Grant Agreement n°764816

Full title:	**Clean clinker production via calcium looping process**
Acronym:	**CLEANKER**
Type of action:	**H2020-LCE-2016-2017/LCE-29-2017**
Grant Agreement number:	**764816**
Project starting date – Duration:	**1st October 2017 – 48 months**

Screening environmental LCA of the CLEANKER technology

WP6 – Deliverable D6.4

Deliverable number	D6.4
Deliverable title	Screening environmental LCA of the CLEANKER technology
Work package	WP6: Screening environmental LCA of the CLEANKER technology
Due delivery date	30th September 2019 (M24)
Actual delivery date	24st September 2019
Lead participant	QUANTIS
Dissemination level (PU, CO)	PU

PU=Public
CO=Confidential, only for members of the consortium (including the Commission Services)

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Key word(s)
Life Cycle Assessment – Cement plant - CO_2 emissions reduction – Calcium-looping – Oxyfuel – Entrained flow carbonator

Short description
The purpose of this screening environmental Life Cycle Assessment is to identify the most probable hotspots in the life cycle and where more in-depth information is necessary, and provide recommendations on the most promising options and configurations from an environmental point of view. The screening LCA also aims at preparing the framework for the subsequent final LCA. In particular, it defines the goal and scope of the study, the reference conventional technologies and the priority environmental indicators to be addressed. The results of the screening environmental LCA will be used as much as possible to guide the design and development strategy towards sustainable solutions and provide best-practice recommendations.

History of changes

Version	DATE	Changes	Author
V2	2019-09-24	First release	Filippo Sessa (QUANTIS)

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Abstract

The purpose of this screening environmental Life Cycle Assessment is to identify the most probable hotspots in the life cycle and where more in-depth information is necessary, and provide recommendations on the most promising options and configurations from an environmental point of view. The results of this study show that the CLEANKER technology (calcium looping) can contribute to the reduction of the climate change impact of cement (around 73% less impact compared to a reference cement plant without CO_2 capture). Hotspots of clinker production with the calcium looping technology are fuel and electricity consumption, which is the reason why a further improvement can be achieved by using energy from renewable sources. The calcium looping technology was also compared to other carbon capture technologies.

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1. INTRODUCTION

1.1 Context

CLEANKER is a project funded by the European Union Horizon2020 programme addressing CO_2 capture from cement production. Given that the calcium looping (CaL) is one of the most promising technologies for CO_2 capture in cement plants, the core activity of the project is the design, construction and operation of a CaL demonstration system in the cement plant operated by Buzzi Unicem sited in Vernasca (Piacenza, Italy).

An important finding of the project is a full understanding of the CLEANKER technology life cycle impacts. This work assesses all of the environmental impacts associated with all the stages of a product's life cycle, including raw materials extraction, processing, distribution, use and disposal.

D6.4 summarizes the findings of the LCA of the novel technology, compared to conventional emitting plant and current carbon capture technologies, focusing on the following environmental indicators: GHG emissions (carbon footprint), non-renewable primary energy use (energy footprint), water use (water footprint), as well as impacts on human health and impacts on the ecosystem.

1.2 European Commission emission targets

The EU has set itself targets for reducing its greenhouse gas emissions progressively up to 2050, with quantified targets for 2020, 2030 and 2050 (European Commission 2018).

For example, the 2030 climate and energy framework sets three key targets for the year 2030:

- Cut emissions in EU territory by at least 40% below 1990 levels by 2030
- Boost the share of renewables to at least 27% of EU energy consumption by 2030
- Improve energy efficiency to have an indicative energy savings target of 27% by 2030

Furthermore, the 2050 low-carbon economy roadmap suggests that, by 2050, the EU should cut its emissions to 80% below 1990 levels through domestic reductions alone (i.e. rather than relying on international credits).

These cross-sectorial objectives can be then translated into sectorial objectives, cement production being key contributors to global GHG emissions. The cement industry accounts for around 5% of global anthropogenic greenhouse gas emissions (International Energy Agency Environmental Projects (IEAGHG) 2013). The changes in GHG emissions from cement production induced by the implementation of the Direct Separation technology can be projected and compared to these 2030 and 2050 emission targets.

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1.3 Life cycle assessment

A leading tool for assessing environmental performance is life cycle assessment (LCA), a method defined by the International Organization for Standardization (ISO) 14040-14044 standards (ISO 2006a; ISO 2006b). LCA is an internationally-recognized approach that evaluates the relative potential environmental and human health impacts of products and services throughout their life cycle, beginning with raw material extraction and including all aspects of transportation, manufacturing, use, and end-of-life treatment. It is important to note that LCA does not exactly quantify the real impacts of a product or service due to data availability and modelling challenges. However, it allows to estimate and understand the potential environmental impacts which a system might cause over its typical life cycle, by quantifying (within the current scientific limitations) the likely emissions produced and resources consumed. Hence, environmental impacts calculated through LCA should not be interpreted as absolute, but rather relative values within the framework of the study. Ultimately, this is not a limitation of the methodology, since LCA is generally used to compare different systems performing the same function, where it's the relative differences in environmental impacts which are key for identifying the solution which performs best.

