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

Part 5: Lime industry

National foreword

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Contents

European foreword

This document (EN 19694-5:2016) has been prepared by Technical Committee CEN/TC 264 “Air quality”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2017, and conflicting national standards shall be withdrawn at the latest by January 2017.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate M/478 given to CEN by the European Commission and the European Free Trade Association.

This part of EN 19694 deals with sector-specific aspects for the determination of greenhouse gas (GHG) emissions from lime manufacture.

This European Standard can be used to measure, report and compare the GHG emissions of a lime manufacturing plant. Data for individual plants, sites or works may be combined to measure, report and compare GHG emissions for an organization, corporation or group.

EN 19694, *Stationary source emissions – Determination of greenhouse gas (GHG) emissions in energy intensive industries* is a series of standards that consists of the following parts:

- *Part 1: General aspects*
- *Part 2: Iron and steel industry*
- *Part 3: Cement industry*
- *Part 4: Aluminium industry*
- *Part 5: Lime industry*
- *Part 6: Ferroalloy industry*

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This European Standard provides a harmonized methodology for calculating GHG emissions from the lime industry. It includes the manufacture of lime, and any downstream lime products manufactured at the plant, such as ground or hydrated lime. This standard allows for reporting of GHG emissions for various purposes and on different basis, such as plant basis, company basis (by country or by region) or international organization basis.

Since lime is defined as the generic name for quicklime, dolime and sintered dolime, plants manufacturing at least one of these products shall be covered by this standard.

This European Standard addresses all of the following direct and indirect sources of GHG included as defined in ISO 14064-1:

- direct greenhouse gas emissions from greenhouse gas sources that are owned or controlled by the company, such as emissions resulting from the following sources:
  - calcination of carbonates and combustion of organic carbon contained in the kiln stone;
  - combustion of kiln fuels (fossil kiln fuels, alternative fossil fuels, mixed fuels with biogenic carbon content, biomass fuels and bio fuels) related to lime production and/or drying of raw materials;
  - combustion of non-kiln fuels (fossil kiln fuels, mixed fuels with biogenic carbon content, biomass fuels and bio fuels) related to equipment and on-site vehicles, heating/cooling and other on-site uses;
  - combustion of fuels for on-site power generation.
- indirect greenhouse gas emissions from the generation of imported electricity, heat or steam consumed by the organization;
- other indirect greenhouse gas emissions, other than energy indirect GHG emissions, which is a consequence of an organization's activities, but arises from greenhouse gas sources that are owned or controlled by other organizations such as from imported kiln stone.

This European Standard is to be used in conjunction with EN 19694-1, which contains generic, overall requirements, definitions and rules applicable to the determination of GHG emissions for all energy-intensive sectors, provides common methodological issues and defines the details for applying the rules. The application of this standard to the sector-specific standards ensures accuracy, precision and reproducibility of the results and is for this reason a normative reference standard.

Together these standards provide a harmonized method for:

a) measuring, testing and quantifying methods for GHG emissions;

b) assessing the level of GHG emissions performance of production processes over time, at production sites;

c) establishment and provision of reliable, accurate and quality information for reporting and verification purposes.

GHG emissions offset mechanisms, including but not limited to voluntary offset schemes or nationally or internationally recognized offset mechanisms, shall not be used at any point in the GHG assessment according to this standard.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 459-2, *Building lime — Part 2: Test methods*

EN 932-1, *Tests for general properties of aggregates — Part 1: Methods for sampling*

EN 12485, *Chemicals used for treatment of water intended for human consumption — Calcium carbonate, high-calcium lime, half-burnt dolomite, magnesium oxide and calcium magnesium carbonate — Test methods*

EN 13639, *Determination of total organic carbon in limestone*

EN 15442, *Solid recovered fuels — Methods for sampling*

EN 19694-1:2016, *Stationary source emissions — Determination of greenhouse gas (GHG) emissions in energy-intensive industries — Part 1: General aspects*

ISO 5069-1, *Brown coals and lignites — Principles of sampling — Part 1: Sampling for determination of moisture content and for general analysis*

ISO 13909 (all parts), *Hard coal and coke — Mechanical sampling*

ISO 18283, *Hard coal and coke — Manual sampling*

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

3 Terms and definitions

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

3.1
activity data
information on material flow, consumption of fuel, input material or production output

Note 1 to entry: Expressed as energy [GJ] or as mass or volume [t or m^3_N] in the case of fuels and mass or volume in the case of raw materials or products [t or m^3_N].

3.2
dolime
product resulting from the calcination of kiln stone consisting of calcium carbonate and magnesium carbonate

3.3
downstream lime product
downstream lime products including Run-Of-Kiln lime (ROK), Lime Kiln Dust (LKD) and products made from them at the plant including ground lime and hydrated lime

3.4
free CaO and MgO

calcium oxide or magnesium oxide that has been produced in the kiln during the decarbonation of calcium carbonate or magnesium carbonate

Note 1 to entry: The terminology free CaO and MgO as used in this standard may differ from the terminology applied in other standards.

3.5
kiln battery

group of kilns at the same plant and of the same design

EXAMPLE Parallel Flow Regenerative Kilns, Annular Shaft Kilns, Mixed Feed Shaft Kilns, Preheater Rotary Kilns or Long Rotary Kilns

3.6
kiln stone

limestone that is fed into the kiln

3.7
lime
LI

generic name for quicklime, dolime or sintered dolime

3.8
lime kiln dust
LKD

partly calcined kiln stone material which is extracted by the kiln particulate abatement system

3.9
limestone
LS

sedimentary rock consisting of calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), mineral and other minor impurities, including in some cases a small fraction of organic carbon

3.10
non kiln stone aggregates

all stones extracted from a quarry except that used as kiln stone

3.11
quicklime

product resulting from the calcination of limestone consisting primarily of calcium carbonate

3.12
residual CO_2

CO_2 that remains in the product leaving the kiln which is bound with CaO in the form of $CaCO_3$ and possibly with MgO in form of $MgCO_3$

3.13
run-of-kiln lime
ROK

direct output from the kiln

3.14
sintered dolime
dolime heated to temperatures below its melting temperature, so as to increase its density

4 Symbols and abbreviations

$m_{CO2-stack}$	mass of CO_2 emitted through the stack	t
$\bar{x}$	arithmetic mean of the measured values	
$CaCO_{3\ LI-ROK}$	weight fraction of calcium carbonate in the dry ROK lime produced by the kiln	
$CaCO_{3\ LKD}$	weight fraction of calcium carbonate in the dry LKD	
$CaCO_{3\ LS}$	weight fraction of calcium carbonate in the dry limestone fed into the kiln	
CaO_{fr}	free *CaO*	
CaO_{LI-ROK}	weight fraction of free calcium oxide in the dry ROK lime produced by the kiln	
CaO_{LKD}	weight fraction of free calcium oxide in the dry LKD	
CaO_t	total *CaO*	
CV_{Fy}	calorific value of the fuel (y). It is important to note that the applied calorific 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)	GJ/t or GJ/m3N
d_i	the transport distance of the kiln stone for the mode i	
EF_{LI}	emission factor of the ROK lime, here the CO_2 emissions resulting from the calcination of the limestone factor per mass of ROK lime	CO_{2e} / t
EF_{LS}	emission factor of the limestone, here the CO_2 emissions resulting from the calcination of the limestone factor per mass of limestone	CO_{2e} / t
EF_{ELEC}	emission factor of externally generated electricity	(CO_{2e} / kWh)
EF_{Fy}	emission factor of the fuel (y) expressed as (combustion emissions)	t_{CO2e}/GJ
$EF_{LS-PUR\ i}$	the greenhouse gas emission factor of imported kiln stone	
LI	lime	
LKD	lime kiln dust	
LS	limestone	
m_{LI-ROK}	dry mass of ROK lime	t
m_{LKD}	dry mass of LKD generated by the process	t
m_{LS}	dry mass of limestone fed into the kiln or kiln battery	t
M_{MgCO3}	molar mass of magnesium carbonate	84,314 g/mol
M_{MgO}	molar mass of magnesium oxide	40,304 g/mol

M_{CaCO3}	molar mass of calcium carbonate	100,087 g/mol
M_{CaO}	molar mass of calcium oxide	56,077 g/mol
M_{CO2}	molar mass of carbon dioxide	44,010 g/mol
m_{Fy}	material flow of a fuel (y), i.e. the fuel consumption expressed as mass for solid and liquid fuels or as volume for gaseous fuels	t or m^3_N
$MgCO_{3\ LI\text{-}ROK}$	weight fraction of magnesium carbonate in the dry ROK lime produced by the kiln. In practice, this mass fraction can be considered as close to 0 as the magnesium carbonate is fully converted to magnesium oxide due to the temperatures prevailing in the kiln	
$MgCO_{3\ LKD}$	weight fraction of magnesium carbonate in the dry LKD	
$MgCO_{3\ LS}$	weight fraction of magnesium carbonate in the dry limestone fed into the kiln	
$MgO_{\ LI\text{-}ROK}$	weight fraction of free magnesium oxide in the dry ROK lime produced by the kiln	
$MgO_{\ LKD}$	weight fraction of free magnesium oxide in the dry LKD	
MgO_{fr}		
m_i	the mass of load i	t
$m_{LI\text{-}Prod}$	measured mass of downstream lime product	
$m_{LKD\text{-}out}$	dry mass of LKD that is not blended with the downstream lime	t
$m_{LS\text{-}PUR\ \ i}$	the annual total (wet) mass of imported kiln stone from the third party that is imported into the plant and used for lime manufacture during the 12 month reporting period	t
Ox_{Fy}	oxidation factor of the fuel (y)	
Q_{ELEC}	quantity of electricity consumed	
ROK	run of kiln	
t	metric tonne	t
t_e	tonnes of aggregates used for the production of fillers	t_e
$TF_{LS\text{-}PUR}$	emission factor per wet mass for kiln stone imported	$kgCO_2/t$
$TF_{LS\text{-}PUR\ i}$	the GHG emission factor of transport mode i	
t_{gt}	a given period of time	t_{gt}
$TOC_{\ LS}$	total organic carbon content of the limestone	
Ua	uncertainty associated with the overall analytical procedure	
U_i	relative expanded uncertainty	
Um	uncertainty associated with the sampling procedure	
Umi	uncertainty of the weighbridge for measurement of load I	
Umtotal	total relative uncertainty of the mass measurement	
w	average moisture content of the kiln stone determined according to the provisions of 9.2.2.3	

x_i	absolute amount of mass flow or material in stock in the mass balance
y	fuel consumed
η_{LI}	mass flow of LKD generated in the dedusting system(s) of the kiln divided by the mass flow of ROK lime produced by the kiln
η_{LS}	mass flow of LKD generated in the dedusting system(s) of the kiln divided by the dry mass flow of limestone fed into the kiln

5 Introduction

5.1 Overview of the lime manufacturing process

Lime manufacture includes three main process steps: 1

a) kiln stone preparation including quarrying, crushing, washing, screening and transporting to the lime kiln;

b) kiln operation including lime manufacture using pyro-processing to calcine the kiln stone in a lime kiln;

c) downstream processing including crushing, screening, transporting to silos, grinding/milling, hydrating and packing.

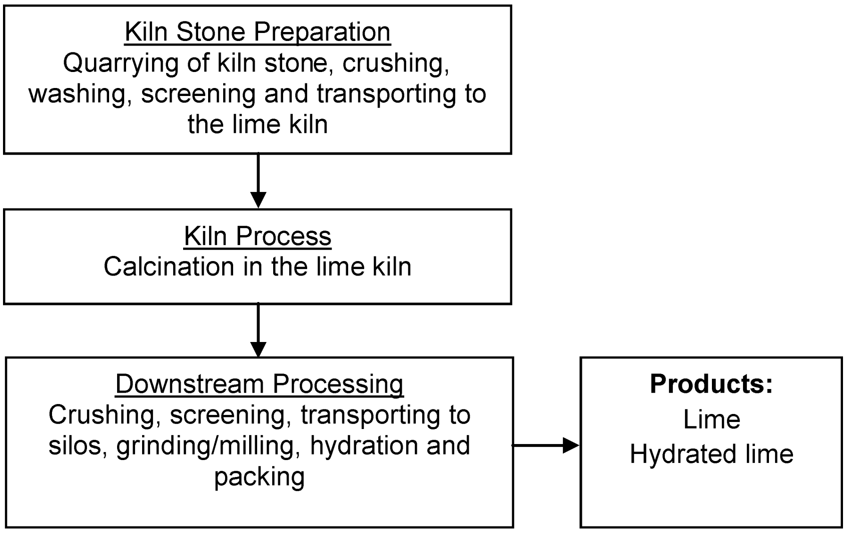

Figure 1 — Process steps in lime manufacture

A lime manufacturing plant may also encompass the use of additional fuel for on-site power generation and for preparation or processing of fuels for use in the plant.

There are two main sources of direct greenhouse gas emissions in the lime manufacturing process:

— calcination of kiln stone through pyro-processing in the lime kiln (known as process emissions);

— combustion of kiln fuels (known as combustion emissions).

These two sources are described in more detail below.

Other minor direct greenhouse gas emissions may come from non-kiln fuels such as on-site transport, pumps, room heating and other on-site uses.

The main source of energy indirect greenhouse gas emissions in the lime manufacturing process come from external power production or transport but these sources are relatively small in comparison to the direct greenhouse gas emissions.

For the lime sector, only the greenhouse gas CO_2 is relevant as demonstrated by different field tests. Details about these tests are provided in Annex A.

5.2 Direct greenhouse gas emissions from calcination of kiln stone (process emissions)

In the lime manufacturing process, CO_2 is released due to the chemical decomposition of calcium, magnesium and other carbonates in the kiln stone when the kiln stone is heated to high temperatures:

$$CaCO_3 \rightarrow CaO + CO_2 \tag{1}$$

$$MgCO_3 \rightarrow MgO + CO_2 \tag{2}$$

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

- CO_2 from kiln stone used for lime production;
- CO_2 from materials leaving the kiln system as partly calcined LKD.

The CO_2 from lime production is dependent on the quality of the final lime product, i.e. the degree of calcination. This varies depending on the kiln design and targeted final lime product properties. The amount of LKD leaving the kiln system varies with kiln type. The associated greenhouse gas emissions are likely to be relevant and so shall be accounted for.

CO_2 emissions from calcination can be determined as a part of the measurement method or by using the following mass-balance-based methods which are in principle equivalent:

a) the Input Method, based on the mass of kiln stone entering the kiln and chemical composition of the limestone, lime and LKD leaving the kiln system;

b) the Output Method, based on the mass and chemical composition of the lime and LKD leaving the kiln system;

c) direct greenhouse gas emissions from organic carbon in kiln stone.

