined from the specific CaO and MgO content does not account for CO_2 emissions resulting from CKD leaving the kiln system and CO_2 emissions, which originate from the TOC of raw materials. Consequently, these CO_2 emissions are accounted additionally to the CO_2 emissions from calcination of raw material for clinker production (for details, see Formula (12) and corresponding descriptions in 7.2.3).

7.4 Determination of the FD calcination rate

The FD calcination rate, *d,* shall be calculated according to Formula (14), based on the weight fractions of carbonate CO_2 in the FD and in the raw meal, respectively. The two input parameters $fCO_{2\ FD}$ and $fCO_{2\ RM}$ shall be measured by chemical analysis. Possible analysis methods include, for example, a loss on ignition test, titration or CO_2 emission analysis by IR detection.

$$d = 1 - \frac{fCO_{2,FD} \times (1 - fCO_{2,RM})}{(1 - fCO_{2,FD}) \times fCO_{2,RM}} \tag{14}$$

where

$fCO_{2,FD}$ is the weight fraction of carbonate CO_2 in the FD (t CO_2 /t FD);

$fCO_{2,RM}$ is the weight fraction of carbonate CO_2 in the raw meal (t CO_2 /t RM).

In the absence of measurement data on the composition of the FD, a default value of 1 shall be used for the calcination rate *d*. This value is conservative, i.e. it will in most cases lead to an overstatement of FD-related emissions, because FD is usually not fully calcined.

Alternatively, the maximum degree of calcination, *d,* is calculated from the analysis of cement kiln dust samples only as quotient of the maximum CO_2 potentially released during the calcination process (determined from CaO and MgO analyses) and the analysed remaining carbonate CO_2 content of the sample as given in Formula (15):

$$d = \frac{CO_{2,CaO} + CO_{2,MgO} - CO_{2,\text{sample}}}{CO_{2,CaO} + CO_{2,MgO}} \tag{15}$$

where

$CO_{2,CaO}$ is the stoichiometric maximum content of carbonate CO_2 calculated from CaO;

$CO_{2,MgO}$ is the stoichiometric maximum content of carbonate CO_2 calculated from MgO;

$CO_{2,\text{sample}}$ is the carbonate CO_2 content of the sample (carbon dioxide according to EN 196-2[11]).

7.5 Direct determination of the CO_2 emission factor of FD from analysis of CO_2 content

For the direct determination of the CO_2 emission factor of FD, the combination of Formulae (1) and (14) yields:

$$EF_{FD} = \frac{fCO_{2,RM} - \dfrac{fCO_{2,FD} \times (1 - fCO_{2,RM})}{(1 - fCO_{2,FD})}}{(1 - fCO_{2,RM}) + \dfrac{fCO_{2,FD} \times (1 - fCO_{2,RM})}{(1 - fCO_{2,FD})}} \tag{16}$$

Formula (16) is simplified after complementation of the left-hand term by multiplication with Formula (17):

$$\frac{\dfrac{(1 - fCO_{2,FD})}{(1 - fCO_{2,RM})}}{\dfrac{(1 - fCO_{2,FD})}{(1 - fCO_{2,RM})}} = 1 \tag{17}$$

As a result, the CO_2 emission factor of FD can equally be determined directly by the following formula:

$$EF_{FD} = fCO_{2,RM} \times \frac{(1 - fCO_{2,FD})}{(1 - fCO_{2,RM})} - fCO_{2,FD} \tag{18}$$

In Formula (18), the terms in round brackets correct the mass reference of the carbonate CO_2 content $fCO_{2\ RM}$ determined in samples of the uncalcined raw meal to the mass reference of FD, which potentially is partially calcined. The CO_2 emission factor of FD, EF_{FD} is determined from the difference of the carbonate CO_2 content between the potentially partially calcined state and the hypothetical uncalcined state of FD.

7.6 Cement specific issues for fuels

7.6.1 Conventional fossil fuels

Conventional fossil fuels are fossil fuels including, for example, coal, petcoke, fuel oil and natural gas. The preferred approach is to calculate CO_2 from conventional fossil fuels (but also alternative and non-kiln fuels, see 7.6.2 and 7.8) based on fuel consumption, lower heating values and the matching CO_2 emission factors.

Fuel consumption and lower heating values (LHV or net calorific value NCV) of fuels are routinely measured at plant level. It is important to note that the applied heating value always has to match the status of the fuel, especially with respect to the correct moisture content during its weighing (e.g. raw coal or dried coal). Normally, the lower heating value is determined from a dried sample. Subsequently, a moisture correction has to be applied to the result, correcting the mass reference from the dried sample back to the original moisture content of the fuel as it is consumed or weighed.

Furthermore, the correct reference of the CO_2 EF shall be ensured. The reference shall be to the heat determined by the LHV. For the conversion of higher heating values (HHV or gross calorific value GCV) to LHV the formula defined in the 2006 IPCC Guidelines (Vol. II, Section 1.4.1.2, Box 1.1)[4] can be applied.

Companies are encouraged to use plant- or country-specific emission factors if reliable data are available. The emission factor of fuels shall be based on the total carbon content. If a fuel contains significant amounts of TIC, it can be reported based on its TOC content if, in addition, CO_2 emissions from its TIC content are reported as CO_2 emissions from raw material calcination. Direct calculation of emissions based on fuel consumption (in tonnes) and fuel carbon content (in percent) is acceptable on the condition that material variations in the composition of the fuel, and especially its water content, are adequately accounted for.

Generally, IPCC recommends accounting for incomplete combustion of fossil fuels. However, usually 99 % to 100 % of the carbon is oxidized.

Compare IPCC 2006, Vol. II, Section 1.4.2.1[4] and IPCC 1996, Vol. III, p.1.29[26] default carbon oxidation factors: 98 % for coal, 99 % for oil, and 99,5 % for natural gas.

In cement kilns, incomplete oxidation is negligible, due to very high combustion temperatures and long residence time in kilns and no, or minimal, residual carbon found in clinker. Consequently, carbon in all kiln fuels shall be treated as fully oxidized. The CO_2 emission factors of fuels shall always be determined based on the TC content.

7.6.2 Alternative fuels

IPCC 1996[26] and IPCC 2006[4] guidelines for national GHG inventories require the following:

— CO_2 from biomass and bioliquids is reported as a "memo item" but excluded from the national emissions totals.

— CO_2 from fossil fuel-derived wastes (also called alternative fossil fuels or fossil AF): According to IPCC guidelines, GHG emissions from industrial waste-to-energy conversion are reported in the "energy" source category of national inventories, while GHG emissions from conventional waste disposal (landfilling, incineration) are reported in the "waste management" category.

— CO_2 from mixed fuels with biomass and fossil fractions: In the case, that biomass or bioliquids are combusted jointly with fossil fuels (e.g. pre-treated industrial and/or domestic wastes), a split between the fossil and non-fossil fraction of the fuel should be established and the emission factors applied to the appropriate fractions (IPCC 2006, Vol. II, Section 2.3.3.4[4]).

To ensure consistency with the guidelines of IPCC, there is a need for transparent reporting of the direct CO_2 emissions resulting from AF combustion in cement plants. Therefore, this document requires reporting as follows:

— Direct CO_2 from combustion of biomass (including pure biomass or bioliquids, biomass wastes and the biomass fraction of mixed fuels) shall be reported as a memo item but excluded from absolute direct GHG emissions. The IPCC default emission factor of 110 kg CO_2/GJ for solid biomass shall be used, except where other, reliable emission factors are available, see Reference [26]. This value lies in the range of different values for solid biomass or bioliquids, which are specified as default emission factors in IPCC 2006, Vol. II, Section 1.4.2.1[4].

— Direct CO_2 from combustion of fossil AF and the fossil fraction of mixed fuels shall be calculated and included in the direct CO_2 emissions. CO_2 emission factors depend on the type of AF or mixed fuel used and, therefore, shall be specified at the plant level where practical. In the absence of plant- or organization- specific data, companies shall use the default emission factors.