Among other uses, LCA can identify opportunities to improve the environmental performance of products, inform decision-making, and support marketing, communication, and educational efforts. The importance of the life cycle view in sustainability decision-making is sufficiently strong that over the past several decades it has become the principal approach to evaluate a broad range of environmental problems, identify social risks and to help make decisions within the complex arena of socio-environmental sustainability.

Through the use of LCA, the environmental performance of the CLEANKER technology can be quantitatively compared to a conventional emitting plant and current carbon capture technologies through several key indicators.

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2. GOAL AND SCOPE OF THE STUDY

This section describes the goal and scope of the study, along with the methodological framework of the LCA. It includes the objectives of the study, a description of the product function and product system, the system boundaries, time horizon, reference scenarios, data sources, and the impact assessment framework.

2.1 Objectives of the study

This study aims at evaluating the benefits of CLEANKER technology compared to other carbon capture technologies from an environmental point of view, with a special focus on the impact on global warming (carbon footprint). These benefits can be evaluated on a product perspective as well as a European perspective with projections for future GHG emission scenarios at the sectorial level.

2.2 Functional unit

Life cycle assessment relies on a “functional unit” (FU) for comparison of alternative products or processes that may substitute each other in fulfilling a certain function for the user or consumer. The FU describes this function in quantitative terms and serves as an anchor point of the comparison ensuring that the compared alternatives do indeed fulfil the same function. It is therefore critical that this parameter is clearly defined and measurable.

In this study the functional unit used is the production of 1 t of cement using clinker produced with the calcium looping technology.

In the final environmental LCA also the European total cement production will be used as functional unit to provide a further interpretation angle.

2.3 System boundaries

The system boundaries identify the life cycle stages, processes, and flows considered in the LCA and should include all activities relevant to attaining the above-mentioned study objectives. The following paragraphs present a general description of the system as well as temporal and geographical boundaries of this study.

This study assesses the life cycle of cement from the extraction and processing of all raw materials through the end-of-life of all components as depicted in Figure 1.

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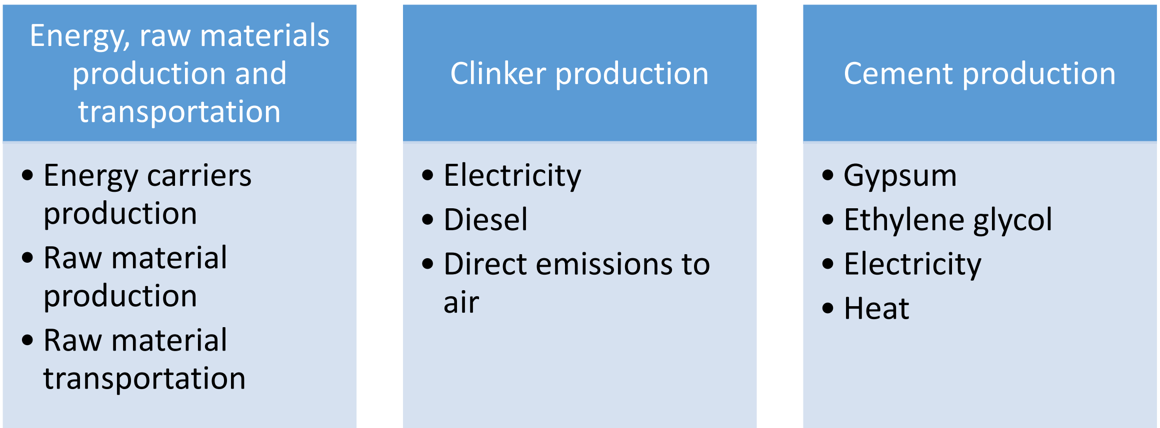

Figure 1 – System boundaries of the life cycle assessment

As is generally done in LCA, within the above shown steps, the assessment considers all identifiable “upstream” activities to provide as comprehensive a view as possible of the product’s cradle-to-gate life cycle. For example, when considering the environmental impact of transportation, not only are the emissions of the truck considered, but also included are the impacts of additional processes and inputs needed to produce the fuel and the vehicle. In this way, the production chains of all inputs are traced back to the original extraction of raw materials.

This LCA is representative of cement production in the present as well as future projected time. Data and assumptions are intended to reflect current and future equipment, processes, and market conditions. It should be noted, however, that some processes within the system boundaries might take place anywhere or anytime. For example, the processes associated with the supply chain and with waste management can take place in Asia, North America or elsewhere in the world. In addition, certain processes may generate emissions over a longer period of time than the reference year. This applies to landfilling, which causes emissions (biogas and leachate) over a period of time whose length (several decades to over a century/millennium) depends on the design and operation parameters of the burial cells and how the emissions are modelled in the environment.