Some kiln stone sources contain a small fraction of organic carbon, which can be expressed as total organic carbon (TOC) content. Organic carbon in the kiln stone is converted to CO_2 during pyro-processing. The contribution of this component to the overall CO_2 emissions is typically very small. The organic carbon content of kiln stone can, however, vary substantially between locations and shall be assessed.

5.3 Direct greenhouse gas emissions from fuels for kiln operation (combustion emissions)

The lime industry uses various fossil fuels to heat the kiln, including natural gas, coal and fuel oil. In recent years, fuels derived from waste materials have become important substitutes. These alternative fuels (AF) include fossil fuel-derived fractions, such as waste oil, as well as biomass-derived fractions, such as waste wood. Furthermore, fuels are increasingly used which contain both fossil and biogenic carbon, such as municipal and pre-treated industrial wastes or waste tyres (containing natural and synthetic rubber).

Both traditional and AF result in direct greenhouse gas emissions through the kiln stack. However, biomass fuels and the biomass component of mixed fuels are considered “climate-neutral” in accordance with IPCC definitions.

Greenhouse gas emissions from combustion of fuels can be calculated based on the mass, calorific value and chemical composition of fuels entering the kiln.

The mass-balance-based method used in this standard is compatible with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories issued by the Intergovernmental Panel on Climate Change (IPCC).

Alternatively, kiln GHG emissions, from combustion, calcination and organic carbon in the kiln stone, can be determined by direct measurement at the kiln stack using the stack-measurement-based method. Emissions from the kiln stack all sources are determined based on continuous measurement of the concentration of the relevant GHG in the flue gas and of the flue gas volume flow. For the stack-measurement-based method non-kiln emissions are measured using a mass balance approach similar to the mass-balance-based method. Direct greenhouse gas emissions from non-kiln fuels (combustion emissions)

Greenhouse gas emissions from use of fuels in non-kiln applications which are part of the lime manufacturing plant, such as on-site transport, fuel heating, and room heating are determined in a similar way to the greenhouse gas from fuels for kiln operation.

5.4 Energy indirect greenhouse gas emissions

In lime manufacture the main energy indirect greenhouse gas emission source is electricity purchased by the plant but generated off-site. Where kiln stone is imported to the plant, the emissions associated with its manufacture to the plant shall be included within the scope of this standard. The emissions associated with the off-site transport of purchased kiln stone to the plant may be included within the scope of this standard.

6 System boundaries

6.1 Appropriate boundaries to distinguish

The reporting entity shall define appropriate boundaries in line with ISO 14064-1 which distinguishes between organizational and operational boundaries.

6.2 Organizational boundaries

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.

The rules for defining organizational boundaries in EN 19694-1 shall be applied.

In particular, the lime industry shall include the following types of activities:

- kiln stone preparation including quarrying, crushing, washing, screening and transporting to the lime kiln;
- calcination in the lime kiln;
- downstream processing including crushing, screening, transporting to silos, grinding/milling, hydrating and packing;
- fuel use for on-site power generation or heat;
- preparation or processing of fuels in own installations.

6.3 Operational boundaries

6.3.1 Scopes of emissions to be included

Operational boundaries define the types of sources of emissions covered by this standard.

The requirements for defining the scopes of emissions in EN 19694-1 shall be applied.

Subject to the limitations set out in 6.4 below, the following greenhouse gas emissions sources shall be measured for lime manufacturing plant facilities:

- all direct greenhouse gas emissions (direct emissions) from greenhouse gas sources owned or controlled by the organization;
- all energy indirect greenhouse gas emissions (indirect emissions) from the generation of imported electricity, heat or steam consumed by the organization;
- other indirect greenhouse gas emissions (other indirect emissions) from the production and transportation of imported kiln stone.

Each lime plant shall undertake an assessment of its direct greenhouse gas emission sources, energy indirect greenhouse gas emission sources and, where relevant, other indirect greenhouse gas emission sources. The assessment shall include GHG emissions from all stages of the lime manufacturing process undertaken at the plant including kiln stone preparation, calcination and downstream processing of the lime products such as into ground lime or hydrated lime. Where kiln stone is imported into the site, GHG emissions from its production shall be included for use in performance assessments.

By way of example, but not restricted to, the following greenhouse gas emissions as shown in Table 1 are relevant for a typical lime manufacturing plant:

Table 1 — Relevant GHG emissions for a lime manufacturing plant

	Scope	**Process steps**
Kiln stone preparation	direct greenhouse gas emissions	Direct greenhouse gas emissions including extraction, quarry operations, transport to stone processing plant, processing (washing, crushing, screening), transport to the lime kiln
	energy indirect greenhouse gas emissions	Indirect greenhouse gas emissions including extraction, quarry operations including quarry dewatering, transport to stone processing plant, processing (washing, crushing, screening), transport to the lime kiln
	other indirect greenhouse gas emissions	Includes imported kiln stone extraction, quarry operations including quarry dewatering, transport to stone processing plant, processing (washing, crushing, screening), transport to the lime kiln
Kiln process	direct greenhouse gas emissions	Direct greenhouse gas emissions from the manufacture of lime
		Direct greenhouse gas emissions from the production of LKD
		Direct greenhouse gas emissions from the combustion of fossil fuels
	energy indirect greenhouse gas emissions	Indirect greenhouse gas emissions from kiln operation and infrastructure
Downstream processing	direct greenhouse gas emissions	Includes transport to silos, grinding/milling, hydrating or packing
	energy indirect greenhouse gas emissions	Includes transport to silos, grinding/milling, hydrating or packing

It is not necessary to include the following greenhouse gas emissions as these are deemed to be insignificant or out of scope:

- greenhouse gas emissions from overburden removal in the quarry;

- greenhouse gas emissions from the rehabilitation or restoration of the quarry and plant;
- greenhouse gas emission from manufacture and use of explosives during quarrying;
- greenhouse gas emissions from the original development of the plant, including the manufacturing the infrastructure;
- greenhouse gas emissions from the production, transportation and distribution of fossil and alternative fuels;
- other indirect greenhouse gas emissions, other than for kiln stone imported to the plant.

If these greenhouse gas emissions are incorporated within the available measured values, and cannot be separately measured, then they shall be included in the reported information.

6.3.2 Structure of plants and processes

The reporting entity shall document all production units at the plant, including the downstream processes, such as grinding and hydration.

If there is more than one type of industry being operated at the plant the reporting entity shall clearly identify the operations associated with lime manufacture.

6.4 Sources and greenhouse gases to be included

All greenhouse gas emissions sources necessary for producing lime shall be included.

The following greenhouse gas shall be reported as carbon dioxide equivalent (CO_{2e}) using the relevant Global Warming Potential for a time horizon of 100 years (GWP 100 factor), consistent with reporting under the second assessment report of the Intergovernmental Panel on Climate Change (IPCC):

- carbon dioxide (CO_2).

As demonstrated during different field tests, other greenhouse gasses are not relevant for the lime industry (Annex A).

6.5 Internal lime transfers

Some lime companies transfer lime products internally between different lime plants for further downstream processing, for example, milling/grinding or hydration. These transferred products shall be accounted for in a manner that avoids double counting between different plants or distortion of the performance indicators. Such transfers shall be taken into account in the calculation of the performance indicators.

6.6 Assessment period

Data for determination of greenhouse gas emissions and performance indicators shall be collected over a minimum 12 months' period. If data are collected over a shorter period this shall be reported by the reporting entity wherever results are published.

7 Principles

Accounting and performance assessment of greenhouse gas emissions shall be based on the principles as described in the Introduction to EN 19694-1.

8 Determination of greenhouse gas emissions: general requirements

8.1 Monitoring Plan and other requirements for identifying, calculating and reporting of greenhouse gas emissions

The reporting entity shall develop a monitoring plan to identify, calculate and report greenhouse gas emissions according to EN 19694-1.

The monitoring plan shall contain at least the elements laid down in Annex A of EN 19694-1:2016 and in Annex B of this standard.

8.2 Stack-measurement-based method or mass-balance-based method

The amount of kiln direct greenhouse gas emissions can be determined by stack-measurement-based methods or a mass-balance-based method.

Both techniques with the corresponding requirements are described in Clause 9 of EN 19694-1:2016.

For lime plants, it is not usually practical for the concentration of emissions from all emission sources to be measured directly. The stack-measurement-based method therefore involves only the continuous measurement of the greenhouse gasses from the kiln exhaust stack(s) and application of the mass-balance-based method for other emission sources in accordance with 9.4.

Where biomass or mixed fuels containing biomass are used, the greenhouse gas emissions associated with the biomass fraction shall be determined using the mass-balance-based method described in 9.2. The annual proportion for greenhouse gas emissions from the biomass shall be deducted from the total kiln greenhouse gas emissions as measured continuously at the exhaust stack(s).

9 Direct greenhouse gas emissions) and their determination

9.1 Sources of direct greenhouse gas emissions and the applicability of determination methods

In the production of lime direct greenhouse gas emissions may arise from, but are not restricted to, the following sources:

- calcination of carbonates and organic carbon contained in the kiln stone (and other raw materials where relevant);

- combustion of fuels used to heat the kiln, including:

    - combustion of traditional fuels;

    - combustion of alternative or mixed fuels with biogenic content;

    - combustion of biomass and bio-fuels (including biomass wastes).

- combustion of fuels for non-kiln processes, including:

    - combustion of traditional fuels;

    - combustion of mixed fuels with biogenic content;

    - combustion of biomass and bio-fuels (including biomass wastes);

- combustion of fuels for on-site power generation.

The reporting entity shall prepare a full inventory of all direct greenhouse gas emissions sources of the plant.

The amount of kiln direct greenhouse gas emissions can be determined by the continuous stack-measurement-based method or by the mass-balance-based method.

Determination using the stack-measurement-based method involves the continuous measurement of the concentration of the relevant greenhouse gases in the flue gas and the flue gas volume. The stack-measurement-based method can only be applied to the kiln greenhouse gas emissions and cannot be applied to other site or plant greenhouse gas emissions which require application of a mass-balance-based method. If the stack-measurement-based method is selected, the provisions specified in clauses 9.2.2.1 to 9.2.2.6 of EN 19694-1:2016 shall to be met.

Determination using the mass-balance-based method involves emissions from each source stream being determined based on input or production data obtained by means of measurement systems and additional parameters from laboratory analyses (e.g. chemical analysis, calorific value, carbon content, biomass content) and/or standard factors. According to site trials the mass-balance-based method achieves a significantly lower uncertainty than the measurement method. Therefore the calculation based method should be the preferred method.

9.2 Direct CO_2 greenhouse gas emissions from the calcination of kiln stone (process emissions) using the mass-balance-based method

9.2.1 Introduction and overview of the methods

Calcination is the release of CO_2 from carbonates and organic carbon in the kiln stone during pyro-processing. During calcination of kiln stone CO_2 is released:

— either when the kiln stone is decarbonated according to the reactions (1) and (2);

— or when organic carbon contained in the kiln stone is oxidized when the kilnstone is heated according to the following generic reaction:

$$C + O_2 \rightarrow CO_2 \tag{3}$$

CO_2 emissions from calcination therefore include:

— CO_2 emissions from the partial or full calcination of kiln stone;

— CO_2 emissions from the partial or full calcination of LKD leaving the kiln system;

— CO_2 emissions from the oxidation of organic carbon in the kiln stone.

CO_2 emissions associated with the calcination of kiln stone can be determined by the mass-balance-based method in two ways:

— the **input method**, based on the mass, contents of carbonates and carbon of the kiln stone consumed, composition of the Lime Kiln Dust (LKD) leaving the kiln system as well as the carbonate content of the lime;

— the **output method**, based on the mass and composition (free calcium and magnesium oxides) of the lime and the LKD leaving the kiln system.

The mass flows and chemical compositions of the kiln stone and LKD refer systematically to a dry state (< 1 % humidity). The moisture content of the required mass flows shall be determined as far as relevant to convert the as measured (wet) mass flows into dry mass flows.

The reporting entity may choose which of these methods to apply. The selection of method shall be made according to the availability and location of sampling and measurement equipment (Table 2).

Table 2 — Overview of methods for the determination of direct greenhouse gas CO_2 emissions from the calcination of kiln stone (process emissions) using the mass-balance-based method

			Input Method	**Output Method**
CO_2 from lime production	All plants	Mass	Measured kiln stone consumed according to the provisions of 9.2.2.2	Measured lime production according to the provisions of 9.2.3.2
		Composition	Measured moisture, $CaCO_3$, $MgCO_3$ and organic carbon contents in kiln stone according to the provisions of 9.2.2.3	Measured organic carbon content in kiln stone according to the provisions of 9.2.3.4
			Measured $CaCO_3$ in ROK lime according to the provisions of 9.2.2.6	Measured free CaO and free MgO in ROK lime according to the provisions of 9.2.3.3
CO_2 from LKD	All plants	Mass	Continuous measurement of LKD production or Estimation of the LKD production based on spot measurements according to the provisions of 9.2.2.4 or Use of a default value for the estimation of LKD production as defined in 9.2.2.4	Continuous measurement of LKD production or Estimation of the LKD production based on spot measurements according to the provisions of 9.2.3.4 or Use of a default value for the estimation of LKD production as defined in 9.2.3.4
		Composition	Measured $CaCO_3$, $MgCO_3$, free CaO and free MgO in LKD according to the provisions of 9.2.2.5 or Use the composition of the lime product according to the provisions of 9.2.2.5	Measured free CaO and free MgO in LKD according to the provisions of 9.2.3.5 or Use the default values according to the provisions of 9.2.3.5

In this standard free CaO and MgO are to be calculated according to the following formula, providing that the amount of MgO does not exceed 5 %:

$$free\ CaO = total\ CaO - CaO\ bound\ in\ form\ of\ CaCO_3 \tag{4}$$

$$free\ MgO = total\ MgO \tag{5}$$

If the amount of MgO exceeds 5 %, the method and assumptions used to calculate the free CaO and free MgO shall be specified.

$MgCO_3$ decomposes at a lower temperature than $CaCO_3$ so all residual CO_2 can be assumed to be as $CaCO_3$.

9.2.2 Input method

9.2.2.1 The main formula of the input method

The input method is based on determining the amount of limestone consumed in manufacturing lime.