— Indirect GHG savings achieved through the utilization of AF shall be accounted as net emissions in this document. The definition is further described in 5.5.

Generally, the CO_2 emission factors of all fuels shall represent the complete CO_2 emissions from the use of the fuel based on the TC content.

Some AF, for example used tyres and impregnated saw dust, contain both fossil and biomass carbon. These fuels shall be treated as mixed fuels and the CO_2 emissions shall be separated in their fossil and biogenic part. This is done by determining the share of the biogenic carbon in the fuel's overall carbon content, according to ISO and EN international standards (e.g. EN 15440[14]) or suitable national standards. For some fuel types, this share is difficult, costly to measure and very variable. Companies are advised to use a conservative approach in determining the biogenic carbon content, meaning that the biogenic carbon content should not be overestimated. A fossil carbon content of 100 % shall be assumed for fuel types in case of a lack of reliable information on their biogenic carbon content until more precise data becomes available.

Fuels, which contribute significantly to the mass of the product clinker with their ash content and which have a significant TIC content can be reported as fuel with a CO_2 emission factor based on the TOC content. In this case and when reporting CO_2 emissions from raw materials based on their input (see 7.2.2), the CO_2 emissions from the TIC content shall be reported additionally. This shall be done by using the detailed input method A2 and the option for reporting ADRM which are not part of the kiln feed. If CO_2 emissions from TOC of the material are already reported as fuel, the CO_2 content specified for the additional raw material shall only reflect the remaining TIC content so that CO_2 emissions from the TC content are reported (see 7.2.2.5).

7.7 GHG from fuels for kilns

Kiln fuels in this document are all fuels fed to the kiln system plus fuels that are used for drying and processing the raw materials or other kiln fuels. Included in this definition are fuels inserted through a main firing system of the kiln as well as fuels added to a calciner or directly to the kiln inlet. In this document, such fuels are regarded as kiln fuels, irrespective of the potential use of waste heat for the production of electrical power. Also, fuels used for fuel heating (e.g. for heavy fuel oil used for clinker production) shall be reported under kiln fuels. Fuels used for the drying of MICs used in cement grinding and fuels used for electricity production in an installation that is separate from the kiln system shall be reported as non-kiln fuels.

The specific GHG emissions and the specific fuel energy consumption of clinker production are determined by the use of kiln fuels including the raw material and fuel preparation.

7.8 GHG from non-kiln fuels

Non-kiln fuels include all fuels which are not included in the definition of kiln fuels. For instance, fuels used

- for plant and quarry vehicles,
- for room heating,
- for thermal process equipment (e.g. dryers), which can be used in the preparation of MICs for cement grinding, and
- in a separate installation for on-site production of electrical power.

Cement companies shall ensure the complete reporting of GHG emissions from non-kiln fuels combusted on site. These emissions are accounted for as follows:

- GHG from non-kiln fuels is reported separately, by application type, to provide flexibility in the aggregation of emissions for the following applications:
  - equipment and on-site vehicles;
  - room heating or cooling;
  - drying of MIC such as slag or pozzolana;
  - on-site power generation in separately fired boilers and diesel or gasoline engine power generation.

Note that fuels consumed for drying of raw materials for the production of clinker and kiln fuels are included in the kiln fuel section.

- GHG from off-site transports by organization-owned fleets is currently excluded from the boundary (see 10.1).
- Carbon in non-kiln fuels is assumed to be fully oxidized, i.e. carbon storage in soot or ash is not accounted for. The resulting overestimation of emissions is usually small (approximately 1 %).

See also Table 7 regarding the process steps which need to be covered to ensure complete reporting according to this document.

Measured plant-specific lower heating values shall be used, if available. Alternatively, IPCC or CSI default values can be applied. If the same type of fuel is used as non-kiln fuel and kiln fuel, then the CO_2 emission factors used for reporting shall correspond. Otherwise, measured plant-specific emission factors shall be used, if available. Alternatively, IPCC or CSI defaults values can be applied.

7.9 GHG from the combustion of wastewater

Some cement plants inject wastewater in their kilns, for example as a flame coolant for control of nitrogen oxides (NO_x). The carbon contained in the wastewater is emitted as CO_2. This document does not require cement companies to quantify their CO_2 emissions related to wastewater consumption, because these emissions are usually small and, in addition, difficult to quantify:

— most cement plants do not consume wastewater;

— where wastewater is consumed, its carbon content usually contributes less than 1 % of the plant's overall CO_2 emissions;

NOTE If a plant uses wastewater, the volume consumed is typically about 10 kg/t of clinker. At a typical carbon content in the wastewater of 5 % by weight, this corresponds to CO_2 emissions of about 2 kg/t of clinker or about 0,2 % of a plant's typical overall CO_2 emissions (values based on data provided by several GCCA, formerly CSI, member companies).

— in addition, the carbon contained in the wastewater can be of biomass origin (e.g. sewage), in which case it would have to be counted as a memo item only.

7.10 Non-CO_2 GHG emissions from the cement industry

In Annex A of the Kyoto Protocol[27], the UNFCCC defines the following chemical compounds as relevant anthropogenic GHGs causing climate change:

— carbon dioxide (CO_2),

— methane (CH_4),

— nitrous oxide (N_2O),

— hydrofluorocarbons (HFCs),

— perfluorocarbons (PFCs), and

— sulfur hexafluoride (SF_6).

During the clinker and cement production process, no HFCs, PFCs or SF_6 are applied. The only possible entry pathways would be minimal quantities of gas remaining in wastes containing foamed plastics. However, such materials are not used as such and are not normally contained in any significant quantity in mixed alternative fuels utilized in the cement industry. Used tyres utilized as alternative fuel in cement plants do not allow for any significant remains of SF_6.

Non-CO_2 GHG gases, i.e. methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), and fluorinated hydrocarbons (PFCs, HFCs) have been measured during field tests[20]. As a main result of the field tests the conclusion can be drawn that non-CO_2 GHG gases are not significant in the waste gases of cement industry. The main blank values of these measurements are discussed in Annex A.

8 Indirect GHG emissions and their determination

8.1 General

Indirect GHG emissions are emissions that are a consequence of the operations of the reporting entity but occur at sources owned or controlled by another entity. Cement production is associated with indirect GHG emissions from various sources. Key examples include the CO_2 emissions from:

- external production of electricity consumed by cement producers (see 8.2);
- production of clinker purchased from other producers and interground with own production;
- production and processing of conventional fossil and alternative fuels by third parties;
- transport of inputs (raw materials, fuels) and outputs (cement, clinker) by third parties.

The definition of the boundaries for the indirect GHG emissions is included in 6.2 under reporting boundaries.

Data on indirect GHG emissions, consisting of several categories, can be useful to assess overall carbon footprint of an industry. To this end, cement companies shall calculate and report GHG both from "external electricity production" [see ISO 14064-1:2018, 5.2.4 b)] and "purchased clinker" [see ISO 14064-1:2018, 5.2.4 d)] of energy indirect and other indirect GHG emissions which have a significant impact on GHG emissions.

8.2 CO_2 from external electricity production

CO_2 from external electricity production shall be calculated based on the measured delivery of grid electricity and, preferentially, emission factors obtained from the electricity supplier. Alternatively, it is recommended to use governmental data for the national power grid. If both data are not available, an average emission factor for the country may be used. Such factors are based on IEA data which are updated annually (see Reference [28] for the latest update). Emissions associated with the consumption of electricity during transport and distribution (T&D losses) shall not be included in this calculation. This document differentiates between the different power sources (purchase, production on-site) and paths of power usage: use for cement production, consumption of power generation auxiliaries (difference between gross and net power production of the power plant) and power sold externally. Power given to other non-cement installations within the same plant shall be treated such as power sold externally.