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2.4 Time horizon

This screening LCA assess the current cement production technologies.

The final LCA will assess both the current cement production as well as future time horizons for which cement production with different carbon capture technologies will be assessed.

- Current production: current production of cement without carbon capture technology
- Future time: the production of cement will then be modelled for year 2030 and 2050 based on extrapolations of the technology uptake.

The 2030 and 2050 models will be compared with the 2030 scenario with the European Commission emission targets for 2030 (i.e. a 40% cut in greenhouse gas emissions compared to 1990 levels, at least a 27% share of renewable energy consumption, at least 27% energy savings compared with the business-as-usual scenario) as well as the 2050 European low-carbon economy roadmap (i.e. a 80% cut in greenhouse gas emissions below 1990 levels through domestic reductions).

2.5 Scenarios assessed

In this screening environmental LCA five scenarios are assessed:

1. Reference cement plant without CO_2 capture
2. Integrated CaL process (CLEANKER technology)
3. Tail-End CaL process
4. Full Oxyfuel process
5. Partial Oxyfuel process

These scenario, described in the following paragraphs, are those reported in the deliverable D5.8 “Performance of CaL processes in full scale cement plants, with full sensitivity analysis and comparison with benchmark” prepared by POLIMI and LEAP.
For all the scenarios the thermal energy source is assumed to be 100% coal (LHV=27.2 MJ/kg) and the electricity mix considered is the EU average.

2.5.1 Reference cement plant without CO_2 capture

The reference cement plant without CO_2 capture relies on the Best Available Technique (BAT) standard as defined in the European BREF-Document (Best Available Technique Reference) for the manufacture of cement (Schorcht et al., 2013). (Schorcht et al., 2013). In this reference configuration the cement kiln consists of a two-string five-stage cyclone preheater, a pre-calciner with a tertiary air duct, a rotary kiln and a grate clinker cooler.

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2.5.2 Integrated CaL process

This scenario corresponds to the integration of the CaL process into the cement production process through the use of Entrained Flow Reactors (EFR). In this configuration, the raw meal is used as CO_2 sorbent instead of pure limestone, as it is commonly done in the standard CaL process. A single oxyfuel calciner is adopted, which represents both the cement kiln pre-calciner and the calciner of the CaL system.

2.5.3 Tail-End CaL process

In the Tail-End configuration the flue gas from the cement kiln is sent to the CaL system, which is then integrated in the cement kiln as an end-of-pipe system. One of the advantages of the CaL technology is that most of the fuel chemical energy introduced into the calciner can be recovered as high temperature heat in the cooled carbonator and potentially converted into electricity with high efficiency. The analysis was carried out for different Integration Levels (IL): 20% and 50%.

2.5.4 Full Oxyfuel process

In the full oxyfuel configuration, the burning line process is carried out with an oxidant mainly composed of oxygen and CO2, in order to produce a CO2-rich stream can be treated directly in the CPU.

2.5.5 Partial Oxyfuel process

The partial oxyfuel configuration is one of the most promising CCS technologies for the cement industry considered in current literature. This configuration is inspired by the idea that about 80% of CO_2 generated in the cement production process comes from the pre-calciner, which is the only reactor converted to oxyfuel operation in this configuration. In this way the modifications to the plant are limited to the pre-calciner only, and the rotary kiln and the clinker cooler can work as in the reference cement plant. The energy penalty associated to the capture process is due to the additional consumption of fuel and electricity, which is required for the oxygen production and for the CO_2 compression and purification process.

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2.6 Data sources

- Data on energy (fuel and electricity) consumption and CO_2 emissions at stack for clinker production with the different technologies (Table 1) are from the deliverable D5.8 "Performance of CaL processes in full scale cement plants, with full sensitivity analysis and comparison with benchmark" prepared by POLIMI and LEAP.
- Data on raw materials consumption and other emissions related to clinker production and on cement production (Table 2 and Table 3) are from the WBCSD-CSI tool for EPDs of concrete and cement (Dauriat et al 2014). This tool aims at supporting the implementation of cement and concrete EPDs. The inventory data is based on reference ecoinvent clinker and cement dataset ("clinker, at plant [t]– CH" and "Portland cement, strength class Z 42.5, at plant [t] – CH").
- 5 km truck for clinker, 50 km for all other materials, 100 km truck + 600 km train for ethylene glycol were assumed to model the transportations related to cement production (source: WBCSD-CSI tool).
- 5 km truck for clinker, 50 km for all other materials, 100 km truck + 600 km train for ethylene glycol were assumed to model the transportations related to clinker production (source: WBCSD-CSI tool).
- The clinker /cement factor 0.737 t clinker/t cement has been taken from the deliverable D5.8 "Performance of CaL processes in full scale cement plants, with full sensitivity analysis and comparison with benchmark"
- All the secondary Life Cycle Inventory (LCI) datasets, used for example to model coal extraction, electricity production and transportation, are from the LCI database Ecoinvent[1].