CO_2 emissions are determined using the following formula [1]

$$m_{CO2-stack} = (EF_{LS} \times m_{LS}) + m_{CO2-oxy} \tag{6}$$

where

$$\begin{array}{l} EF_{LS} = \left\{ \left(CaCO_{3LS} - \eta_{LS} \times CaCO_{3LKD} \right) \times 0.4397 + \left(MgCO_{3LS} - \eta_{LS} \times MgCO_{3LKD} \right) \times 0.5231 \right\} \\ - \left\{ \begin{array}{l} \dfrac{CaCO_{3LI-ROK} \times 0.4397 + MgCO_{3LI-ROK} \times 0.5231}{1 - \left(CaCO_{3LI-ROK} \times 0.4397 + MgCO_{3LI-ROK} \times 0.5231 \right)} \times \\ \left[\begin{array}{l} \left(\left(1 - CaCO_{3LS} - MgCO_{3LS} \right) + CaCO_{3LS} \times 0.5603 + MgCO_{3LS} \times 0.4780 \right) - \eta_{LS} \\ \times \left(\begin{array}{l} \left(1 - CaO_{LKD} - MgO_{LKD} - CaCO_{3LKD} - MgCO_{3LKD} \right) + CaO_{LKD} + CaCO_{3LKD} \\ \times 0.5605 + MgO_{LKD} + MgCO_{3LKD} \times 0.4780 \end{array} \right) \end{array} \right] \end{array} \right\} \end{array} \tag{7}$$

and where

$$m_{CO2-oxy} = \frac{44}{12} \times m_{LS} \times TOC_{LS} \tag{8}$$

In the above equations all masses shall be expressed in t t

The reporting entity shall:

- apply this calculation formula to each kiln or kiln battery and each type of lime manufactured at the plant;
- and sum the $m_{CO2-stack}$ for each to give a total $m_{CO2-stack\ tot}$ for the plant.

The parameters in this equation shall be determined as follows:

9.2.2.2 Determination of the mass of kiln stone

The annual total wet mass (t) of kiln stone processed through each kiln or kiln battery shall be measured (m_{LS-wet}). This mass shall be corrected to take into account the moisture content of the kiln stone according to the following formula:

$$m_{LS} = m_{LS-wet} \times (1 - w) \tag{9}$$

9.2.2.3 Determination of the composition of kiln stone

The moisture and the calcium carbonate ($CaCO_{3\ LS}$), magnesium carbonate ($MgCO_{3\ LS}$) and total organic (TOC) contents of the kiln stone shall be determined for each kiln or kiln battery according to the frequency of sampling and analytical methods of analytics specified in Table 3.

If the reporting entity can demonstrate that the moisture of the kiln stone is consistently below or equal to 1 %, then the kiln stone mass does not have to be corrected for moisture.

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1) The detailed derivation of the formula is explained in Annex C.

Table 3 — Sampling and type of analyses to be performed on the kiln stone in the input method

Parameter	Sampling location	Frequency of sampling	Sampling method	Frequency of analysis	Test method
Moisture	Conveyor belt or other suitable location before the kiln feed system	1 sample per month per kiln or kiln battery	EN 932-1	1 analysis per 50 000 t [a] per kiln or kiln battery and minimum 1 analysis per quarter [a] per kiln or kiln battery	Water content: EN 12485 or EN 459-2
$CaCO_{3\,LS}$					Calcium carbonate and magnesium carbonate content: EN 12485 EN 459-2
$MgCO_{3\,LS}$					
(TOC_{LS}) [b]					EN 13639

[a] Can be reduced by a factor of 2 if tests show after an initial period of one annum: The ratio between the standard deviation (Ss) of the historical results and their average ($\overline{x}$) does not exceed 0,1. All test results range between ($\overline{x}$ – S_s) and ($\overline{x}$ + S_s). If at least one series of results does not comply with the above criteria, the initial sampling rates in Table 3 shall be reapplied.

[b] If the TOC_{LS} content of the kiln stone can demonstrated to be below or equal to 0,15 % on a dry basis it does not need to be measured routinely and can be assumed to be zero.

9.2.2.4 Determination of the mass of LKD

The annual total mass (t) of LKD (m_{LKD}) generated by each kiln or kiln battery should be measured. The measured quantity shall then include all LKD collected in the abatement system before it is blended into commercial products or disposed. A kiln specific ratio of LKD to kiln stone (η_{LS}) shall be calculated using the following formula:

$$\eta_{LS} = \frac{m_{LKD}}{m_{LS}} \tag{10}$$

For plants unable to measure the annual total mass of LKD, the mass may be determined by developing a kiln specific ratio (η_{LS}) on the basis of short term sampling as specified in Table 4.

Table 4 — Procedure for determining the ratio of LKD to kiln stone in the input method

Parameter	Sampling location	Frequency of sampling	Sampling method	Frequency of test	Test method
η_{LS}	Non applicable	Not applicable	Not applicable	1 test per annum for vertical kilns or battery of vertical kilns or 1 test per quarter for horizontal kilns or battery of horizontal kilns	Total mass of LKD generated (m_{LKD}) and total dry mass of kiln stone (m_{LS}) fed into the kiln during the same defined period of time (e.g. 4 to 8 h) Internal measurement with calibrated weighing system

$$\eta_{LS} = \frac{m_{LKD}(t_{gt})}{m_{LS}(t_{gt})} \tag{11}$$

Where short term tests cannot be performed the reporting entity may use the default values in Table 5.

Table 5 — Default values for the ratio of LKD to kiln stone in the input method

Type of lime kiln	$\eta_{LS} = m_{LKD} / m_{LS}$
Vertical kilns: Parallel flow regenerative kiln Annular shaft kiln Mixed feed shaft kiln Other shaft kiln	1 %
Horizontal kiln: Preheater rotary kiln	5,5 %
Horizontal kiln: Long rotary kiln	8 %

9.2.2.5 Determination of the composition of LKD

The calcium carbonate ($CaCO_{3\ LKD}$), magnesium carbonate ($MgCO_{3\ LKD}$), free calcium oxide (CaO_{LKD}) and free magnesium oxide (MgO_{LKD}) contents of the LKD shall be measured according to the frequency of sampling and the method of analysis specified in Table 6.

Table 6 — Sampling and type of analyses to be performed on the LKD in the input method

Parameter	Sampling location	Frequency of sampling	Sampling method	Frequency of analysis	Test method
CaO_{LKD}	Discharge screw of the dedusting system, flow of LKD leaving the kiln system or other suitable sampling location	1 sample per month per kiln or kiln battery	EN 932-1	1 analysis per quarter[a] on composite sample	Calcium carbonate, magnesium carbonate, calcium oxide and magnesium oxide contents: EN 12485 EN 459-2
MgO_{LKD}					
$CaCO_{3\ LKD}$					
$CaCO_{3\ LKD}$					
If at least one series of results does not comply with the above criteria, the initial sampling rates in Table 6 shall be reapplied.					

[a] Can be reduced by a factor of 2 if tests show after an initial period of one annum: The ratio between the standard deviation (Ss) of the historical results and their average ($\overline{X}$) does not exceed 0,1. All test results range between ($\overline{X} - S_s$) and ($\overline{X} + S_s$).

Where the reporting entity does not sample and analyse the LKD, the composition of the LKD shall be assumed to be same as the ROK lime (see 9.2.2.6).

9.2.2.6 Run-of-Kiln Lime (ROK lime)

The calcium carbonate ($CaCO_{3\ LI\text{-}ROK}$) content of the ROK lime shall be determined on the basis of a chemical analysis performed according to the methods specified in Table 7**.** It can be assumed that the magnesium carbonate is completely transformed into magnesium oxide ($MgCO_{3\ LI\text{-}ROK} = 0$).

Table 7 — Sampling and type of analyses to be performed on the ROK lime in the input method

Parameter	Sampling location	Frequency of sampling	Sampling method	Frequency of analysis	Test method
$CaCO_3$ $_{LI\text{-}ROK}$ (assuming that **$MgCO_3$** $_{LI\text{-}ROK}$ ≈ 0	Conveyor belt at kiln discharge or other suitable sampling location	1 sample per month per kiln or kiln battery	EN 932-1	1 analysis per quarter[a] on composite	Calcium carbonate content: EN 12485 EN 459-2
[a] Can be reduced by a factor of 2 if test show after an initial perod of one annum: The ratio between the standard deviation (Ss) of the historical results and their average ($\overline{X}$) does not exceed 0,1. All test results range between ($\overline{X}$ – S_s) and ($\overline{X}$ + S_s). If at least one series of results does not comply with the above criteria, the initial sampling rates in Table 7 shall be reapplied.					

9.2.3 Output method

9.2.3.1 The main formula of the output method

The output method is based on determining the mass of ROK-lime produced. CO_2 emissions shall be determined according to the following formula

$$m_{co2-stack} = (EF_{LI} \times m_{LI-ROK}) + m_{CO2-oxy}\ {}^{2)} \qquad (12)$$

where

$$EF_{LI} = (CaO_{LI-ROK} + \eta_{LI} \times CaO_{LKD}) \times 0.7848 + (MgO_{LI-ROK} + \eta_{LI} \times MgO_{LKD}) \times 1{,}092 \qquad (13)$$

and where

$$m_{CO2-oxy} = \frac{44}{12} \times 2 \times m_{LI-ROK} \times TOC_{LS}\ {}^{3)} \qquad (14)$$

In the above formulae all masses shall be expressed in t.

The reporting entity shall:

— apply this calculation formula to each kiln or kiln battery and each type of lime at the plant;

— and sum the $\boldsymbol{m}_{\boldsymbol{CO2-stack}}$ for each to give a total $\boldsymbol{m}_{\boldsymbol{CO2-stack}\ \mathbf{tot}}$ for the plant.

9.2.3.2 Determination of the mass of ROK lime

The annual total mass (t) of ROK lime produced by each kiln and kiln battery shall where possible be directly measured (m $_{LI\text{-}ROK}$). If the mass of ROK lime cannot be directly measured or where a more accurate measurement can be obtained by measuring the mass of downstream lime products, this mass

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2) The detailed derivation of the formula is explained in Annex C.

3) In this formula, it is assumed that the dry mass of kiln stone fed into the kilns is approximately twice the mass of the ROK lime produced. This approximation is based on the chemical composition of the limestone. Thus for a pure calcium carbonate that is fully decarbonated in the kiln the theoretical ratio is equal to 1,79 and for a dolomitic limestone consisting of 50 % calcium carbonate and 50 % of magnesium carbonate which is fully decarbonated, the theoretical ratio is equal to 1,91.

can be used to derive the mass of ROK lime produced. The reporting entity shall then specify in the monitoring plan the method used to assess the mass of ROK lime produced.

For downstream lime products consisting of a blend of ROK lime and LKD, the mass of LKD that is not blended with lime shall be measured and the following formula can be used for calculating the mass of ROK lime:

$$m_{LI-ROK} = \frac{m_{LI-\mathrm{Prod}} + m_{LKD-out}}{1+\eta_{LI}} \tag{15}$$

9.2.3.3 Determination of the composition of ROK lime

The sampling and analysis of the lime shall be undertaken on ROK lime unless not technically possible according to the frequency of sampling and the method of analysis specified in Table 8.

Table 8 — Sampling and type of analyses to be performed on ROK lime in the output method

Parameter	Sampling location	Frequency of sampling	Sampling method	Frequency of analysis	Test method
CaO_{LI-ROK}	Conveyor belt at kiln discharge or other suitable sampling location for ROK lime	1 sample per month per kiln or kiln battery	EN 932-1	1 analysis per 50 000 t[a] per kiln or kiln battery and minimum 1 analysis per quarter[a] per kiln or kiln battery	Calcium oxide and magnesium oxide contents: EN 12485 EN 459-2
MgO_{LI-ROK}					
If at least one series of results does not comply with the above criteria, the initial sampling rates in Table 8 shall be reapplied.					
[a] Can be reduced by a factor of 2 if tests show after an initial period of one annum: The ratio between the standard deviation (Ss) of the historical results and their average ($\overline{X}$ + S_s) does not exceed 0,1. All test results range between ($\overline{X}$ − S_s) and ($\overline{X}$ + S_s).					

If the analyses cannot be carried out on the ROK lime and on the LKD, the reporting entity can perform analyses on the downstream lime products. Based on these analyses, it shall assess the free calcium oxide and free magnesium oxide contents of the ROK lime. The reporting entity shall then specify in the monitoring plan the method used to assess the chemical composition of the ROK lime. It shall also demonstrate that the composition determined is equivalent to the composition that would be based on a direct measurement on the ROK lime.

$$CaO_{LI-ROK} = \frac{CaO_{LI-\mathrm{Prod}} \times m_{LI-\mathrm{Prod}} \times (1+\eta_{LI})}{m_{LI-\mathrm{Prod}} + m_{LKD-out}} - \eta_{LI} \times CaO_{LKD} + \frac{CaO_{LKD} \times m_{LKD-out} \times (1+\eta_{LI})}{m_{LI-PROD} + m_{LKD-out}} \tag{16}$$

$$MgO_{LI-ROK} = \frac{MgO_{LI-\mathrm{Prod}} \times m_{LI-\mathrm{Prod}} \times (1+\eta_{LI})}{m_{LI-\mathrm{Prod}} + m_{LKD-out}} - \eta_{LI} \times MgO_{LKD} + \frac{MgO_{LKD} \times m_{LKD-out} \times (1+\eta_{LI})}{m_{LI-PROD} + m_{LKD-out}} \tag{17}$$

9.2.3.4 Determination of the mass of LKD

The annual total mass (t) of LKD (m_{LKD}) generated by each kiln or kiln battery should preferably be measured. The measured quantity shall include all LKD collected in the abatement system before it is blended into downstream lime products or disposed. A kiln specific ratio of LKD to ROK lime (η_{LI}) shall be calculated using the following formula:

$$\eta_{LI} = \frac{m_{LKD}}{m_{LI-ROK}} \tag{18}$$

If the annual total mass of LKD cannot be directly measured, the mass may be determined by developing a kiln specific ratio (ηLI) on the basis of short term measurements as specified in Table 9.

Table 9 — Procedure for determining the ratio of LKD to ROK lime in the output method

Parameter	Sampling location	Frequency of sampling	Sampling method	Frequency of test	Test method
η_{LI}	Not applicable	Not applicable	Not applicable	1 test per annum for vertical kilns or battery of vertical kilns and 1 test per quarter for horizontal kilns or battery of horizontal kilns	Total mass of LKD generated (m_{LKD}) and total mass of ROK lime (m_{LI}) produced during the same defined period of time (e.g. 4 h to 8 h) Internal measurement with calibrated weighing system

$$\eta_{LI} = \frac{\text{Dry Mass of LKD generated during a given period of time}}{\text{Dry mass of ROK lime during the same period of time}} \tag{19}$$

Where short term tests cannot be performed the reporting entity may use the default values in Table 10.

Table 10 — Default values for the ratio of LKD to ROK lime in the output method

Type of lime kiln	$\eta_{LI} = m_{LKD} / m_{LI-ROK}$
Vertical kilns: Parallel flow regenerative kiln Annular shaft kiln Mixed feed shaft kiln Other shaft kiln	2 %
Horizontal kiln: Preheater rotary kiln	10 %
Horizontal kiln: Long rotary kiln	15 %

9.2.3.5 Determination of the composition of LKD

The free calcium oxide (CaO_{LKD}) and free magnesium oxide (MgO_{LKD}) contents of the LKD shall be determined according to the frequency of the sampling and the method of analysis specified in Table 11.