8.3 CO_2 from purchased clinker

CO_2 from production of purchased clinker shall be calculated based on the net clinker transfer (purchased clinker minus sold clinker plus internal clinker transfer) of the reporting entity, and the emission factor of the clinker. With respect to clinker transfers within the organization, the real emission factor of the sending plant should be used. If clinker is purchased externally, this value is usually not available. In this case, a default value shall be used. As a first priority, national or regional values shall be applied, if available. As a second priority, the global average value can be used.

Please note that the default emission factor of 865 kg CO_2/t should only be used for calculating the indirect GHG emissions impact associated with net clinker purchases. For a net clinker seller, the clinker purchase balance and hence the resulting emissions will be negative, indicating that the company's clinker sales have indirectly helped to avoid emissions at another cement plant. The same default emission factor should not be used for calculating the gross and net direct GHG emissions of the reporting organization.

The approaches for calculating these two types of indirect GHG emissions are summarized in Table 12. Besides CO_2 from purchased clinker, quantification of other indirect GHG emissions is not required by this document. This applies, in particular, for indirect GHG emissions related to transports.

Table 12 — Parameters and data sources for calculation of indirect GHG emisssions from imported energy and other indirect CO_2 emissions as required by this document

Emission	Parameters	Units	Source of parameters
CO_2 from external power production (energy indirect GHG emission)	Power purchased from external grid	GWh	Measured at plant level
	Emission factor excluding T&D losses	t CO_2/GWh	Supplier-specific value or country grid factor
CO_2 from clinker purchased (other indirect GHG emission)	Net clinker purchases	t cli	Measured at plant level (purchased minus sold clinker + internal clinker transfer)
	Emission factor	t CO_2/t cli	Default factor (from GNR database[10])

GHG emissions associated with the production of clinker- or cement-substituting MICs shall not be considered as other indirect GHG emission of the cement industry if these emissions are the result of another industrial process. This applies, in particular, to slag produced by the steel industry, and to fly ash produced by power plants.

9 Baselines, acquisitions and disinvestments

GHG emissions performance is often measured relative to a past reference year (the “base year”). As a default, the “Kyoto base year” 1990 can be used as a reference. In many cases however, the lack of reliable and accurate historical data justifies the use of a more recent base year, especially when compliance or emissions trading is concerned.

NOTE Some Annex 1 countries with economies in transition have chosen other years than 1990 as their base year or base period (e.g. Bulgaria and Romania: 1989, Poland: 1988, Hungary: 1985 to 1987). In addition, all Annex 1 countries can choose 1995 as their base year for hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride.

The choice of base year also depends on individual country regulations.

Acquisitions and divestitures, as well as the opening or closing of plants, will influence an organization’s consolidated emissions performance, both in absolute and specific terms. To ensure consistency of baselines (i.e. emissions in and after the base year), companies shall apply the following rules in a consistent way.

— Adjust the baseline for change by acquisition and divestiture: Consolidated emissions reported for past years shall always reflect the current amount of shares held in an organization. If an organization is acquired, its past emissions shall be included in the consolidated emissions of the reporting organization. This shall be done either back to the base year, or back to the year the acquired organization came into existence, whichever is later. If an organization is divested, past emissions shall be removed from the consolidated emissions. These adjustments shall be made in accordance with the consolidation rules (see 6.3).

— No baseline adjustment for “organizational” change: In case of organic growth of production due to investment in new installations, capacity expansions or improved capacity utilization, the baseline shall not be adjusted. In the same sense, the baseline shall not be adjusted for organizational negative growth; closure of kilns or decrease of production shall not result in a change of the baseline.

10 Reporting

10.1 General

GHG emissions monitoring and reporting has multiple goals, such as, for example, internal management of environmental performance, public environmental reporting, reporting for taxation schemes, voluntary or negotiated agreements, and emissions trading. Additional purposes can be, for example, performance benchmarking and product life cycle assessment. If verification is required, further guidance is given in Annex E.

This document has been designed as a flexible tool to satisfy these different reporting purposes. The information is structured in such a way that it can be aggregated and disaggregated according to different reporting scopes. Examples include:

- Reporting to national GHG inventories should be compatible with IPCC guidelines. Hence, it should cover all direct GHG emissions, including GHG from fossil wastes. CO_2 from biomass should be reported as a memo item.
- Reporting under CO_2 compliance and taxation schemes will have varying reporting requirements, depending on local conventions. This document allows reporting of gross and net emissions, and indirect GHG emissions, as appropriate.

This document does not define any threshold for excluding “immaterial” emission sources. In practice, the decision whether to include or exclude certain emission sources also depends on the requirements of the respective reporting framework.

Also, the overall uncertainty of a GHG inventory should be reported, see Clause 11 on uncertainty assessment.

10.2 Corporate environmental reporting

The objective of voluntary environmental reporting is to provide the reader with a sufficiently accurate picture of the environmental footprint of the reporting organization. This implies that the reporting of cement companies shall cover all relevant emission components:

- gross direct GHG emissions of the reporting entity (calcination, conventional fossil kiln fuels, alternative kiln fuels, non-kiln fuels, with biomass CO_2 as a memo item);
- net emissions (if applicable), calculated from gross emissions minus emissions from the use of alternative fuels;
- main indirect GHG emissions (consumption of grid electricity and purchased clinker).

Reporting shall be in absolute (Mt CO_2/year) as well as specific (kg CO_2/t cement constituents material) units. Reporting of net emissions alone, omitting gross emissions is not acceptable.

In order to be complete, reporting shall include the CO_2 emissions (including indirect CO_2 emissions from consumption of grid electricity and accounting for own on-site power generation) from the different process steps (see Table 13).

Additional requirements for voluntary reporting include the following.

- It shall be clearly stated when GHG sources are excluded from the inventory. To this end, this document requires companies to state the GHG inventories.
- Companies shall clearly state that they report according to this document and any material deviations from it.

Table 13 — Recommended reporting boundaries for GHG reporting

Process step	Is CO_2 reporting mandatory?	Comments
Raw material supply (quarrying, mining, crushing)	Yes – unless NA	Can require consolidating emissions of two legal entities, if raw material supply is contracted out. See 7.3 for details.
Preparation of raw materials, fuels and additives	Yes – unless NA	—
Kiln operation (pyro-processing)	Yes – unless NA	—
Cement grinding, blending	Yes – unless NA	—
On-site (internal) transports	Yes – unless NA	CO_2 from owned vehicles (including leased vehicles, excluding owner-drivers) shall be reported. If third-party transports: it is NA
Off-site transports	No	Reporting is not mandatory. If reported, distinguish direct CO_2 (own vehicles, incl. leased vehicles) from indirect CO_2 (third-party vehicles).
On-site power generation	Yes – unless NA	Also report CO_2 if operated only occasionally.
Room heating and cooling	Yes – unless NA	—

Key

NA : not applicable

10.3 Reporting periods

Reporting GHG emissions can be based on calendar years or on financial years, if it helps to reduce reporting costs. From a GHG perspective, there is no problem to report based on financial years, provided that it is done consistently over time, with no gaps or overlaps. Changes in the reporting year should be clearly indicated.

10.4 Performance indicators

10.4.1 General

This document gives guidelines for providing a flexible basis for GHG emissions monitoring and reporting. The calculation of individual emission components as described above is quite straightforward. The definition of emission totals and specific indicators, in contrast, is highly dependent on the reporting context and purpose, such as: input to national inventories, GHG compliance regimes and emissions trading, industry benchmarking. GHG inventories for such reporting depend largely on conventions and practical requirements, rather than on scientific arguments.

With this background, a section on performance indicators is included in this document. It contains a number of indicators which are deemed most useful in the light of the current business and policy environment, and associated reporting requirements. Generally, the subclause on performance indicators is conceived as a flexible vessel where companies can introduce additional parameters according to their needs, for instance different emission totals or subtotals.

A summary of the definitions of the performance indicators (KPIs) is presented in Table 14.