Table 11 — Sampling and type of analyses to be performed on the LKD in the output method

Parameter	Sampling location	Frequency of sampling	Sampling method	Frequency of analysis	Test method
CaO_{LKD}	Discharge screw of the dedusting system, flow of LKD leaving the kiln system or other suitable sampling location	1 sample per month per kiln or kiln battery	EN 932-1	1 analysis per quarter [a] on composite sample	Calcium carbonate, magnesium carbonate, calcium oxide and magnesium oxide contents: EN 12485 EN 459-2
MgO_{LKD}					
If at least one series of results does not comply with the above criteria, the initial sampling rates in Table 11 shall be reapplied.					
[a] Can be reduced by a factor of 2 if tests show after an initial period of one annum: The ratio between the standard deviation (Ss) of the historical results and their average ($\overline{X}$) does not exceed 0,1. All test results range between ($\overline{X} - S_s$) and ($\overline{X} + S_s$).					

Where the reporting entity does not sample and analyse the LKD, the composition of the LKD shall be assumed to be is the same as the ROK lime (9.2.2.3)

9.2.3.6 Determination of the TOC content of the kiln stone

The TOC content of the kiln stone shall be determined according to the frequency of sampling and method of analysis specified in Table 12. If the TOC content of the kiln stone can demonstrated to be below or equal to 0,15 %, a default TOC value of 0,0 % can be assumed.

Table 12 — Sampling and type of analyses to be performed on the kiln stone in the output method

Parameter	Sampling location	Frequency of sampling	Sampling method	Frequency of analysis	Test method
TOC_{LS}	Conveyor belt or other suitable location before the kiln feed system	1 sample per month per kiln or kiln battery	EN 932-1	1 analysis per 50 000 t[a] per kiln or kiln battery and minimum 1 analysis per quarter[a] per kiln or kiln battery	EN 13639
[a] Can be reduced by a factor of 2 if tests show after an initial period of one annum: The ratio between the standard deviation (Ss) of the historical results and their average ($\overline{X}$) does not exceed 0,1. All test results range between ($\overline{X} - S_s$) and ($\overline{X} + S_s$). If at least one series of results does not comply with the above criteria, the initial sampling rates in Table 12 shall be reapplied.					

9.2.4 Direct greenhouse gas emissions during kiln start up or shutdown

Lime kilns typically experience some start-ups and shutdowns as part of their normal operational cycle. Such events result in the generation of partially calcined material which has nonconforming composition in comparison with the target lime product and which may have a material effect on the calculated direct greenhouse gas emissions from calcination. The effect of these events shall be taken into account in the monitoring plan.

9.3 Direct greenhouse gas emissions from kiln fuels (combustion emissions) using the mass-balance-based method

9.3.1 Introduction to the mass-balance-based method for kiln fuels

Kiln fuels are all fuels used in the kilns plus fuels used for drying kiln stone (where carried out). The following shall be reported under kiln fuels:

— fuel heating;

— preheating air fed into the kiln;

— the treatment of the flue gas (e.g. in post combustion equipment).

Fuels used for the electricity production shall be reported as non-kiln fuel.

Fuels used for the drying of carbonates (as by-products of the lime production) are outside the scope of this standard.

Greenhouse gas emissions from fuels used at the plant during the reporting period shall be calculated from measurements of the activity data of each fuel consumed (*y*), its lower heating value (net calorific value), its net CO_2 emission factor and the degree of oxidation. It is important to note that the applied net calorific value always has to match the status of the fuel, especially with respect to the correct moisture content during its weighing (wet or dry).

The greenhouse gas emissions from each fuel (*y*) shall be determined using the following equation:

$$m_{CO2-Fy} = m_{Fy} \times CV_{Fy} \times EF_{Fy} \times Ox_{Fy} \tag{20}$$

The greenhouse gas emissions from each fuel shall be summed to give the total $m_{CO2-Ftot}$ for the plant.

9.3.2 Determination of the activity data of kiln fuels

The activity data of each fuel used in each kiln or battery of kilns shall be determined from the delivered quantity adjusted for any stock changes. Alternatively the reporting entity may determine the activity data of each fuel using a measurement device. The activity data of fuels shall be expressed in t, litres or $\mathbf{m}_{\mathbf{N}}^{3}$.

9.3.3 Determination of fuel emission factors for kiln fuels

9.3.3.1 Determination of fuel factors for plants with greenhouse gas emissions ≥ 50,000 tCO_2e per annum

The determination of fuel factors differs per type of fuel, there are three different approaches:

a) Solid and liquid fossil fuels

Where a plant has total absolute emissions exceeding 50 000 tCO_2e per annum, the reporting entity shall determine fuel emission factors by sampling and analysing each fuel according to relevant European Standards at the frequency defined in Table 13. Where a relevant European Standard is not available, the reporting entity shall use an International Standard. If a relevant International Standard is not available, an appropriate national standard may be used. The reporting entity can use fuel factors provided by the fuel supplier as long as the fuel is sampled and analysed in accordance with the requirement of this standard.

The factors for each fuel used by each kiln or each kiln battery shall be determined at the frequency specified in Table 13.

Table 13 — Sampling frequency of solid and liquid fuels to determine their fuel factors

Type of fuel	Fuel factors	Frequency of sampling	Sampling method	Frequency of analysis
Traditional solid fossil fuels (coal, petcoke, lignite, ...)’ and traditional liquid fossil fuels (fuel oil, gas oil, ...)	net calorific value (GJ / t)	Every 20 000 t and at least six times per annum	ISO 18283 or ISO 13909 ISO 5069-1	Every 20 000 t and at least six times per annum[a]
	emission factor (t_{CO2} / GJ)			Every 20 000 t and at least six times per annum[a]
	oxidation factor (dimensionless)			To be defined by the reporting entity or Use a default value of 1
Liquid fuels (fuel oil, gas oil, ...)	net calorific value (GJ / t) or (GJ / litre)	Every 20 000 t and at least six times per annum		Every 20 000 t and at least six times per annum[a] or Use a standard value (only for standardized fuels like heavy or light fuel oil)
	emission factor (t_{CO2} / GJ)			Every 20 000 t and at least six times per annum[a] or use a standard value (only for standardized fuels like heavy or light fuel oil)
	oxidation factor (dimensionless)			To be defined by the reporting entity or Use a default value of 1
Solid alternative fuels	net calorific value (GJ / t)	Every 5 000 t and at least four times per annum	EN 15442	Every 5 000 t and at least four times per annum[a]
	emission factor (t_{CO2} / GJ)			Every 5 000 t and at least four times per annum[a]
	oxidation factor (dimensionless)			To be defined by the reporting entity or Use a default value of 1
Liquid alternative fuels	net calorific value (GJ / t)	Every 10 000 t and at least four times per annum		Every 10 000 t and at least four times per annum[a]
	emission factor (t_{CO2} / GJ)			Every 10 000 t and at least four times per annum[a]
	oxidation factor (dimensionless)			To be defined by the reporting entity or Use a default value of 1

[a] Can be reduced by a factor of 2 if tests show after an initial period of one annum: The ratio between the standard deviation (Ss) of the historical results and their average ($\overline{X}$) does not exceed 0,1. All test results range between ($\overline{X} - S_s$) and ($\overline{X} + S_s$). If at least one series of results does not comply with the above criteria, the initial sampling rates in in Table 13 shall be reapplied. If fuels are sampled and the fuel factors are analysed by the fuel supplier according to the same methods as in Table 13 these values can be used by the reporting entity without the requirement for further testing.

b) Traditional gaseous fossil fuels

c) For natural gas the relevant fuel factors shall be obtained from the supplier or if not available then appropriate national factors shall be used.

d) Alternative fuels

For reporting purposes Alternative fuels (AF) have to be split into following three sub-categories:

a) Greenhouse gas from biomass fuels: greenhouse gas from biomass fuels is considered climate-neutral, because emissions can be compensated by re-growth of biomass in the short term. A list of biomass materials is in Annex B of EN 19694-1:2016. Greenhouse gas emissions from biomass fuels shall be accounted for in the greenhouse gas inventory and may be reported separately as a memo item by the reporting entity. 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[4]) This value lies in the range of different values for solid bio-fuels, which are specified as default emission factors in IPC C 2006 (Vol. II, Section 1.4.2.1) [5]. Greenhouse gas emissions from biomass shall be excluded from the total greenhouse gas emissions total.

b) Greenhouse gas from fossil fuel-derived wastes: the greenhouse gas emissions from waste-derived fuels consisting solely of fossil fuel-derived fractions such as waste oil or plastics are a priori not climate-neutral. Therefore these emissions shall be reported as direct greenhouse gas emissions like those of traditional fuels. Waste-derived fuels that do not contain biomass shall be treated as in 9.3.3.1.

c) Greenhouse gas from mixed fuels with biomass and fossil fractions: Mixed fuels include fossil and biogenic carbon e.g. pre-treated industrial wastes (containing plastics, textiles, paper etc.) or waste tyres (containing natural and synthetic rubber).

Greenhouse gas from mixed fuels shall be measured. The proportion of emissions from the biomass fraction and the proportion from the fossil fraction shall be determined. This is done by determining the share of the biogenic carbon in the fuel's overall carbon content, according to international standards (e.g. EN 15440 [4]).

If bio-fuels form part of the mixed fuel (e.g. pretreated industrial and/or domestic wastes), the proportion of fossil and non-fossil fraction of the fuel shall be established and the appropriate emission factors applied to each fraction

Greenhouse gas emissions from the biomass fraction shall be accounted for in the greenhouse gas inventory as specified in (a) above.

The greenhouse gas emission from the fossil fraction shall be included and reported in the total greenhouse gas emissions. Appropriate emission factors shall be applied to the suitable fractions. The emission factors for each fuel used by each kiln shall be determined at a frequency of sampling and using the method of analyses specified in Table 13.

For some biomass or mixed fuels representative sampling and testing may not be technically or economically feasible. In such cases reporting entities are advised to use a conservative approach in determining the biogenic carbon content, meaning that the biogenic carbon

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[4]) See IPCC 1996, Vol. III, p.1.13

content should not be overestimated. A fossil carbon content of 100 % shall be assumed for fuel types wherever there is a lack of reliable information on their biogenic carbon content.

If fuels are sampled and the fuel factors are analysed by the fuel supplier according to the same methods in Table 13 these values can be used by the reporting entity without the requirement for further testing.

9.3.3.2 Determination of fuel factors for plants with greenhouse gas emissions < 50,000 tCO_2e per annum

Where a plant has a total absolute emission below 50.000 tCO_2e per annum, the reporting entity may:

- determine the emission factors using the methodologies described in 9.3.3.1;
- or use measured values from its own sampling and analysis or from suppliers sampling and analysis according to 9.3.3.1 where such factors are available;
- or use fuel emission factors from recognized national sources such as the latest National Greenhouse Gas Inventory as submitted to the United Nations Framework Convention on Climate Change (UNFCCC) by the country in which the plant is located;
- or, where national data is not available, use the latest emission factor published by the IPCC or the World Business Council for Sustainable Development (WBCSD) tCO_2e.

9.3.3.3 Determination of fuel factors for minor fuels

For fuels which jointly correspond to less than 5,000 t of fossil CO_{2e} per annum or jointly correspond to less than 10 % of fossil CO_{2e} emitted by the plant per annum, the reporting entity may use one of the approaches described in 9.3.3.1.

9.3.4 Determination of the greenhouse gas emissions from heat transfer to external parties

Part of the waste heat generated by the kilns can be valorised as heat transferred to external parties. The greenhouse gas emissions related to the energy consumed to produce this heat are already accounted for according to the provisions set in 9.3.2 and 9.3.3. However the energy indirect greenhouse gas savings due to the use of waste heat shall be recognized in the greenhouse gas inventory.

However the indirect greenhouse gas savings due to the use of waste heat shall be recognized in the GHG inventory.

The following procedure shall be applied for the assessing the greenhouse gas savings:

a) determine the amount of heat transferred according to the information from the invoices to the external consumers (TJ / annum);

b) the avoided greenhouse gas emissions from the heat transferred are calculated from the total of heat transferred multiplied by the factor 62.3 tCO_{2e} / TJ.

This amount shall be reported separately as memo item in the greenhouse gas inventory.

9.3.5 Determination of the greenhouse gas emissions from exported on-site power generation

Part of the waste heat generated by the kilns can be directly used to produce electricity. The greenhouse gas emissions related to the energy consumed to produce this electricity are already accounted according to the provisions set in 9.3.2 and 9.3.3.

Where electricity is exported, the corresponding amount does not need to be produced by other power generators. Thus greenhouse gas emissions are avoided in other locations. In order to take this effect into account in the greenhouse gas inventory, the following procedure shall be applied for the assessing the avoided greenhouse gas emissions:

a) determine the amount of electricity exported according to the information provided by the fiscal electricity meter (kWh per annum);

b) the avoided greenhouse gas emissions from the electricity produced on site and exported are then calculated from the amount of electricity exported multiplied by the official greenhouse gas emission factor for the national power grid (provided by the national state).

This amount shall be reported separately as a memo item.

9.4 Direct greenhouse gas emissions from non-kiln fuels (combustion emissions) using the mass-balance-based method

9.4.1 Introduction of the mass-balance-based method for non-kiln fuels

Non-kiln fuels are fuels consumed by the plant in the manufacture of lime products during the reporting period but which are not included in the definition of kiln fuels. For instance non-kiln fuels include those fuels used:

— in the quarry for the extraction, processing and the on-site (internal) transport of kiln stone;

— for external transport of kiln stone or lime between different quarries, lime kilns or hydration plants. Transport modes include rail, water, and road;

— on-site electricity generation;

— for on-site (internal) transport of products to storage, grinding/milling, hydration and packing installations;

— for thermal process equipment like dryers for hydrated lime;

— for plant vehicles other than those used in the quarry or for the transportation of raw materials or products;

— for other heating or cooling of the workplace and equipment.

Greenhouse gas emissions from off-site transport by company-owned fleets are outside the system boundary but the reporting entity may choose to include them on a voluntary basis.

Greenhouse gas arising from off-site transport of kiln stone to the plant by third parties shall be included in the greenhouse gas inventory other indirect greenhouse gas emissions.

The greenhouse gas emissions from each fuel (y) shall be determined using the following formula:

$$m_{CO2-FY} = m_{Fy} \times CV_{Fy} \times EF_{Fy} \times Ox_{Fy} \qquad (21)$$

The greenhouse gas emissions from each fuel shall be summed to give the total m $_{\text{CO2-Ftot}}$ for the plant.