10.4.2 Denominators

10.4.2.1 General

From a sustainable development and business point of view, the reporting of GHG efficiency – the specific or unit-based emission – is at least as important as the reporting of absolute emissions. This raises the question how the denominator of the specific emissions and other ratio indicators should be defined.

Three denominators are appropriate in the cement industry:

a) clinker,

b) cement (equivalent), and

c) cement constituents-based products.

Each of these three denominators gives a different weighting to the GHG performance involved in different stages of cement manufacturing.

For selected ratio indicators which do not use GHG in the numerator, it is appropriate to include purchased clinker, and exclude sold clinker, from the denominator. This applies for:

- specific power consumption per tonne of cement constituents-based products, which should take into account grinding of purchased clinker: cement (equivalent);
- the clinker/cement factor, which should describe the ratio between total clinker consumption and total production of cement or concrete additions: cement and concrete additions.

10.4.2.2 Clinker

In the context of this document, clinker refers to grey and white clinker used for the production of grey and white cement. The production of clinker is the main source of CO_2 in cement production and is calculated according to Formula (19).

$$cli_{\text{prod,own}} = cli_{\text{cons,own}} + cli_{\text{sold,own}} \tag{19}$$

where

$cli_{\text{prod,own}}$ is the own clinker production (t);

$cli_{\text{cons,own}}$ is the own clinker consumed (t);

$cli_{\text{sold,own}}$ is the own clinker sold directly (t).

10.4.2.3 Cement (equivalent)

Cement (equivalent) is a cement production value, which is determined from clinker produced on-site applying the plant specific clinker/cement-factor. Hence, it is a virtual cement production under the assumption that all clinker produced in a plant is consumed for cement production in the same plant and applying the real plant specific clinker/cement ratio [see Formula (20)].

$$cem_{\text{eq}} = \frac{cli_{\text{prod,own}}}{R_{\text{cli,cem}}} \tag{20}$$

where

cem_{eq} is the cement (equivalent) (t);

$cli_{\text{prod,own}}$ is the own clinker production (t);

$R_{\text{cli,cem}}$ is the clinker / cement (equivalent) ratio (t/t).

with

$$R_{cli,cem} = \frac{cli_{\mathrm{cons}}}{cli_{\mathrm{cons,own}} + cem_{\mathrm{const,ex,cli}} + cli_{\mathrm{cons,bought}}} \tag{21}$$

where

$R_{\mathrm{cli,cem}}$	is the clinker / cement (equivalent) factor (t/t);
cli_{cons}	is the clinker consumed (t);
$cli_{\mathrm{cons,own}}$	is the own clinker consumed (t);
$cem_{\mathrm{const,ex,cli}}$	is the CKD and onstituents other than clinker (gypsum, limestone, etc.) consumed for blending (t);
$cli_{\mathrm{cons,bought}}$	is the clinker bought and consumed (t).

The factor in Formula (21) is based on clinker consumption. Hence, in the denominator sold clinker is excluded and purchased clinker is included. Concrete additions are excluded.

See 10.4.2.5 for guidance on stock changes.

The companies shall calculate their specific emissions as shown in Figure 7.

$$\begin{array}{c}\text{Specific CO}_2\text{ per}\\ \text{t of cement (eq.)}\end{array} = \frac{\begin{array}{c}\text{direct CO}_2\text{ emission from}\\ \text{cement manufacturing}\end{array}}{\underbrace{\text{own clinker production}}_{=\ \begin{array}{c}\text{own clinker}\\ \text{consumed}\end{array} + \begin{array}{c}\text{own clinker}\\ \text{sold directly}\end{array}}} \times \text{clinker/cement (eq.) factor}$$

Figure 7 — Calculation of specific emissions

10.4.2.4 Cement constituents-based products

Cement constituents-based products consist of all clinker produced by the reporting organization for cement making or direct clinker sale, plus gypsum, limestone, CKD and all cement constituents other than clinker consumed for blending, plus all concrete additions processed at the cement plant in view of changing their properties [see Formula (22)].

Any dust volumes which leave the kiln system and are ultimately incorporated in cement constituents should be included in the denominator. Examples include CKD added to the cement mill, and direct sales of CKD as a binder. In this document, such dust volumes should be counted as cement constituents other than clinker used for blending, or counted as concrete additions which are pure mineral components (pure MIC) processed at the plant. In contrast, landfilled dust should be excluded from the denominator.

Therefore, this denominator is the sum of on-site produced clinker and processed mineral components. Note that the denominator excludes the following:

a) purchased clinker, used for cement production;

b) granulated slag and fly ash from coal fired power plants, which are stored or sold to another organization without any processing for changing their properties (e.g. grinding or thermal treatment);

c) cement volumes which are traded without any processing

$$cem_{\text{products}} = cli_{\text{prod,own}} + cem_{\text{const,ex,cli}} + MIC \tag{22}$$

where

cem_{products} is the cement constituents-based products (t);

$cli_{\text{prod,own}}$ is the own clinker production (t);

$cem_{\text{const,ex,cli}}$ is the CKD and constituents other than clinker (gypsum, limestone, etc.) consumed for blending (t);

MIC is the concrete additions (pure mineral components) processed at plant (t).

The specific CO_2 emissions per ton of cement constituents-based product shall be calculated as shown in Figure 8.

$$\begin{array}{c}\text{Specific}\\ \text{CO}_2\text{ pro t}\\ \text{cement}\\ \text{constituents}\\ \text{based product}\end{array} = \frac{\text{direct CO}_2\text{ from cement manufacturing}}{\underbrace{\begin{array}{c}\text{own clinker}\\ \text{consumed}\end{array} + \begin{array}{c}\text{own clinker}\\ \text{sold directly}\end{array}}_{=\text{ own clinker production}} + \begin{array}{c}\text{CKD \& cement}\\ \text{constituents}\\ \text{other than}\\ \text{clinker (gypsum,}\\ \text{limestone, etc)}\\ \text{consumed}\\ \text{for blending}\end{array} + \begin{array}{c}\text{concrete}\\ \text{additions}\\ \text{(pure MIC)}\\ \text{processed}\\ \text{at plant}\end{array} + \cancel{\begin{array}{c}\text{clinker bought}\\ \text{\& consumed}\end{array}}}$$

Figure 8 — Calculation of specific CO_2 emissions per ton of cement constituents-based product

For the specific GHG per t of cement constituents-based products, the denominator is based on clinker production, hence sold clinker is included and purchased clinker is excluded, cement constituents other than clinker and concrete additions are included. See 10.4.2.5 for guidance on clinker stock changes.

In order to calculate the fair and comparable specific power consumption, companies shall calculate their clinker/cement constituents-based product factor as shown in Figure 9.

$$\begin{array}{c}\text{clinker/}\\ \text{cement}\\ \text{constituents}\\ \text{based product}\\ \text{factor}\end{array} = \frac{\text{clinker consumed}}{\underbrace{\begin{array}{c}\text{own clinker}\\ \text{consumed}\end{array} + \cancel{\begin{array}{c}\text{own clinker}\\ \text{sold directly}\end{array}}}_{=\text{ own clinker production}} + \begin{array}{c}\text{CKD \& cement}\\ \text{constituents}\\ \text{other than}\\ \text{clinker (gypsum,}\\ \text{limestone, etc)}\\ \text{consumed}\\ \text{for blending}\end{array} + \begin{array}{c}\text{concrete}\\ \text{additions}\\ \text{(pure MIC)}\\ \text{processed}\\ \text{at plant}\end{array} + \begin{array}{c}\text{clinker bought}\\ \text{\& consumed}\end{array}}$$

Figure 9 — Clinker/cement constituents-based product (or ratio)

The factor (or ratio) is based on clinker consumption. Hence, in the denominator sold clinker is excluded and purchased clinker is included. Furthermore, concrete additions are included.