9.4.2 Determination of the quantity of externally generated electricity used (activity data)

9.4.2.1 Plant producing only lime

The activity data for each fuel used shall be determined from the delivered quantities adjusted for any stock changes. Alternatively the reporting entity may determine the activity data of each fuel using a measurement device. The activity data of fuels shall be measured in t, litres or $m^3{}_N$.

Table 14 provides an example of parameters needed to determine the quantities of non-kiln fuels consumed.

Table 14 — Parameters to be determined to calculate the amounts of non-kiln fuels used

Fuel	Parameter	Frequency of measurement	Underlying required data for determining the activity data of fuel consumed
Gasoil consumed e.g. by the equipment, the on-site vehicles and the electricity generator(s)	Volume consumed (litres)	Annual	Fuel invoices Fuel meters Fuel stocks
	Density (kg / litre)		Densities from supplier based on EN ISO 3675 [2] or EN ISO 12185 [3] measurements
Gasoline	Volume consumed (litres)	Annual	Fuel invoices Fuel meters Fuel stocks
	Density (kg / litre)		Densities from supplier based on EN ISO 3675:1998 [2], EN ISO 12185:1996 measurements [3] or standard densities according to EN 228 [1] (gasoline)
Liquefied petroleum gas – LPG (propane, butane)	Volume consumed (litres)	Annual	Fuel invoices Fuel meters Fuel stocks
	Density in liquid phase (kg / litre)		Densities from supplier or default value: 0,51 kg/l at T=15°C
Light fuel oil consumed e.g.by dryers or room heating	Volume consumed (litres)	Annual	Fuel invoices Fuel meters Fuel stocks
	Density (kg / litre)		Densities from supplier based on EN ISO 3675 [2] or EN ISO 12185 measurements [3]

For plants consuming natural gas as a non-kiln fuel, its (usually small) volume can be included with the volume of natural gas consumed by the kilns.

For non-kiln fuels that are not referred to in Table 14, the methodology used to determine the activity data shall be consistent with the methodology in Table 14.

Plant manufacturing products in addition to lime

If the plant manufactures products, such as aggregates or fillers in addition to lime, where possible the energy consumption for manufacturing these products shall not be included in the total amount of non-kiln fuels as these products are outside the boundary of the lime greenhouse gas reporting system.

Assessment of the activity data for the proportion of non-kiln fuels related solely to lime manufacture depends on the availability of suitable measurement devices:

a) Where the plant is equipped with sufficient sub-meters to precisely allocate the energy consumption from the non-kiln fuels to lime manufacturing and to the manufacturing of other products this shall be done.

b) Where the plant is not equipped with sufficient sub-meters to precisely allocate energy consumption between products, for each non-kiln fuel the total amount of fuel consumed at plant level shall be determined according to the provisions set in 9.4.2.1. A specific amount of fuel can be deducted from this total according to the following provisions:

   1) Deduction for the production of aggregates and aggregates used for the production of fillers

c) Where a sub-metering of the non-kiln fuels for quarry operations and stone processing is available, the following procedure shall be applied to each non-kiln fuel used in the quarry operations / stone processing:

   1) determine the quantity of all non-kiln stone aggregates produced (t per annum);

   2) determine the total quantity of all non-kiln stone aggregates and kiln stone produced (t per annum);

   3) dalculate the total consumption of non-kiln fuel used for quarry operations / stone processing according to the provisions set in 9.4.2.1;

   4) the amount of non-kiln fuel that can be deducted is then equal to:

$$\frac{Total\ consumption\ of\ non\ kiln\ fuel\ used\ for\ quarry\ operations}{stone\ processing} \times \frac{t\ of\ non\ kiln\ stone\ aggregates}{t\ of\ non\ kiln\ stone\ aggregates + kiln\ stone\ produced}$$

d) Where a sub-metering of the non-kiln fuels for quarry operations and stone processing is not possible, no deduction can be made. Therefore, all greenhouse gas emissions arising from non-kiln fuels shall be attributed to the lime plant;

   1) Deduction for the production of fillers from aggregates

e) Where sub-metering of the non-kiln fuels used for milling / drying the aggregates for the production of fillers is available the amount of fuel consumed as monitored by the sub-meter can be directly deducted from the total amount of non-kiln fuel.

f) Where a sub-metering of the non-kiln fuels for milling / drying the aggregates for the production of fillers is not available, the following default value for the specific drying energy of the aggregates should be used:

   1) Determination of the amount of aggregates used for the production of fillers with the default value

   $E = 250$ MJ / t_a

   The amount of non-kiln fuel that can be deducted from the total amount is then equal to:

   - the above specific energy consumption;

   - multiplied by the tonnage of aggregates used for the production of fillers.

9.4.3 Determination of fuel factors for non-kiln fuels

The fuel factors for non-kiln fuels shall be determined in accordance with 9.3.3.

Determination of the greenhouse gas emissions from exported on-site power generation

Greenhouse gas emissions of non-kiln fuels used for electricity produced on-site shall be accounted according to 9.4.2 and 9.4.3.

Where electricity is exported, the corresponding amount does not need to be produced by other power generators. Thus greenhouse gas emissions are avoided in other locations. In order to take this effect into account in the greenhouse gas inventory, the following procedure shall be applied:

a) determine the **amount of electricity exported** according to the information provided by the fiscal electricity meter (kWh per annum);

b) the avoided greenhouse gas emissions from the electricity produced on site and exported are then calculated from the amount of electricity exported multiplied by the official greenhouse gas emission factor for the national power grid (provided by the national state).

This amount shall be reported separately as memo item in the greenhouse gas inventory.

10 Energy indirect greenhouse gas emissions and their determination

10.1 Overview of the sources of energy indirect greenhouse gas emissions

Indirect greenhouse gas emissions arise as a consequence of the operations of the reporting entity, but occur at sources owned or controlled by another entity. Lime manufacture is associated with energy indirect greenhouse gas emissions from external production of electricity consumed during lime manufacture including:

— electricity consumed for kiln stone extraction, processing and on-site transport;

— electricity consumed by pumps for dewatering the quarry;

— electricity consumed by the kiln;

— electricity consumed for on-site transfer of product to storage;

— electricity consumed in grinding/milling, hydration and packing.

Quantification of other energy indirect greenhouse gas emissions is not required by this standard.

Greenhouse gas emissions from externally generated electricity used at the plant during the reporting period shall be calculated from measurements of the quantity of electricity consumed (q_{ELEC}) according to the following formula:

$$m_{co2-ELEC} = q_{ELEC} \times EF_{ELEC} \tag{22}$$

10.2 Determination of the quantity of externally generated electricity used (activity data)

10.2.1 Plant producing only lime

The greenhouse gas emissions from externally generated electricity shall be separately evaluated for each process stage where possible and then summed to give the total m CO_{2-ELEC} for the plant.

The quantity of externally generated electricity used shall be measured in kWh. Table 15 provides an example of parameters required to determine the quantities of electricity consumed.

Table 15 — Parameters to be determined to calculate the amounts of non kiln fuels used

Fuel	Parameter	Frequency of measurement	Example of underlying required data for determining the activity data of electricity consumed
Electricity	Electricity consumed (kWh)	Annual	Fiscal electricity meter Invoices from the electricity supplier Plant electricity submeter

10.2.2 Plant manufacturing products in addition to lime

If the plant manufactures products, such as aggregates or fillers, where possible the electricity consumption for manufacturing these products shall not be included in the total amount of electricity consumed for the lime manufacturing as these products are outside the boundary of the lime greenhouse gas reporting system.

Assessment of the electricity related solely to lime manufacture depends on the availability of sub-meters at the plant. Where the plant is equipped with sufficient sub-meters to precisely allocate electricity consumption to the manufacture of lime and to other products this shall be done. Where there are insufficient sub-meters to precisely allocate electricity consumption to the manufacture of lime and to other products the total amount of electricity consumed at plant level shall be determined according to the provisions set in 10.2.1. A specific amount of electricity can be deducted from this total amount according to the following provisions:

a) deduction for the production of aggregates and aggregates used for the production of fillers:

    1) Where sub-metering of electricity used for quarry operations / stone processing is possible, the following procedure shall be applied:

        i) determine the quantity of all non-kiln stone aggregates produced (t per annum);

        ii) determine the total quantity of all non-kiln stone aggregates and kiln stone produced (t / annum);

        iii) calculate the total consumption of electricity used for quarry operations / stone processing according to the provisions set in 10.2.1.

        The amount of electricity used that can be deducted is then equal to:

$$\frac{total\ consumption\ of\ electricity\ used\ for\ quarry\ operations}{stone\ processing} \times \frac{all\ aggregates}{t\ of\ all\ aggregates + kiln\ stone\ produced}$$

    2) Where sub-metering of electricity used for quarry operations and stone processing is not possible, no deduction can be made.

b) Deduction for the production of fillers from aggregates:

    1) Where sub-metering of electricity used for milling the aggregates for the production of fillers is possible, the following procedure shall be applied:

    The amount of electricity consumed as monitored by the sub-meter can be directly deducted from the total amount of electricity used;

2) Where sub-metering of the electricity used for milling the aggregates for the production of fillers is not possible, the following default value for the specific electricity consumption for milling the aggregates should be used:

Determination of the amount of aggregates used for the production of fillers with the default value

$E = 23\ \text{kWh} / t_{\text{aggregates used for the production of fillers}}$

The amount of electricity that can be deducted from the total amount is then equal to the above specific electricity consumption; multiplied by the tonnage of aggregates used for the production of fillers.

10.3 Determination of the emission factor for externally generated electricity

The reporting entity shall use relevant emission factors for purchased electricity:

- preferentially from the electricity supplier;
- alternatively from government databases providing information about the latest Member State data available;
- or in the absence of other sources of information, average emission factors for the country based on International Energy Agency (IEA) data which are updated annually:

http://www.iea.org/stats/index.asp or http://www.ghgprotocol.org/calculation-tools/lime-sector

11 Other indirect greenhouse gas emissions from imported kiln stone and transport of kiln stone by third parties

11.1 Other indirect indirect greenhouse gas emissions, third party and of site transportation

The reporting entity shall determine the greenhouse gas emissions arising from the manufacture of kiln stone imported from a third party as this is within the system boundary as defined by this standard.

The reporting of greenhouse gas emissions arising from off-site transportation of kiln stone by third parties is not mandatory. However if the reporting entity decides to include these emissions in its greenhouse gas inventory, it shall also include the greenhouse gas emissions arising from the off-site transportation of kiln stone to the site by its own fleet according to the provisions set in 9.4.

11.2 Greenhouse gas emissions from manufacture of imported kiln stone

GHG emissions from the manufacture of imported kiln stone shall be calculated according to the following formula:

$$m_{CO_2-PUR} = EF_{LS-PUR} \times m_{LS-PUR} \qquad (23)$$

The quantity of imported kiln stone (activitiy data) shall be based on the measured delivery of kiln stone as shown in Table 16.

Table 16 — Parameters to be determined to calculate the amounts of imported kiln stone

Raw material	Parameter	Frequency of measurement	Underlying required data for determining the mass of imported kiln stone (activity data)
Externally produced kiln stone	Tonnages of kiln stone (t)	Annual	Invoices from the supplier / producer of kiln stone

If possible the reporting entity should obtain from the supplier a GHG emission factor per wet mass (in kgCO_2/t) for kiln stone imported (EF_{PUR}). The supplier shall determine the GHG emission factor in accordance with this standard or with the provisions set in ISO 14040 and ISO 14044 for the derivation of Carbon Footprints or Life Cycle Inventories of products.

Where a GHG emission factor ($EF_{LS\text{-}PUR}$) in compliance with these standards is not available the reporting entity shall use:

— either official GHG emission factors for aggregates published by national sources;

— or the default value of 3,7 kg CO_{2e} / t.

11.3 GHG from transport of kiln stone by third parties

For each mode of transport k (by road, rail, river or sea) GHG emissions from transportation of kiln stone by third parties shall be calculated according to the following formula:

$$m_{CO2-TR-PUR} = \sum_{i=1}^{n} m_{LS-PURi} \times TF_{LS-PURi} \times d_i \tag{24}$$

where

The quantity of imported kiln stone (activity data) shall be based on the measured delivery of kiln stone as shown in Table 17.

Table 17 — Parameters to be determined to calculate the amounts of transported kiln stone

Raw material	Parameter	Frequency of measurement	Underlying required data for determining the mass of imported kiln stone (activity data)
Kiln stone	Tonnages of kiln stone transported by trucks (t)	Annual	Invoices from the logistic companies
	Tonnages of kiln stone transported by train (t)	Annual	Invoices from the logistic companies
	Tonnages of kiln stone transported by barges (on rivers or channels) (t)	Annual	Invoices from the logistic companies
	Tonnages of kiln stone transported by vessels (on sea) (t)	Annual	Invoices from the logistic companies

Where possible the reporting entity should obtain the GHG emission factor for the transport of kiln stone from the supplier ($TF_{LS\text{-}PUR}$).expressed in kgCO_{2e} / (t × kilometre) The supplier shall determine the GHG emission factor in accordance with this standard or with the provisions set in ISO 14040 and ISO 14044 for the derivation of Carbon Footprints or Life Cycle Inventories of products.

Where a GHG emission factor ($TF_{LS\text{-}PUR}$) in compliance with these standards is not available the reporting entity shall use:

— either official emission factors published by well recognized national bodies;

— or the default values in Table 18.

Table 18 — Default GHG emission factors for transport of kiln stone by third parties

Transportation mode	**GHG emission factor for transportation** **$TF_{LS\text{-}PUR}$** **Kg CO_2e / (t × kilometre)**
Road (semi –trailers with a payload of 27 t)	0,092
Rail (combined electrical and Diesel locomotives)	0,023
Barges (up to 1200 t pay load capacity)	0,025
Vessels (bulk carriers up to 20 000 dwt)	0,0075

For determination of transport distance, only one way from the quarry to the lime plant shall be included as the return journey is already included in the GHG emission factor ($TF_{LS\text{-}PUR\ k}$).

If possible the reporting entity should obtain from the supplier the distances (in kilometres) for each type of transport mode.

Where such information is not available, publicly available distance calculators should be used

12 Reporting and performance assessment

12.1 Reporting data to include

GHG emissions monitoring and reporting has multiple uses, such as, internal management and performance assessment, as part of a life cycle analysis, for public environmental reporting or reporting for compliance with legislative requirements. This standard has been designed as a flexible tool to satisfy different reporting purposes.

Reported GHG emissions shall include all relevant emissions as required by EN 19694-1.

The following data shall be reported:

— the total absolute greenhouse gas emissions (direct greenhouse gas emissions, energy indirect greenhouse gas emissions and other indirect greenhouse gas emission) associated with the manufacturing plant;

— the boundaries used for the assessment of the GHG emissions;

— all material deviations from this standard;

— the overall uncertainty (see Clause 13 on uncertainty assessment);

— process emissions shall be included in the total greenhouse gas emissions reported.

When assessing the outputs of this standard the user shall always take into consideration the product quality.

12.2 Performance assessment

Performance assessment to benchmark or compare for internal or public reporting may also be undertaken on a voluntary basis using the outputs from this standard. The nature of such voluntary reports can be highly dependent on the reporting context and purpose. System boundaries for such reporting depend on conventions and practical requirements, as much as on scientific arguments.

To assess the performance of kilns, plants, company or group data the Performance Indicators (PIs) relating to absolute emissions in Table 19 may be useful for the lime industry to the extent that disaggregated data is available.

Table 19 — PI's relating to absolute GHG emissions

	Direct greenhouse gas emissions		**Energy indirect greenhouse gas emissions**	**Direct greenhouse gas emissions, energy indirect greenhouse gas emissions and other indirect greenhouse gas emissions**	**Emissions from biomass**
	Process emissions	**Combustion emissions (excl. biomass)**			
Kiln stone preparation					
Internal kiln stone preparation		**[t CO_2e / annum]**	**[t CO_2e / annum]**	**[t CO_2e / annum]**	
Imported kiln stone preparation				**[t CO_2e / annum]**	
Lime process					
Lime	**[tCO_2e / annum]**	**[t CO_2e / annum]**	**[t CO_2e / annum]**	**[t CO_2e / annum]**	**[t CO_2e / annum]**
Downstream processing					
			[t CO_2e / annum]	**[t CO_2e / annum]**	
TOTAL (Kiln stone preparation + Lime process + Downstream processing)					
	[tCO_2e / annum]	**[t CO_2e / annum]**	**[t CO_2e / annum]**	**[t CO_2e / annum]**	**[t CO_2e / annum]**

To assess the performance of kilns, plants, company or group the PIs relating to relative emissions may be useful for the lime industry to the extent that disaggregated data is available.

For the determination of relative PI's, the denominator specified in Table 20 shall be used.

Table 20 — Denominator to calculate PI's relating to relative GHG emissions

Lime (quicklime, dolime, sintered dolime) sold + LKD sold	**[t / annum]**

The PI's mentioned in Table 21 are voluntary and can be used to assess performance. Reporting entities can select the PIs most relevant to their circumstances.

Table 21 — PI's relating to specific GHG emissions

	Direct greenhouse gas emissions		**Direct greenhouse gas**	**Direct greenhouse gas emissions, energy indirect greenhouse gas emissions and other indirect greenhouse gas emissions**	**Emissions from biomass**
	Process emissions	**Combustion emissions (excl. biomass)**			
Kiln stone preparation					
Internal production		**[t CO_2e per t]**	**[t CO_2e per t]**	**[t CO_2e per t]**	
Imported kiln stone				**[t CO_2e per t]**	
Lime process					
Lime	**[t CO_2e per t]**	**[t CO_2e per t]**	**[t CO_2e per t]**	**[t CO_2e per t]**	**[t CO_2e per t]**
Downstream processing					
			[t CO_2e per t]	**[t CO_2e per t]**	
TOTAL (Kiln stone preparation+ Lime process + Downstream processing)					
	[t CO_2e per t]	**[t CO_2e per t]**	**[t CO_2e per t]**	**[t CO_2e per t]**	

13 Uncertainty of GHG inventories

13.1 General principles

Due to their scientific nature, the parameters required for determining GHG emissions are not precise point estimates, but involve an uncertainty that can be expressed as an uncertainty range or confidence interval. The aggregate uncertainty of a GHG emissions estimate for a plant or organization will depend 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.

Besides the uncertainty of parameters, there are other error sources that can contribute to the uncertainty of GHG emissions estimates. These include model uncertainty – the question of how precisely a mathematical model reflects a specific context – and scientific uncertainty, for example related to the global warming potentials used to aggregate different greenhouse gases. This standard is designed to reduce the model uncertainty inherent in lime industry inventories to minimal levels. Addressing scientific uncertainty is beyond the scope of lime industry inventories.

The general principles in EN 19694-1 apply for the determination of uncertainty according to the requirements of the Guidance on Uncertainty Assessment and ISO/IEC Guide 98-3 (formerly GUM: Guide to the Expression of Uncertainty in Measurement).

Where standards for measurement of specific materials, energy consumption or any other emissions include the analysis of uncertainty they shall be applied.

13.2 Assessment of uncertainty for the mass-balance- base method

13.2.1 Major sources of uncertainty

The overall uncertainty of the mass-balance-based method depends on the uncertainty of the measurement and analytical methods used. The main sources of uncertainty normally being associated with:

a) Measurement of activity data (including production volume and fuel quantities);

b) Determination of analytical parameters (including chemical composition, emissions factors and lower or higher heat value);

c) Representativeness of sampling.

Table 22 provides advice about how to minimise the main sources of measurement uncertainty.

Table 22 — Typical major sources of uncertainty in lime industry inventories and measures to minimize them

Parameter	**Measures to minimize parameter uncertainty**
Lime production (t/a)	Use alternative methods to cross-check activity data: - Based on kiln stone consumption and kiln stone to lime ratio - Based on direct lime weighing (where applicable)
Kiln stone consumption [a] (t/a)	Use alternative estimation methods to cross-check activity data: - Based on lime and LKD production(where lime and LKD are weighed) and kiln stone to lime ratio - Based on direct limestone weighing (where applicable) and measurement of the kin stone moisture
EF_{LI} (kg CO2e /t lime)	Calculate lime plant-specific emission factor based on measured lime composition (free CaO and free MgO content) and LKD leaving the kiln system, rather than using default factor Account for variations in lime composition over time
EF_{LS} (kg CO2e /t kiln stone)	Calculate lime plant-specific emission factor based on measured composition of kiln stone (carbonate content), rather than using default factor Account for variations in kiln stone composition over time
Fuel consumption (t/a or l/a)	Use alternative methods to cross-check fuel consumption: - Based on weighing at delivery, or fuel bills; adjusting for stock changes - Based on weigh-feeders (where applicable)
Lower and higher heat values (GJ/t)	Ensure that fuel volumes and lower or higher heat values are based on the same moisture content
EF_{Fy} (kg CO_2e/GJ)	If using specific types of traditional fuels, use matching emission factors Measure emission factor of fuel if default factors are deemed non-representative Account for biomass carbon in, e.g. used tyres and impregnated saw dust Use analysis data for biomass content in heterogeneous mixed fuels like pre-treated industrial or domestic wastes (where applicable)
[a] Parameters marked with an asterisk are only relevant if input methods are used for calculating CO2 from the calcination of kiln stone.	

13.2.2 Uncertainty of activity data

If the annual amount of ROK lime is determined by mass balance, the aggregated uncertainty for the activity data has to be calculated via error propagation considering the diverse uncertainties of each of the weighing instruments involved.

Also the uncertainty of stocks in stockpiles, silos, tanks and other stocks has to be considered.

The information on the uncertainty of a measuring device for activity data can be found in number of sources including:

- certificates of calibration under national metrological control (where the operational error limits the uncertainty under normal operational conditions),
- the specification from the manufacturer of the measuring device and estimate of the additional uncertainty under operational conditions concerning relevant influences or
- an individual uncertainty assessment under operational conditions (e.g. via regular testing and adjustment of the measuring device)

It is necessary to determine whether the measuring device is subject to national metrological control and whether it is installed in an environment appropriate for its specification. In most cases the device will be suitably installed but often is not subject to national metrological control. The uncertainty can then be determined in two ways:

- based on maximum permissible error,
- based on uncertainty obtained by calibration modified by a conservative adjustment factor.

The device will usually have a valid calibration and the second bullet point above will apply. In the absence of other information or experience ISO/IEC Guide 98-3 recommends that a Conservative Adjustment Factor (CAF) of 2 be applied.

For an individual uncertainty assessment of a measuring device used to determine activity data of materials or fuels, the 95 % confidence interval should be calculated from the deviations of the measuring device observed within regular maintenance and control calibrations using check weights or other methods recommended by the manufacturer.

The measured standard uncertainty associated with the measurement of ROK lime activity data (production) during a site trial can be calculated as follows.

$$U_{mtotal} = \frac{U_{m1} + U_{m2} + U_{m3} + \ldots.. + U_{m24}}{M1 + M2 + M3 + \ldots.. + M24} \tag{25}$$

An example calculation is provided in Annex D.

13.2.3 Aggregated uncertainties of activity data

In accordance with the GUM, if the annual amount of kiln stone, lime, LKD or a consumed fuel is determined by using the mass-balance-based method, 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 weighing/measuring methods involved in the calculation of activity data. Also the uncertainty of measuring or estimating stocks in stockpiles, silos, tanks and other stocks in the mass balance has to be considered.

The following equation for error propagation can be applied to estimate the aggregated relative uncertainty of a sum, if all determinations of the mass balance parameters and their related uncertainties are independent:

$$u_t = \frac{\sqrt{\sum\limits_{i=1}^{n} \left(u_i \cdot x_i\right)}}{\sum\limits_{i=1}^{n} x_i} \tag{26}$$

13.2.4 Uncertainty of analytical parameters

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

- uncertainty of the analytical method,
- the frequency of analysis (a decrease of uncertainty is possible by raising the frequency of analysis) and
- uncertainty due to the representativeness of the sampling.

Also the qualification and experience of the technician performing the analyses can also influence the quality of analysis results.

In accordance with the GUM, the aggregated uncertainty for the laboratory analysis has to be calculated via error propagation considering the diverse uncertainties of each parameter.

For the sample handling (division) process, one sample is used and sub-divided into n. These samples are then measured by the same technique. The variation in CaO content in the results is attributed to the uncertainty introduced via the sampling dividing process. The associated uncertainty is determined by calculating the standard deviation and then assessing this in terms of the normal measurements made:

For the determination of the uncertainty due to the sample handling, the following procedure can be used:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{27}$$

$$S_s(x_{i)} = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}} \tag{28}$$

The uncertainty associated with the sampling procedure (Us) is then:

$$Us = \frac{S_s(x_i)}{\sqrt{t}} \tag{29}$$

where

t is the number of samples in the actual measurement.

For the determination of the uncertainty associated with the analytical measurement, the following procedure can be used:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{30}$$

$$S_m(x_{i)} = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}} \tag{31}$$

The uncertainty associated with the sampling procedure (Um) is then:

$$Um = \frac{S_m(x_i)}{\sqrt{t}} \tag{32}$$

Where t is the number of measurements carried out on the same sample.

The uncertainty associated with the overall analytical procedure (*U*a) is determined by error propagation by determining the root of the sum of the squares:

$$U_a = \sqrt{U_{s^2} + U_{m^2}} \tag{33}$$

13.2.5 Application of default values instead of analytical results

If default values are used in the GHG inventory, the uncertainty of those default values shall be considered when assessing a GHG inventory.

13.2.6 Evaluation of the overall uncertainty of a GHG inventory

In order to determine the overall uncertainty of a GHG inventory, the assessed uncertainties of activity data and fuel and material parameters have to be aggregated by the error propagation laws in accordance with the GUM.

The results of site field trials carried out in accordance with the requirements of this standard at lime manufacturing plants showed that the uncertainty of the mass-balance-based method was close to 2%. Further information is provided in Annex A.

13.3 Assessment of uncertainty for the stack-measurement-based method

When using the stack- measurement-based method, uncertainty assessments shall take account of the general guidance on uncertainty assessment provided in EN 19694-1 and in accordance with the GUM.

The results of site field trials carried out in accordance with the requirements of this standard at lime manufacturing plants showed that the uncertainty of the stack-measurement-based method ranged between 15 % and 25 %. Further information is provided in Annex A.

14 Verification / certification

For the purposes of transparency in reporting CO_2 emissions to stakeholders, the inventory and any associated assertion may be verified in accordance with the requirements identified in Annex C. ISO 14064-3 also gives guidance on the verification of GHG emissions and removals.

Annex A
(informative)

Objective and outcome of the site trails

Following the development of the mass-balance-based methods (input and output) and the stack-emission-measurement based method, site field trials were carried out to validate the methodologies and demonstrate that they are fit for purpose.

The site filed trials had three specific objectives:

- a detailed assessment of the methodologies for quantifying direct GHG emissions generated by the kiln, undertaken by comparing the results of the input/output mass-balance-based method and the stack-emissions-measurement-based method;
- a general assessment of the methodology proposed for quantifying non-kiln GHG emissions and indirect kiln GHG emissions based on verified annual data;
- an assessment of the relevance of non-CO_2 GHGs using stack measurements (CH_4, N_2O, HFCs, PFCs and SF_6);

Two plants were selected as host sites for the trials to represent typical plants used in the lime industry

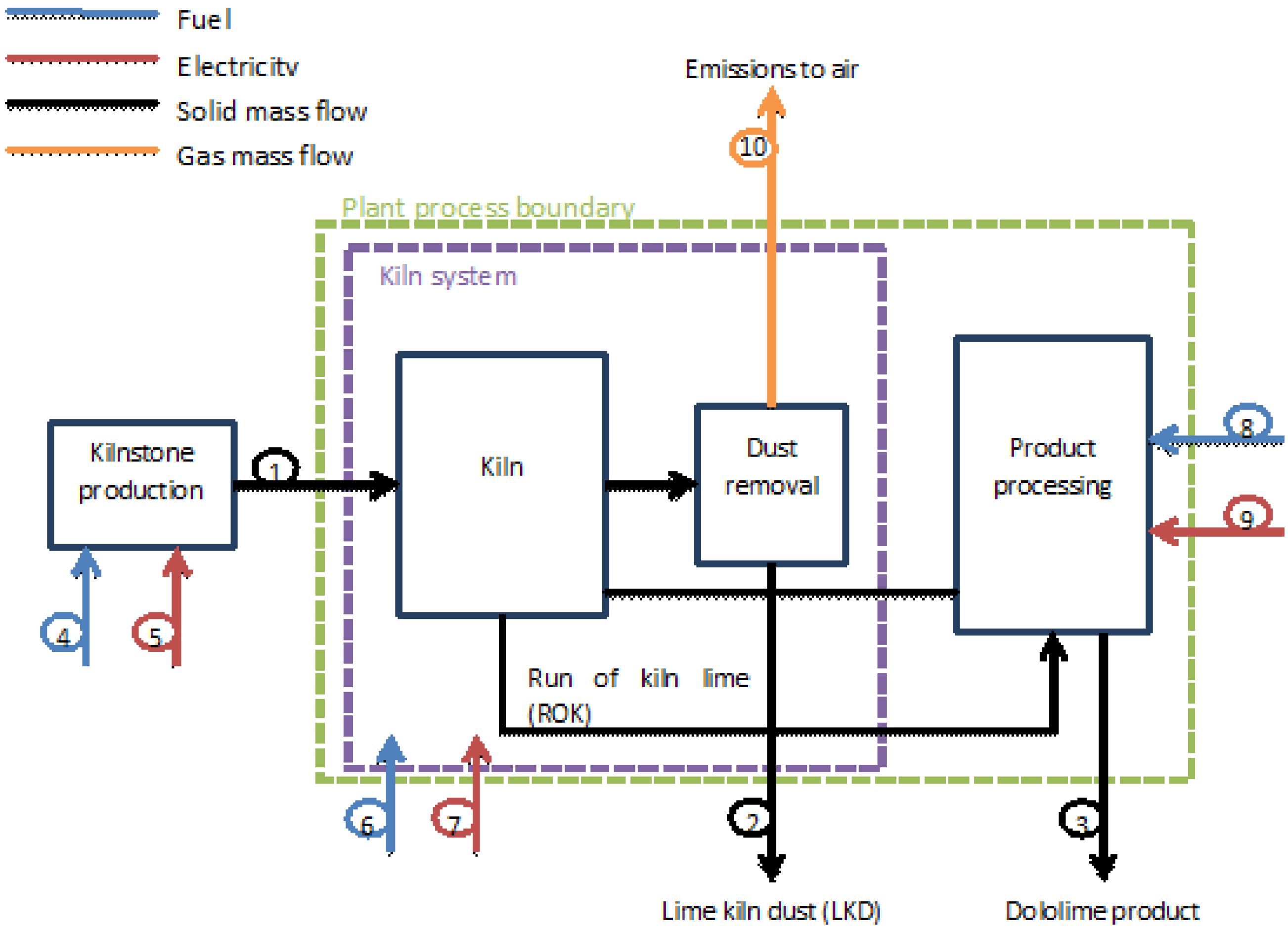
Plant A:

- parallel flow regenerative kiln (PFRK);
- single fuel fired (natural gas);
- limestone purchase from neighbouring quarry;
- quicklime and hydrated lime product;

Plant B:

- rotary kiln;
- multiple fuel fired (coal, solvent waste, biomass);
- limestone purchase from neighbouring quarry;
- dololime product.