Afterwards, calculate the specific power consumption as given in Formula (23):

$$W_{\text{spec}} = \frac{W_{\text{cons}}}{cli_{\text{prod,own}}} \times R_{cli\text{,cemproducts}} \tag{23}$$

where

W_{spec} is the specific kWh of cement constituents-based products (t);

W_{cons} is the kWh consumed;

$cli_{prod,own}$ is the own clinker production (t);

$R_{cli,cemproducts}$ is the clinker / cement constituents-based product ratio.

See 10.4.2.5 for guidance on stock changes where kWh consumed includes power consumed in clinker and cement production.

10.4.2.5 Dealing with stock changes, and sold and purchased clinker

Direct GHG emissions resulting from clinker production should be reported for the year in which it is emitted. To avoid distortion, specific emissions per tonne of cement constituents-based products should therefore be based on the full clinker production of the same year, irrespective of whether the produced clinker is consumed, sold or stored.

Other ratio indicators such as specific electricity consumption and clinker/cement factors, in contrast, should be based on actual amounts of clinker (plus gypsum and MIC) consumed, irrespective of whether the clinker was produced this year, taken from stock or purchased. When calculating clinker production from clinker consumption or vice-versa, changes in clinker stocks as well as sales and purchases of clinker need to be taken into account (for accounting of material transfers see also 6.3.4).

10.4.2.6 Key performance indicators

Table 14 — List of KPIs

KPI	Unit	Description and comment
Fossil direct GHG (including CO_2 from on-site power generation)	t CO_2/yr	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, including CO_2 from on-site power generation
Gross emissions (equals to the fossil direct GHG excluding CO_2 from on-site power generation)	t CO_2/year	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation
— calcination component of gross emissions	t CO_2/year	Fossil direct GHG emissions from raw materials
— fuel component of gross emissions	t CO_2/year	Fossil direct t GHG emissions from kiln fuels and non-kiln fuels, excluding CO_2 from on-site
Net emissions (i.e. gross emissions minus emissions from alternative fossil fuels and non-biogenic content of mixed fuels; excluding CO_2 from on-site power generation)	t CO_2/year	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, minus emissions from alternative fossil fuels and non-biogenic content of mixed fuels
CO_2 from biomass sources (including biomass content of mixed fuels)	t CO_2/year	—
Specific gross emissions per tonne of clinker produced	kg CO_2/t cli	Fossil direct GHG emissions, excluding CO_2 from on-site power generation, divided by own clinker production
— calcination component	kg CO_2/t cli	Fossil direct GHG emissions from raw materials, divided by own clinker production
— fuel component	kg CO_2/t cli	Fossil direct GHG emissions from kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, divided by own clinker production

[a] For clinker/cement (equivalent) ratio determination, see 10.4.2.3.

[b] For clinker/cement constituents-based product ratio determination, see 10.4.2.4.

[c] In the specific power consumption KPI, the power consumption is related to the processing of cement constituents (consumed) and concrete additions (pure MIC processed and sold separately, but exported clinker is excluded.

Table 14 *(continued)*

KPI	Unit	Description and comment
Specific net emissions per tonne of clinker produced	kg CO_2/t cli	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, minus emissions from alternative fossil fuels and non-biogenic content of mixed fuels, divided by own clinker production
Specific gross emissions per tonne of cement constituents-based product — calcination component — fuel component	kg CO_2/t cem prod kg CO_2/t cem prod kg CO_2/t cem prod	Fossil direct GHG emissions, excluding CO_2 from on-site power generation, divided by cement constituents-based products Fossil direct GHG emissions from raw materials, divided by cement constituents-based products Fossil direct GHG emissions from kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, divided by cement constituents-based products
Specific net emissions per tonne of cement constituents-based product	kg CO_2/t cem prod	Fossil direct GHG emissions from raw materials, kiln fuels and non-kiln fuels, excluding CO_2 from on-site power generation, minus emissions from alternative fossil fuels and non-biogenic content of mixed fuels, divided by own production of cement constituents-based products
Improvement rate: net emissions per tonne of cement constituents-based product relative to base year (e.g. 1990)	%	—
Specific indirect GHG emissions from external power generation: — per tonne of cement (equivalent) — per tonne of cement constituents-based product	 kg CO_2/t cem eq kg CO_2/t cem prod	—
Specific other indirect GHG emissions from net clinker imports (+) / exports (-) per tonne of cement constituents-based product	kg CO_2/t cem prod	—
Net outbound clinker per net clinker consumption	%	Percentage of direct clinker sales versus clinker consumed to produce cement
Clinker/cement (equivalent) factor[a]	%	Calculated based on total clinker consumed and total Portland + blended cements
Clinker/cement constituents-based product factor[b]	%	Total clinker consumed divided by the cement constituents consumed (produced cements) and concrete additions produced (pure MIC processed)
Specific heat consumption of clinker production	MJ/t cli	Total heat consumption of kilns divided by the clinker production
Heat consumption rates of clinker production (kiln fuels): — conventional fossil fuel rate — alternative fossil fuel rate — biomass fuel rate	 % % %	 Heat consumption of conventional fossil fuels divided by the total heat consumption of kilns Heat consumption of alternative fossil fuels divided by the total heat consumption of kilns Heat consumption of biomass fuels, bioliquids and biomass content of mixed fuels divided by the total heat consumption of kilns
CO_2 emission factor for kiln fuel mix	t CO_2/GJ	Total CO_2 from fossil-based kiln fuels divided by total heat consumption of kilns
Total fuel energy rates at plant level (kiln and non-kiln fuels):		

[a] For clinker/cement (equivalent) ratio determination, see 10.4.2.3.

[b] For clinker/cement constituents-based product ratio determination, see 10.4.2.4.

[c] In the specific power consumption KPI, the power consumption is related to the processing of cement constituents (consumed) and concrete additions (pure MIC processed and sold separately, but exported clinker is excluded.

Table 14 *(continued)*

KPI	Unit	Description and comment
— conventional fossil fuel rate	%	Total conventional fossil fuel energy used in the whole plant (kiln and non-kiln fuels) divided by total fuel energy
— alternative fossil fuel rate	%	Total alternative fossil fuel energy used in the whole plant (kiln and non-kiln fuels) divided by total fuel energy
— biomass fuel rate	%	Total biomass fuel energy used in the whole plant (kiln and non-kiln fuels) divided by total fuel energy
Specific total plant power consumption[c]	kWh/t cem and conc add	Total plant power consumption divided by cement constituents consumed (produced cements) and concrete additions (pure MIC processed and sold separately)
Specific power consumption of clinker production	kWh/t cli	Power consumption up to and including clinker production divided by clinker production
Specific power consumption of cement production[c]	kWh/t cem and conc add	Power consumption of cement production including power consumption of production of clinker consumed divided by cement constituents consumed (produced cements) and concrete additions (pure MIC processed and sold)
National energy conversion factor for power production of national statistics	$MJ_{thermal}/kWh$	Optional parameter, for example, from national statistics
Total energy intensity of clinker production (fuel and power)	MJ/t cli	Optional result

[a] For clinker/cement (equivalent) ratio determination, see 10.4.2.3.

[b] For clinker/cement constituents-based product ratio determination, see 10.4.2.4.

[c] In the specific power consumption KPI, the power consumption is related to the processing of cement constituents (consumed) and concrete additions (pure MIC processed and sold separately, but exported clinker is excluded.

A number of KPIs is recommended according to the experiences from the use of previous reporting schemes: absolute gross emissions excluding emissions from on-site power generation in t CO_2/year.

11 Uncertainty of GHG inventories

11.1 General to uncertainty assessment

11.1.1 Basic considerations

So far as standards for measurement of mass flows and parameters of specific materials, energy consumption or any other emission sources include the analysis of uncertainty, these should be applied.

Applying the described mass balance method to determine GHG emissions of the cement industry in this document, the procedures for analysing the uncertainty of measured or calculated values should be considered as described in the following sections. They are specified in the general rules of the GUM[3].