Two rounds of tests were carried out at each plant between June 2013 and January 2014. Following the first round the methodologies were adjusted according to the recommendations.



Key

Reference Number	GHG Emission Source	Description
1	Kiln-direct	Kiln stone processed
2	Kiln-direct	Lime kiln dust (LKD) produced from the process
3	Kiln-direct	The lime product produced from the process either as run of kiln (ROK) lime or as processed product
4	Non-kiln-indirect	Electricity used in the production of the kiln stone and transport to plant
5	Non-kiln-indirect	Fuel used in the production of the kiln stone and transport to plant
6	Kiln-indirect	Electricity used in the kiln operation including any requirements for transport of the kiln stone or fuel from plant delivery point to the kiln
7	Kiln-direct	Fuel used in kiln operations
8	Non-kiln-indirect	Electricity used in post kiln processing
9	Non-kiln-direct	Fuel used in post kiln processing
10	Kiln-direct	GHG emissions from the kiln system released to atmosphere via the plant exhaust stack

Figure A.1 — Boundaries of the system used in the site field trials

The site field trials concluded that:

a) The mass-balance-based methods, input and output, are entirely workable and produce results in relatively close agreement and with acceptable levels of uncertainty of close to 2 %.

b) The uncertainty of the stack-emission-measurement-based method ranged between 15 % and 25 %. Whilst further refinements to site specific measurement techniques may enable a reduction in this level of uncertainty, the results are considered systematically higher than those achieved using the mass-balance-based method.

c) The main reason for this difference was identified as the high uncertainty of the volume flow measurement due to the nature of the stack arrangement and fluctuating process conditions, although variations in the CO_2 concentration across the sampling plane and the difficulties in obtaining a representative measurement are also likely to have had a considerable influence.

d) Whilst an initial homogeneity assessment to EN 15259 indicated an acceptable gas concentration profile in the exhaust stacks and the general velocity profile within the duct was reasonably uniform during periods of measurement, continuous measurements at a single point indicated significant temporal variations during these site trials. As a result, CO_2e emissions determined using the stack-emissions-measurement-based method were around 50 % greater than those determined using the mass-balance-based method.

e) The site field trials identified that the measurements most important for the uncertainty of the mass-balance-based method are:

   1) kiln stone activity data;

   2) kiln stone carbonate content;

   3) ROK activity data;

   4) ROK oxide content;

   5) LKD activity data (in some cases);

   6) LKD oxide content (in some cases);

   7) kiln fuel activity data.

Of the non-CO_2 greenhouse gases, only methane was identified in any measurable amount in some of the tests. All other non-CO_2GHGs were below the measurement technique detection limits. In the worst case, the amount of methane, on a CO_2e basis, was less than 0,2 %. In view of the errors associated with the measurement of methane and the relatively low levels present, it was considered that non-CO_2 greenhouse gases do not have a significant impact on the representativeness of GHG emissions in the lime industry.

Annex B
(normative)

Minimum content of the monitoring plan

a) In addition to the minimum content specified in Annex A of EN 19694-1:2016 the monitoring plan shall contain at least the following information:

    1) a current process flow diagram detailing all processes;

    2) a list of operations associated with lime manufacture;

    3) the boundaries used for the assessment of the GHG emissions;

    4) a clear identification of all GHG emission sources;

    5) an inventory of all internal transfers;

    6) a statement about the inclusion or exclusion of GHG emissions from off-site transport by company-owned fleets;

    7) all material deviations from this standard;

    8) the overall uncertainty of the calculated GHG emissions;

b) direct greenhouse gas emissions from the calcination of kiln stone (scope 1 emissions):

    1) a full inventory of all direct greenhouse gas emissions sources of the plant;

    2) the methodology and the assumptions used to calculate the free CaO and MgO If the residual amount exceeds 5 %;

    3) the demonstration that that the kiln stone moisture content is consistently below or equal to 1 % (only applicable if the input method is used);

    4) the methodology used for determining the ratio of LKD to kiln stone in the input method if the input method is used;

    5) the methodology used for sampling and analysing the LKD in the input method if the input method is used;

    6) the methodology used to derive the mass of ROK lime in the output method if the output method is used;

    7) the methodology used to derive the free calcium oxide (CaO_{LI-ROK}) and free magnesium oxide (MgO_{LI-ROK}) in the output method if the output method is used;

    8) the methodology used for determining the ratio of LKD to ROK lime in the output method if the output method is used;

    9) the methodology used for sampling and analysing the LKD in the output method if the output method is use;

   10) the methodology used to estimate the direct CO_2 emissions from the calcination during kiln start up or shutdown;

   11) the methodology used to derive the mass of ROK lime from the mass of downstream lime products (if the output method is used and the activity data for ROK lime cannot be directly determined);

   12) the methodology used to assess the chemical composition of ROK lime on the basis of the chemical composition of the downstream lime products (if the output method is used and the ROK lime cannot be directly sampled and analysed). In addition it shall be demonstrated that the thus calculated chemical composition of the ROK lime is equivalent to the composition of the ROK lime if it would be directly measured.

c) direct greenhouse gas emissions from kiln fuels (scope 1 emissions):

   1) the methodology used for determining the activity data (masses or volumes) of kiln fuels consumed;

   2) the standards used to sample and analyse the fuels;

   3) the frequency of analysis of the oxidation factor for liquid and solid fuels;

   4) the sampling and monitoring plan of the fuel supplier if the fuels are sampled and the fuel factors are analysed by the fuel supplier;

   5) the documentation and justification of the fuel factors used for natural gas;

   6) the methodology and fuel factors used for determining the GHG emissions of mixed fuels;

   7) the sampling and monitoring plan of the fuel supplier if the alternative fuels (AF) are sampled and the fuel factors are analysed by the fuel supplier;

   8) for plants with GHG emissions below 50,000 t_{CO2e} per annum, the records of the references used for the fuel factors;

   9) a precise description about the methodology used to determine the fuel factors of minor fuels.

d) direct greenhouse gas emissions from non-kiln fuels (scope 1 emissions):

   1) the methodology used for determining the activity data (masses or volumes) of fuels consumed;

   2) the methodology used to determine the activity data (masses or volumes) of consumed non-kiln fuels that are not specified in

   3) Table 14;

   4) a precise description about the methodology used to determine the activity data of non-kiln fuels used respectively for the lime manufacturing and for other products;

   5) a precise description about the methodology used to determine the activity data of non-kiln fuels used for the manufacturing of other products which are deducted from the overall activity of non-kiln fuels;

e) indirect greenhouse gas emissions from electricity (scope 2 emissions):

   1) the methodology used for determining the quantity of externally generated electricity used;

   2) a precise description about the methodology used to determine the quantity of electricity used for the manufacturing of other products which are deducted from the overall electricity;

   3) the methodology and the GHG emission factor of the purchased electricity with its corresponding reference annum.

f) inother direct greenhouse gas emissions from purchased kiln stone and off-site transport (other indirect emissions):

   1) a statement about the inclusion or exclusion of GHG emissions from off-site transport;

   2) the methodology used for assessing the GHG emission factor of imported kiln stone;

   3) the methodology, the emission factors, their origin and the assumptions (e.g. load factor) used to derive the GHG emissions of the transport of imported kiln stone;

   4) the methodology used for determining the transportation distance.

Annex C
(informative)

Details about the calculation of process emissions from lime kilns using the mass balance-based-method

Let's consider the following calcination system:

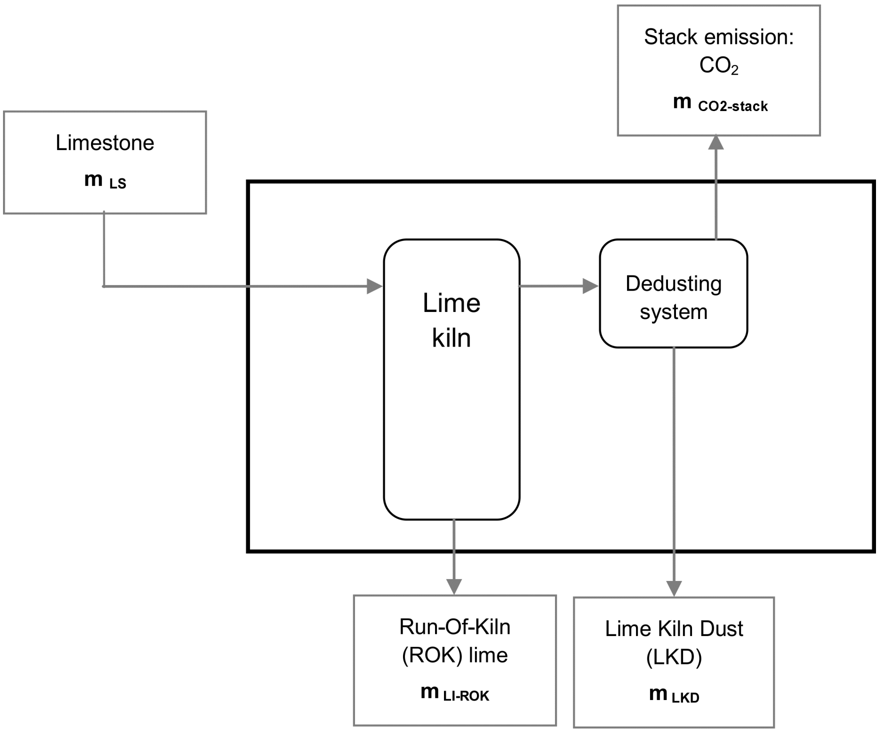


Figure C.1 — Boundaries of the system considered for calculation of the process emissions

The mass balances of CaO, MgO and CO_2 are considered in the following: for each of the three substances, the input mass flow shall be equal to its respective output mass flow.

Thus for the CaO mass balance it follows:

$$m_{LS} \times CaCO_{3\,LS} \times \frac{M_{CaO}}{M_{CaCO3}} = m_{LI-ROK} \times \left(CaO_{LI-ROK} + CaCO_{3\,LI-ROK} \times \frac{M_{CaO}}{M_{CaCO3}} \right) + m_{LKD} \times \left(CaO_{LKD} + CaCO_{3\,LKD} \times \frac{M_{CaO}}{M_{CaCO3}} \right) \tag{C.1}$$

Similarly, the MgO mass balance provides following equation:

$$m_{LS} \times MgCO_{3\,LS} \times \frac{M_{MgO}}{M_{MgCO3}} = m_{LI-ROK} \times \left(MgO_{LI-ROK} + MgCO_{3\,LI-ROK} \times \frac{M_{MgO}}{M_{MgCO3}} \right) + m_{LKD} \times \left(MgO_{LKD} + MgCO_{3\,LKD} \times \frac{M_{MgO}}{M_{MgCO3}} \right) \tag{C.2}$$

From the definition of $m_{CO2-stack}$ it follows for the CO₂ mass balance:

$$\begin{aligned}
& m_{LS} \times \left(CaCO_{3\,LS} \times \frac{M_{CaO}}{M_{CaCO3}} + MgCO_{3\,LS} \times \frac{M_{MgO}}{M_{MgCO3}} \right) \\
& = m_{CO2-stack} + m_{LI-ROK} \times \left(CaCO_{3\,LI-ROK} \times \frac{M_{CO2}}{M_{CaCO3}} + MgCO_{3\,LI-ROK} \times \frac{M_{CO2}}{M_{MgCO3}} \right) \\
& + m_{LKD} \times \left(CaCO_{3\,LKD} \times \frac{M_{CO2}}{M_{CaCO3}} + MgCO_{3\,LKD} \times \frac{M_{CO2}}{M_{MgCO3}} \right)
\end{aligned} \tag{C.3}$$

It is assumed that the concentration of impurities can be assessed as follows:

— In the limestone:

$$\%of\ impurities = 1 - CaCO_{3\,LS} - MgCO_{3\,LS} \tag{C.4}$$

— In the ROK lime:

$$\%of\ impurities = 1 - CaO_{LI-ROK} - MgO_{LI-ROK} - CaCO_{3\,LI-ROK} - MgCO_{3\,LI-ROK} \tag{C.5}$$

— In the LKD:

$$\%of\ impurities = 1 - CaO_{LKD} - MgO_{LKD} - CaCO_{3\,LKD} - MgCO_{3\,LKD} \tag{C.6}$$

The mass balance of the impurities leads then to the following equation:

$$\begin{aligned}
& m_{LS} \times \left(1 - CaCO_{3\,LS} - MgCO_{3\,LS}\right) = m_{LI-ROK} \times \left(1 - CaO_{LI-ROK} - MgO_{LI-ROK} - CaCO_{3\,LI-ROK} - MgCO_{3\,LI-ROK}\right) \\
& + m_{LKD} \times \left(1 - CaO_{LKD} - MgO_{LKD} - CaCO_{3\,LKD} - MgCO_{3\,LKD}\right)
\end{aligned} \tag{C.7}$$

If the **(carbonate) input method is** used to assess the CO₂ emissions, following parameters are known:

— m_{LS};

— $CaCO_{3\,LS}$;

— $MgCO_{3\,LS}$;

— m_{LKD};

— CaO_{LKD};

— MgO_{LKD};

— $CaCO_{3\,LKD}$;

- $MgCO_{3\,LKD}$;
- $CaCO_{3\,LI-ROK}$;
- $MgCO_{3\,LI-ROK}$.