The overall uncertainty depends on the uncertainty of the different parameters:

a) reporting of fuel quantities or production volumes;

b) analyses of conventional parameters such as calorific values;

c) representativeness of sampling.

Due to their scientific nature, the parameters required for estimating GHG emissions, such as fuel mass flows, lower heating values and emission factors, are not precise point estimates, but involve an uncertainty that can be expressed as an uncertainty range or confidence interval.

The aggregate uncertainty of an emissions estimate for a plant or organization depends on the individual uncertainties of the underlying parameters.

Quantifying parameter uncertainties is demanding in terms of data and procedures. As a result, statements about the aggregate uncertainty of emissions estimates are inherently uncertain themselves and often involve a subjective component.

NOTE Besides the uncertainty of parameters, there are other error sources that can contribute to the uncertainty of emissions estimates. These include model uncertainty – i.e. the question how precisely a mathematical model reflects a specific context – and scientific uncertainty, for example related to the global warming potentials[6] used to aggregate different greenhouse gases. This document aims to reduce the model uncertainty inherent in cement organization inventories to minimal levels. Addressing scientific uncertainty, on the other hand, is clearly beyond the scope of corporate inventories.

Nevertheless, there are clear incentives to assess and minimize uncertainty:

- companies can want to rank the sources of uncertainty in their inventory in order to identify priority areas to focus on when improving inventory quality;
- some GHG reporting schemes set quantitative limits for the uncertainty of key parameters used to estimate emissions from cement plants;
- wherever monetary values are assigned to GHG emissions, uncertainty in emissions estimates can have financial consequences.
- with this background, it is recognized that uncertainty in GHG inventories is a longer-term challenge which deserves attention.

Table 15 identifies the sources of uncertainty which are typically the most relevant in a cement organization, along with measures to minimize them.

Table 15 — Typical major sources of uncertainty in cement sector CO_2 inventories and measures to minimize them

Parameter	Measures to minimize parameter uncertainty
Clinker production (t/a)	Use alternative estimation methods to cross-check clinker volumes: — based on raw meal consumption and raw meal: clinker ratio; — based on cement production and clinker: cement ratio, adjusted for clinker sales and purchases and clinker stock changes; — based on direct clinker weighing (where applicable).
Raw meal consumption (t/a)[a]	Account for double-counting of recirculated dust by weighing devices.
Calcination emission factor (kg CO_2/t clinker)	Calculate plant-specific emission factor based on measured clinker composition (CaO- and MgO- content), rather than using default factor. Account for additions of calcined materials to the kiln via slag, fly ash, etc.
Calcination emission factor[a] (kg CO_2/t raw meal)	Calculate plant-specific emission factor based on measured composition of raw meal (carbonate content). Account for variations in raw meal carbonate content over time (e.g. additions of calcined materials).
Fuel consumption (t/a)	Use alternative methods to cross-check fuel consumption: — based on weighing at delivery, or fuel bills; account for stock changes; — based on weigh-feeders (where applicable).
Lower heating values of fuels (GJ/t)	Ensure that fuel volumes and lower heating values are based on the same moisture content.

[a] It is only relevant if the raw meal-based method is used for calculating CO_2 from raw material calcination.

Table 15 *(continued)*

Parameter	Measures to minimize parameter uncertainty
Emission factors of fuels ($kg CO_2/GJ$)	If using fuel mixes (e.g. coal-petcoke mix), disaggregate and apply individual emission factors, or apply weighted emission factor. If using specific types of coal, use matching emission factors. Measure emission factor of fuel if default factors are deemed non-representative. Account for biomass carbon in, for example, used tyres and impregnated saw dust. Use analysis data for biomass content[14] in heterogeneous mixed alternative fuels such as pre-treated industrial or domestic wastes, where applicable.
[a] It is only relevant if the raw meal-based method is used for calculating CO_2 from raw material calcination.	

11.1.2 Materiality thresholds

Materiality thresholds are typically applied in the process of independent verification of GHG inventories. For example, a verifier can apply a pre-defined threshold of 5 % to determine whether a single or aggregate error in an inventory leads to a material misstatement. The level of such a threshold depends on the purpose for which the inventory data are intended to be used.

A materiality threshold should not be interpreted as a permissible quantity of emissions which an organization can leave out of its inventory. For example, exclusion of all sources which contribute less than 1 % to the overall emissions of a cement plant would introduce a systematic bias which is not compatible with the guiding principle that an inventory should be complete. On the other hand, it is important to acknowledge that an organization's resources available for preparing a GHG inventory are always limited, and that companies should focus on reducing the uncertainty related to their main emission sources.

With this background, this document does not define a minimum threshold below which an emission source should be considered "immaterial". Instead, companies are encouraged to apply simplified methods for quantifying their minor sources of CO_2. This applies, for example, for CO_2 emissions from organic carbon in raw materials.

In this context, it is useful to reiterate the reasons why this document does not require quantification of the following sources of direct GHG emissions:

- GHG emissions from off-site transports of inputs and products are typically small, but also difficult to quantify consistently because these transports are often carried out by third parties, see Table 7 in Clause 6;
- GHG emissions from combustion of wastewater (see 7.9), in addition to being small, occur only in relatively few plants, and the carbon can be from biomass sources, see Table 7 in Clause 6;
- CH_4 and N_2O emissions from kilns are not significant – see 7.10.

11.2 Uncertainty of activity data

11.2.1 Measuring instruments for the determination of fuel and material quantities

The information on the uncertainty of a measuring instrument can be found in different sources:

- certificates on calibration under national metrological control (where the operational error limits the uncertainty under normal operational conditions),
- the specification from the manufacturer of an instrument and estimate of the additional uncertainty under operation conditions concerning relevant influences, or

- an individual uncertainty assessment under operational conditions (e.g. via regular testing and adjustment of scales),
- deviations of the scale under operation conditions can normally be determined by comparison to an ensured reference, for example, precisely measured weight loss of a pre-loading silo, determination of the material flow by comparison to an ensured weighing system, scale testing by use of an appropriate check weight.

See Clause C.1 for an example of the calculations.

11.2.2 Aggregated uncertainties in case of mass balances

If the yearly amount of a consumed fuel or of the produced clinker is determined by a mass balance, the aggregated uncertainty for the activity data has to be calculated via error propagation considering the diverse uncertainties of each parameter of the mass balance according to the expanded uncertainty of the involved weighing/measuring method. Also, the uncertainty of measuring or estimating stocks in piles, silos, tanks and other stocks in the mass balance has to be considered.

See Clause C.2 for an example of the calculations.

11.3 Uncertainties of fuel and material parameters

11.3.1 Laboratory analyses for the determination of fuel and material parameters

The uncertainty of analysed parameters of fuels and materials depends mainly on:

- the analysing method,
- the analysing frequency (a decrease of uncertainty is possible by raising the analysing frequency), and
- representative sampling.

Also, the qualification and experience of the persons, who perform the analyses, influences the quality of analysing results.

See Clause C.3 for an example of the calculation of aggregated uncertainties in the case of combined parameters.

11.3.2 Uncertainties of total heat consumption and CO_2 emissions of fuels

An uncertainty evaluation according to the formulae included in the CSI Protocol[1] spread sheet resulted in significantly higher relative uncertainties (10 %) for total heat consumption in the complicated setting. This is due to the fact, that the sum of heat is calculated from individual components. The energy of mixed alternative fuels is separated between fossil fraction and biogenic fraction. Thus, the uncertainty of these energy components depends on the relatively high uncertainty of the biogenic fraction of mixed fuels. However, this differentiation is not relevant to the total sum of heat. Consequently, the uncertainty of the total heat consumption of clinker shall not be assessed from the individual components but from the relevant uncertainties of the amounts of fuels and their corresponding heating values.