The remaining 4 unknown parameters $\left(m_{CO2-stack}, m_{LI-ROK}, CaO_{LI-ROK}, MgO_{LI-ROK}\right)$ can then be theoretically determined with the Formulae (C.1), (C.2), (C.3) and Formula (C.7) as shown hereafter.

Let’s therefore define the following parameters $\mu_1, \kappa_1, \mu_2, \mu_3, \kappa_2, \mu_4, \mu_5, \kappa_3, \mu_6, \mu_7$ as:

$$\mu_1 = m_{LS} \times CaCO_{3\,LS} \times \frac{M_{CaO}}{M_{CaCO3}} \tag{C.8}$$

$$\kappa_1 = CaCO_{3\,LI-ROK} \times \frac{M_{CaO}}{M_{CaCO3}} \tag{C.9}$$

$$\mu_2 = m_{LKD} \times \left(CaO_{LKD} + CaCO_{3\,LKD} \times \frac{M_{CaO}}{M_{CaCO3}} \right) \tag{C.10}$$

$$\mu_3 = m_{LS} \times MgCO_{3\,LS} \times \frac{M_{MgO}}{M_{MgCO3}} \tag{C.11}$$

$$\kappa_2 = MgCO_{3\,LI-ROK} \times \frac{M_{MgO}}{M_{MgCO3}} \tag{C.12}$$

$$\mu_4 = m_{LKD} \times \left(MgO_{LKD} + MgCO_{3\,LKD} \times \frac{M_{MgO}}{M_{MgCO3}} \right) \tag{C.13}$$

$$\mu_5 = m_{LS} \times \left(CaCO_{3\,LS} \times \frac{M_{CO2}}{M_{CaCO3}} + MgCO_{3\,LS} \times \frac{M_{CO2}}{M_{MgCO3}} \right) \tag{C.14}$$

$$\kappa_3 = CaCO_{3\,LI-ROK} \times \frac{M_{CO2}}{M_{CaCO3}} + MgCO_{3\,LI-ROK} \times \frac{M_{CO2}}{M_{MgCO3}} \tag{C.15}$$

$$\mu_6 = m_{LKD} \times \left(CaCO_{3\,LKD} \times \frac{M_{CO2}}{M_{CaCO3}} + MgCO_{3\,LKD} \times \frac{M_{CO2}}{M_{MgCO3}} \right) \tag{C.16}$$

$$\mu_7 = m_{LS} \times \left(1 - CaCO_{3\,LS} - MgCO_{3\,LS}\right) - m_{LKD} \times \left(1 - CaO_{LKD} - MgO_{LKD} - CaCO_{3\,LKD} - MgCO_{3\,LKD}\right) \tag{C.17}$$

The parameters μ_1 to μ_7, κ_1 to κ_3 are fully determined as they are only depending on:

$$m_{LS}, CaCO_{3\,LS}, MgCO_{3\,LS}, m_{LKD}, CaO_{LKD}, MgO_{LKD}, CaCO_{3\,LKD}, MgCO_{3\,LKD}, CaCO_{3\,LI-ROK}$$

which are known in the (carbonate) input method.

Formulae (C.1), (C.2), (C.3) $m_{LI-ROK} \times 3$ and Formula (C.7) can then be rewritten as follows:

$$\left\{\begin{array}{ll} \mu_1 = \left(CaO_{LI-ROK} + \kappa_1\right) + \mu_2 & \text{(C.18)} \\ \mu_3 = m_{LI-ROK} \times \left(MgO_{LI-ROK} + \kappa_2\right) + \mu_4 & \text{(C.19)} \\ \mu_5 = m_{CO2-stack} \times m_{LI-ROK} \times \kappa_3 + \mu_6 & \text{(C.20)} \\ m_{LI-ROK} \times \left(1 - CaO_{LI-ROK} - MgO_{LI-ROK} - CaCO_{3\,LI-ROK} - MgCO_{3\,LI-ROK}\right) = \mu_7 & \text{(C.21)} \end{array}\right.$$

With this system of formulae the unknown $\left(\boldsymbol{m_{CO2-stack}}, \boldsymbol{m_{LI-ROK}}, \boldsymbol{CaO_{LI-ROK}}, \boldsymbol{MgO_{LI-ROK}}\right)$ can be fully determined. It results finally:

$$m_{CO2-stack} = EF_{LS} \times m_{LS} \tag{C.22}$$

With EF_{LS} expressed as follows: (C.23)

$$EF_{LS} = \left\{\left(CaCO_{3\,LS} - \eta_{LS} \times CaCO_{3\,LKD}\right) \times \frac{M_{CO_2}}{M_{CaCO_3}} + \left(MgCO_{3\,LS} - \eta_{LS} \times MgCO_{3\,LKD}\right) \times \frac{M_{CO_2}}{M_{MgCO_3}}\right\} - \left\{\frac{CaCO_{3\,LI-ROK} \times \frac{M_{CO_2}}{M_{CaCO_3}} + MgCO_{3\,LI-ROK} \times \frac{M_{CO_2}}{M_{MgCO_3}}}{1 - \left(CaCO_{3\,LI-ROK} \times \frac{M_{CO_2}}{M_{CaCO_3}} + MgCO_{3\,LI-ROK} \times \frac{M_{CO_2}}{M_{MgCO_3}}\right)} \times \left[\left(\left(1 - CaCO_{3\,LS} - MgCO_{3\,LS}\right) + CaCO_{3\,LS} \times \frac{M_{CaO}}{M_{CaCO_3}} + MgCO_{3\,LS} \times \frac{M_{MgO}}{M_{MgCO_3}}\right) - \eta_{LS} \times \left(\left(1 - CaO_{LKD} - MgO_{LKD} - CaCO_{3\,LKD} - MgCO_{3\,LKD}\right) + CaO_{LKD} + CaCO_{3\,LKD} \times \frac{M_{CaO}}{M_{CaCO_3}} + MgO_{LKD} + MgCO_{3\,LKD} \times \frac{M_{MgO}}{M_{MgCO_3}}\right)\right]\right\}$$

If the **(lime) output method** is used to assess the CO$_2$ emissions, following parameters are known:

- m_{LI-ROK};
- CaO_{LI-ROK};
- MgO_{LI-ROK};
- $CaCO_{3\,LI-ROK}$;
- $MgCO_{3\,LI-ROK}$;
- m_{LKD};

- CaO_{LKD};
- MgO_{LKD};
- $CaCO_{3\,LKD}$;
- $MgCO_{3\,LKD}$;

The remaining 4 unknown parameters $\left(m_{CO2-stack}, m_{LS}, CaCO_{3\,LS}, MgCO_{3\,LS}\right)$ can then be theoretically determined with the Formulae (C.1), (C.2), (C.3) and (C.7) as shown hereafter.

Let’s define the following parameters μ'_1 to μ'_4 as:

$$\mu'_1 = \left\{ m_{LI-ROK} \times \left(CaO_{LI-ROK} + CaCO_{3\,LI-ROK} \times \frac{M_{CaO}}{M_{CaCO3}} \right) + m_{LKD} \times \left(CaO_{LKD} + CaCO_{3\,LKD} \times \frac{M_{CaO}}{M_{CaCO3}} \right) \right\} \times \frac{M_{CaCO3}}{M_{CaO}} \tag{C.24}$$

$$\mu'_2 = \left\{ m_{LI-ROK} \times \left(MgO_{LI-ROK} + MgCO_{3\,LI-ROK} \times \frac{M_{MgO}}{M_{MgCO3}} \right) + m_{LKD} \times \left(MgO_{LKD} + MgCO_{3\,LKD} \times \frac{M_{MgO}}{M_{MgCO3}} \right) \right\} \times \frac{M_{MgCO3}}{M_{MgO}} \tag{C.25}$$

$$\mu'_3 = m_{LI-ROK} \times \left(CaCO_{3\,LI-ROK} \times \frac{M_{CO2}}{M_{CaCO3}} + MgCO_{3\,LI-ROK} \times \frac{M_{MCO2}}{M_{MgCO3}} \right) + m_{LKD} \times \left(CaCO_{3\,LKD} \times \frac{M_{CO2}}{M_{CaCO3}} + MgCO_{3\,LKD} \times \frac{M_{MCO2}}{M_{MgCO3}} \right) \tag{C.26}$$

$$\mu'_4 = m_{LI-ROK} \times \left(1 - CaO_{LI-ROK} - MgO_{LI-ROK} - CaCO_{3\,LI-ROK} - MgCO_{3\,LI-ROK}\right) + m_{LKD} \times \left(1 - CaO_{LKD} - MgO_{LKD} - CaCO_{3\,LKD} - MgCO_{3\,LKD}\right) \tag{C.27}$$

The parameters μ'_1 to μ'_4 are fully determined as they are only depending on:

$m_{LI-ROK}, CaO_{LI-ROK}, MgO_{LI-ROK}, CaCO_{3\,LI-ROK}, MgCO_{3\,LI-ROK}, m_{LKD}, CaO_{LKD}, MgO_{LKD}, CaCO_{3\,LKD}, MgCO_{3\,LKD}$

which are known in the (lime) output method.

Formulae (C.1), (C.2), (C.3) and Formulae (C.7) can then be rewritten as follows:

$$\left\{\begin{array}{l} \mu'_1 = m_{LS} \times CaCO_{3\,LS} \qquad \text{(C.28)} \\ \mu'_2 = m_{LS} \times MgCO_{3\,LS} \qquad \text{(C.29)} \\ m_{CO2-stack} = m_{LS} \times \left(CaCO_{3\,LS} \times \dfrac{M_{CO2}}{M_{CaCO3}} + MgCO_{3\,LS} \times \dfrac{M_{CO2}}{M_{MgCO3}} \right) - \mu'_3 \qquad \text{(C.30)} \\ m_{LS} \times \left(1 - CaCO_{3\,LS} - MgCO_{3\,LS}\right) = \mu'_4 \qquad \text{(C.31)} \end{array}\right.$$

With this system of formulae the unknown $\left(m_{CO2-stack}, m_{LS}, CaCO_{3\,LS}, MgCO_{3\,LS}\right)$ can be fully determined. It results finally:

$$m_{CO2-stack} = EF_{LI} \times m_{LI-ROK} \qquad \text{(C.32)}$$

With EF_{LI} expressed as follows:

$$EF_{LI} = \left(CaO_{LI-ROK} + \eta_{LI} \times CaO_{LKD}\right) \times \frac{M_{CO2}}{M_{CaCO3}} + \left(MgO_{LI-ROK} + \eta_{LI} \times MgO_{LKD}\right) \times \frac{M_{CO2}}{M_{MgCO3}} \qquad \text{(C.33)}$$

Annex D
(informative)

Example of an uncertainty calculation

As an example, the measured standard uncertainty associated with the measurement of ROK lime activity data (production) during a site trial can be calculated as follows:

a) Uncertainty of activity data

During a site trial, the production of ROK lime is collected in a silo and subsequently transferred to trucks for weighing on the site weighbridge. In the trial 24 loads, each of around 22,4 t were recorded. The weighbridge has a valid calibration and the uncertainty determined during the calibration is ± 0,02 t.

The relative uncertainty of the measurement of ROK lime production is given by:

$$U_{mtotal} = \frac{U_{m1} + U_{m2} + U_{m3} + \ldots.. + U_{m24}}{M1 + M2 + M3 + \ldots.. + M24}$$

In this case:

$$U_{mtotal} = \frac{24 \times 0.02}{24 \times 22.4} \approx 0.000\,9$$

The uncertainty is multiplied by a CAF of 2 to provide a standard relative uncertainty for the mass of ROK lime produced. This uncertainty is equal to:

0,000 9 × 2 × 24 × 22,4 = ±0,96 t

b) Uncertainty of analytical parameters

In the example below the carbonate or oxide content of the ROK lime is used. For the determination of the uncertainty due to the sample handling, the procedure presented in the following example can be used:

For the sample handling (division) process, one sample is used and sub-divided into four. These samples are then measured by the same technique to determine the CaO content of the ROK lime. The variation in CaO content in the results is attributed to the uncertainty introduced via the sampling dividing process. The four samples provided the following measured CaO contents (%, dry): 94,73, 95,62, 94,83, 95,01.The associated uncertainty is determined by calculating the standard deviation and then assessing this in terms of the normal measurements made, for example:

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n} = 95{,}05$$

$$S_s(x_i) = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \overline{x})^2}{n-1}} = 0,40$$

The uncertainty associated with the sampling part of the analytical procedure (Us) is then:

$$Us = \frac{S_s(x_i)}{\sqrt{t}} = 0,40$$

where

t is the number of samples in the actual measurement (in this case t = 1).

For the determination of the uncertainty associated with the analytical measurement, the procedure presented in the following example can be used:

The same measurement of CaO content in the ROK lime is undertaken five times giving the following results (%, dry): 94,90, 94,45, 95,00, 94,76, 94,51. The mean and standard deviation calculated are:

$$\overline{x} = 94.72$$

$$S_m(x_i) = 0.24$$

Each measurement is undertaken in duplicate (t = 2) and the uncertainty associated with the measurement procedure is therefore:

$$U_m = \frac{0,24}{\sqrt{2}} = 0.17$$

The uncertainty associated with the overall analytical procedure (*U*a) is then determined by error propagation by determining the root of the sum of the squares, for example:

$$U_a = \sqrt{U_{s^2} + U_{m^2}} = 0.43$$

Thus in the previous example, the standard uncertainty for the determination of the CaO content of ROK lime is ± 0,45 %.

The resulting standard error should be subsequently combined using propagation methodology based on the form of the function being calculated. Convention is that uncertainty be expressed on the basis of a confidence limit. Generally a 95 % confidence limit is employed in EU Directives. The standard uncertainty is expressed on a confidence limit basis multiplied by a coverage factor applicable to the desired limit. To express a standard uncertainty at a 95 % confidence limit the coverage factor is 1,96.

A similar approach can be applied to the annual GHG emission measurement. For this determination the uncertainty calculation should include all relevant sources of measurement uncertainty, including all activity data measurements, sampling and analytical measurements.

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