The uncertainty of CO_2 emissions from fuels in most cases does not depend on the uncertainty of heat values, although the normal way of calculating the emission includes the heat value as in the CSI Protocol and described in the EU Monitoring, Reporting Regulation and Formula (24):

$$CO_{2,\text{fuels}} = AD \times LHV \times EF \times (1 - CC_{\text{bio}}) \qquad (24)$$

where

$CO_{2,\text{fuels}}$ is the CO_2 emission from fuels;

AD is the activity data;

LHV is the lower heat value;

EF is the emission factor;

CC_{bio} is the biogenic carbon content.

Normally, the heat specific CO_2 emission factor of fuels is determined from a total carbon analysis and division by the lower heat value. In this case and if consistent analytical results are used, the uncertainty of the product of the lower heat value multiplied by the CO_2 emissiion factor depends solely on the uncertainty of the sampling and TC analysis.

For the conversion of TC analytical results to CO_2 emission factors, a unique and precise conversion factor shall be used for the CO_2/C molar ratio, for example, 3,664.

11.4 Uncertainties of continuous stack emission measurements

Refer to ISO 20988[2]. The overall uncertainty depends on the uncertainty of the different parameters, for example, measurement of volume flow and concentration measurement. For stack emission measurements (emission data-based method, St), uncertainties of 7 % to 10 % were achieved in the field tests for the total CO_2 including CO_2 from biogenic and fossil carbon.

Stack CO_2 emission measurements were subject to the highest relative uncertainty in the verification tests.

The key influence on the uncertainty of the stack emission method is the accuracy of calibration of the continuous measuring instruments for the stack gas velocity and volume flow. It strongly depends on the uncertainty of the applied SRM.

NOTE The uncertainty results to about 5 % under favourable experiment conditions and when the direct CO_2 emissions were regarded, i.e. CO_2 emissions of total carbon without differentiation of fossil and biogenic carbon content. Uncertainty of about 4 % to 6 % of the stack emission measurements in the verification tests was mainly dependent on the uncertainty of the SRM according to ISO 16911-1, which is used for calibrating and assuring the accuracy of the continuous volume flow measurements in the stack. The indicated uncertainty refers to calibration by 12-fold SRM measurements. SRM uncertainty ranged up to 8 % in case of very low stack gas velocities. A lack of accuracy of the volume flow measurements (activity data) can induce a systematic under- or overestimation of the direct CO_2 emissions of the same magnitude. Systematic differences of +4 % to +6 % were identified in the verification tests and can potentially be caused by a swirl in the stack gas flow and a corresponding systematic effect on the SRM gas velocity measurements.

Additional methods are required for determining the fraction of biogenic CO_2 emissions in case of use of alternative fuels or materials with biogenic carbon content.

11.5 Evaluation of the overall uncertainty of a GHG inventory

In order to determine the overall uncertainty of a GHG inventory, the assessed uncertainties beforehand regarding activity data and parameters have to be aggregated by the error propagation laws.

11.6 Application of default values instead of analysing results

There are different situations for different fuels:

- commercial standard fuels, for example, diesel,
- commercial fuels, for example, natural gas, and

- other fuels, for example, used tyres or mixed industrial waste.

The cost and effort associated with sampling used tyres and processing them to a quality appropriate for analysis is very high. A representative sampling is nearly impossible and clearly not feasible in the same manner as required for monitoring of other fuels and materials. Sample processing and analytical methods applied are very expensive and subject to a high degree of uncertainty on an individual result, which can only be overcome by a high number of repetitions. At the same time, the composition of tyres is defined by their material and quality requirements. Thus, it is highly recommended and perhaps the only practicable solution to apply methods based on standardized average parameters. A focus should be on the correct accounting of the mass of consumed tyres. The content of water and mud in the tyres potentially influence the accuracy of the determined amount of tyres, so it should be ensured if or that no corrections have to be applied.

The results of field tests prove that methods A2 and B2 are well applicable for correctly determining CO_2 emissions in cement plants in complicated plant settings with significant share of alternative raw materials and fuels[20].

The simple input and output methods A1 and B1 are in general not appropriate for GHG reporting in a complicated plant setting. However, these simple methods can serve as valuable source of information for plausibility checks on the results of the more detailed mass balance methods A2 and B2.

Furthermore, the laboratory experience with the raw meal and clinker matrix is an essential requirement for assuring the accuracy of results. As such, materials and corresponding analyses belong to the core competencies of most cement plant laboratories in Europe, less problems with accuracy should be expected from plant laboratory analytical results, as for example verified during all four filed tests.

The laboratory procedures should include inter-laboratory comparisons for the corresponding material matrix, in order to ensure accuracy and prevent systematic errors in results used for CO_2 emission reporting."

The field tests also showed that the simple mass balance methods (A1 and B1) and therefore the application of default values for process emissions should not be used when

- raw materials / raw meal contains a significant content of organic carbon, or
- a significant share of alternative raw materials is used.

Annex A
(informative)

Findings from the field tests (analytical interferences)

A.1 Laboratory analyses and selection of appropriate methods

In one of the four verification tests, external laboratory data showed a systematic error corresponding to −9 % of CO_2 emissions from raw material calcination. This difference was larger than the specified uncertainty. A re-analysis of kiln feed and clinker samples and correction of results was able to decrease this significant systematic error in the most important analytical parameter to −2,5 %. The remaining systematic difference seems due to the selection of different analytical methods for measuring calcium oxide (CaO) and magnesium oxide (MgO): XRF-analysis versus titration. Both methods were subject to large difference in specified measurement uncertainty (about 1 % versus > 5 %, respectively). Furthermore, close agreement of results from two different laboratories gave confidence in the results of the XRF-analysis, which is commonly applied in most cement plant laboratories for regular product quality control – see Table A.1.

The results of the second plant test indicate that analytical results achieved by the titration method for the clinker matrix were not sufficiently precise and robust for emission reporting. It seems utmost important, that sufficient experience with the specific sample matrix, adequate procedures for sample processing and robust analytical methods are applied. Such procedures and methods are often established in cement plant laboratories with key expertise on raw materials, clinker and cement products. External laboratory analysis should be based on similar competence for the methods and sample matrix. For accredited laboratories, not only the analytical parameter but also the corresponding material or sample matrix should be encompassed in the scope of accreditation.

Table A.1 — Systematic errors corrected by application of appropriate analytical methods and accuracy

Clinker	Effect of corrected systematic error on direct CO_2 emissions	Parameter	Relevant method
XRF analysis for CaO, MgO	2 %	Clinker CO_2 EF	Output B2
Raw meal / kiln feed			
XRF analysis for CaO, MgO	1 %	Non-carbonate CaO, MgO, clinker CO_2 EF correction	Output B2
Carbonate CO_2 analysis			
TC analysis	8 %	Raw meal CO_2 EF	Input A2
TOC analysis	2,4 %	Organic CO_2 emissions	Output B2
LOI analysis	2 %	Raw meal CO_2 EF	Input A1, also for plausibility checks of A2, B2

Analyses of the biogenic carbon content in animal meal and sewage sludge with the selective dissolution method (see EN 15440[14]) often lead to erroneous results. This was experienced in the verification tests (field tests) when analytical results of about 85 % biogenic carbon content were found. The assurance of the source of the animal meal clearly confirmed a purely biogenic origin and biogenic carbon content of 100 %. Such confirmation from the material source and well-known composition is also suggested as the method in the EU monitoring and reporting regulation, Article 39 (2)[5].

A.2 Bypass dust calcination rate and determination of its CO_2 emission factor

The calcination rate of bypass dust cannot normally be calculated based on direct measures of the LOI. Bypass dust contains higher amounts of salts such as chlorides, which are also lost during heating. KCl and NaCl often contribute about 10 % to the total weight loss. Thus, the LOI is no precise measure for estimating the calcination rate *d* of bypass dust.

In addition, also inferring the calcination rate, *d,* of bypass dust from the comparison of the carbonate CO_2 content of bypass dust with the originally uncalcined raw meal is complicated. Again, this is due to the accumulation of salts and sulphates in the bypass dust, which change the mass reference. A difference of close to 20 % was identified in one of the field tests. In some plants, this accumulation can amount to 30 % of the mass of bypass dust. A correction of the mass reference is required for correctly determining the CO_2 emissions of bypass dust based on a measure of its remaining carbonate CO_2 content in comparison to the original carbonate CO_2 content of the raw meal consumed.

The maximum carbonate CO_2 content of raw meal consumed can be obtained from assessing the CaO and MgO content of bypass dust. It is then assumed, that all CaO and MgO originated from $CaCO_3$ and $MgCO_3$ carbonates in the raw meal in order to estimate the maximum carbonate CO_2 content. This evaluation automatically yields the correct mass reference for direct comparison to the measured remaining carbonate CO_2 content of bypass dust.

For higher accuracy and if relevant, this maximum carbonate CO_2 content can be corrected by a factor for the amounts of CaO and MgO that do not originate from carbonates.

For the assessment two different methods for determining the CO_2 emission factor of filter dust (EF_{FD} from degree of calcination *d*) and bypass dust (EF_{BPD} from remaining carbonate CO_2 content) are suggested in 7.2. Considering the theory of both methods, the second method (EF_{BPD} from remaining carbonate CO_2 content) is recommended for application in case of significant accumulation of certain compounds such as salts in bypass dust.

The first method represents a conservative approach, which can normally be applied to dusts from the main filter. For BPD, it will often result in increased CO_2 emission factors. The size of overestimating the emission factor of bypass dust (EF_{BPD}) will depend on the accumulation of certain components compared to clinker.

A.3 Correct reference of parameters regarding moisture

For correct reporting it should be ensured that activity data and corresponding parameters are reported with the same mass reference.

This is especially relevant for fuels and their moisture content (see also CSI Guidance Document, p. 17[1]). Correct reporting can be achieved by, for example,

— activity data as tonnes dry material, after correcting process scale data for the moisture content and using the corresponding LHV per dry material, or alternatively

— Activity data as tonnes wet material, for example, as measured by a process scale and LHV per wet material with the same moisture content.

In both cases, the moisture content should be sampled and measured correctly. Careful sample handling is required, in order to preserve the original moisture. The determination of the moisture content may only be omitted, when the material consumption is measured as completely dry material, for example, in case of fly ash or ground and already dried lignite.

An input mass balance for raw materials, raw meal and kiln feed can be calculated much easier and correctly, if mass flow contributions are first all converted to dry mass by subtracting their individual moisture content. In such a dry mass balance, corresponding material parameters such as, for example, LOI of the different materials, should also refer to dry mass.

Some cement plants are used to apply specific process related correction factors to measurement results. For example, energy correction of lower heating values regarding the energy demand for evaporation of water content of fuels. Such corrections can be practical for controlling the process heat input when exchanging fuels. However, they can cause significant errors in the application of material parameters, if the adjusted reference is not stated clearly and correctly. The application of such types of parameter corrections is therefore not recommended for CO_2 emission reporting.

A.4 Summary of stack emission mass flow results (including non-CO_2 GHG)

The CO_2 content of the stack gas was analysed according to ISO 12039. The uncertainty assessment was executed according to the procedure described in EN 15058[15] (for CO) and resulted in uncertainties in the range of 2,4 % to 3,3 %. Small concentrations of carbon monoxide (CO) were converted by the stoichiometric factor and considered in the direct stack CO_2 emissions. The contribution of CO amounts to less than 0,15 % of the direct emissions.

In all field tests methane (CH_4) and nitrous oxide (N_2O) emissions were detected in the kiln stack at the limit of determination (LOD) resulting in an estimated uncertainty of their concentrations and emissions of 50 % or higher. Considering their specific GHG warming potential (GWP) more than 99,5 % of the total CO_2 equivalent emissions consisted of CO_2 and CO.

A total of six spot measurements for fluorinated greenhouse gases performed during two field tests showed that the concentrations of SF_6, HFCs and PFCs were always below the limit of detection. This result meets the expectation, because there are no known sources for these gases in the cement manufacturing process.

A.5 Relevance of non-CO_2 GHG

Apart from CO_2, other GHG emissions can be found in cement industries emissions. Most important are CH_4 (methane) and CO (carbon monoxide), but also some other components have been mentioned.

a) CO emissions: Carbon monoxide (CO) emissions are completely covered by the mass balance input and output methods A1, A2, B1 and B2, which report emissions based on analysing or inferring the TC content of materials. This is confirmed by the plant tests of the verification exercise. The contribution of CO amounts to less than 0,15 % of the direct GHG emission, which is included in the mass balances.

b) CH_4 emissions: Methane (CH_4) emissions in the cement industry can originate from the organic content of raw materials. Thus, their magnitude is likely site and raw material specific. Literature values and results of the plant tests of the verification exercise indicate a maximum contribution to the total greenhouse warming potential of less than 0,01 %.

c) N_2O emissions: Literature values of nitrous oxide (N_2O) emissions indicate values for the contribution to the total emissions expressed as green-house warming potential from 0,02 % to 0,5 %. The value obtained from the measurements in the plant test, is 0,4 %.

d) Other GHG emissions: During the plant tests of the verification exercise some other non-CO_2 GHG have measured: sulfur hexafluoride (SF_6), and fluorinated hydrocarbons (PFCs, HFCs). A total of six spot measurements for fluorinated GHG performed during the plant tests showed that the concentrations of SF_6, HFCs and PFCs were always below the limit of detection.

From the field tests and literature, it is concluded[20] that non-CO_2 GHG emissions should be assumed to make rather insignificant contribution to the total GHG emissions of cement plants. From the current data and literature, the contribution of non-CO_2 GHG emissions to the greenhouse warming potential is assessed to range below 0,5 %. Often the contribution should be expected at less than 0,05 %.

Annex B
(informative)

Emission factors

B.1 Default emission factors

Calculation factors as default values should be in accordance with the requirement of this document and use one of the following values:

a) standard factors used by the member state for its national inventory submission to the secretariat of the United Nations Framework Convention on Climate Change;

b) literature values agreed with the competent authority, including standard factors published by the competent authority, which are representative of more disaggregated sources of fuel streams;

c) values specified and guaranteed by the supplier of a material where the operator can demonstrate that the carbon content exhibits a 95 % confidence interval of not more than 1 %.

Values based on analyses carried out in the past, where the operator can demonstrate that those values are representative for future batches of the same material.

B.2 Derivation of the calculation formula for the emission factor of filter dust

Filter dust is usually not fully calcined. The CO_2 emission factor for FD can be derived from the mass balance between FD, raw meal and released CO_2 indicated in Formula (B.1):

$$FD = RM - CO_{2,RM} \times d \tag{B.1}$$

where

FD is the quantity of filter dust produced (t);

RM is the amount of dry raw meal consumed and converted to FD (t);

$CO_{2,RM}$ is the total carbonate CO_2 contained in the raw meal (t);

d is the FD calcination rate (released CO_2 expressed as a fraction of the total carbonate CO_2 in the raw meal).

The CO_2 emission factor for FD is:

$$EF_{\mathrm{FD}} = \frac{CO_{2,RM} \times d}{FD} = \frac{CO_{2,RM} \times d}{RM - CO_{2\ RM} \times d} \tag{B.2}$$

where EF_{FD} is the emission factor for FD (t CO_2/t FD).

Since $CO_{2\ RM}$ is proportional to the amount of raw meal, Formula (B.2) can be re-written as Formula (B.3):

$$EF_{\mathrm{FD}} = \frac{fCO_{2,RM} \times d}{1 - fCO_{2,RM} \times d} \tag{B.3}$$

where $fCO_{2\ RM}$ is the weight fraction of carbonate CO_2 in the raw meal (t CO_2 /t RM).