Table 1 – Energy consumption and direct CO_2 emissions of the different technologies

	Net electric consumption [kWh_e/t_{clk}]	**Direct fuel consumption [MJ_{LHV}/kg_{clk}]**	**Direct CO_2 [g_{CO2}/kg_{clk}]**	**Direct CO_2 emissions reduction**
Reference cement plant without CO_2 capture	131.6	3.24	865.2	-
Integrated CaL process	173.9	5.44	50.3	94 %
Tail-End CaL process – 20%-IL	-104.3	8.72	111.4	87 %
Tail-End CaL process - 50%-IL	62.6	7.1	75.9	91%

[1] https://www.ecoinvent.org

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Full Oxyfuel process	300.7	3.24	69.2	92 %
Partial Oxyfuel process	277	3.87	180.3	79%

Table 2 – Dataset to produce 1 t cement

Data	**Value**	**Comment**
kg clinker/t cement	737	Deliverable 5.8
Gypsum, with addition of other materials such as filler, blast furnace slag, fly ash	263 kg	BREF document mentions only 50 kg for gypsum, with addition of other materials such as filler, blast furnace slag, fly ash. 263 kg of materials taken as a simplification.
Ethylene glycol	0.19 kg	Ecoinvent
Cement factory	5.36E-8	Ecoinvent
Electricity	29.2 kWh	CSI tool
Heat, waste	135 MJ	Ecoinvent

Table 3- Dataset to produce 1 t clinker production

Data	**Value**	**Comment**
Limestone	1520 kg	According to BREF
Calcareous marl	466 kg	CSI tool, primary material (identical to ecoinvent clinker)
Clay	331 kg	CSI tool, primary material (identical to ecoinvent clinker)
Sand	9.26 kg	CSI tool, primary material (identical to ecoinvent clinker)
Bauxite	0.12 kg	CSI tool, primary material (identical to ecoinvent clinker)
Water	342.72 kg	CSI tool, water (identical to ecoinvent clinker)
Aluminium hydroxide	0.454 kg	CSI tool, secondary material
Aluminium oxide	0.137 kg	CSI tool, secondary material
Ashes	14.84 kg	CSI tool, secondary material (10.3 kg ashes from paper production and 4.54 kg pyrite ashes)
Building bulky goods	1.25 kg	CSI tool, secondary material
Moulding sand	1.93 kg	CSI tool, secondary material
Polluted soil	6.35 kg	CSI tool, secondary material
Refractories	0.2721 kg	CSI tool, secondary material
Sludge from decarbonation	20 kg	CSI tool, secondary material
Industrial sludge	3.06 kg	CSI tool, secondary material
Lime sludge from water treatment	65.79 kg	CSI tool, secondary material
Ammonia	0.908 kg	CSI tool (identical to ecoinvent clinker)

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Diesel	7.2 MJ	CSI tool
Emissions to air		
Nitrogen oxides	0.33 kg	BREF document: min value considered for BAT
Sulfur dioxide	0.503 kg	BREF document: avg value considered for BAT
Carbon monoxide	0.46 kg	BREF document: min value considered for BAT
TOC	0.1 kg	BREF document
Hydrogen chloride	0.000046 kg	BREF document: min value considered for BAT
VOC	0.0023 kg	BREF document: min value considered for BAT
Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	2.76E-14 kg	BREF document: min value considered for BAT
Hydrogen fluoride	0.000021 kg	BREF document: min value considered for BAT
Antimony	16.1 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Arsenic	16.1 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Beryllium	9.2 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Lead	27.6 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Cadmium	46 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Chromium	32.2 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Cobalt	27.6 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Copper	25.3 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Manganese	161 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Nickel	184 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Mercury	11.5 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Selenium	18.4 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Tellurium	3.91mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Thallium	11.5 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Vanadium	16.1 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Zinc	230 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)

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Tin	23 mg	BREF document, lower value of the range considered for BAT (table 1.29, mg/Nm3 * Nm3/t clinker)
Water	1.62 m^3	Assuming 100% of the input water as unspecified natural origin is evaporated

2.7 Impact assessment framework

Life Cycle Impact assessment classifies and combines the flows of materials, energy, and emissions into and out of each product system by the type of impact their use or release has on the environment. Figure 2 shows an example of impact assessment framework from inventory (NO_x emissions, fuel extraction, etc.) to endpoint impact on human health, ecosystem quality, resource depletion and climate change.

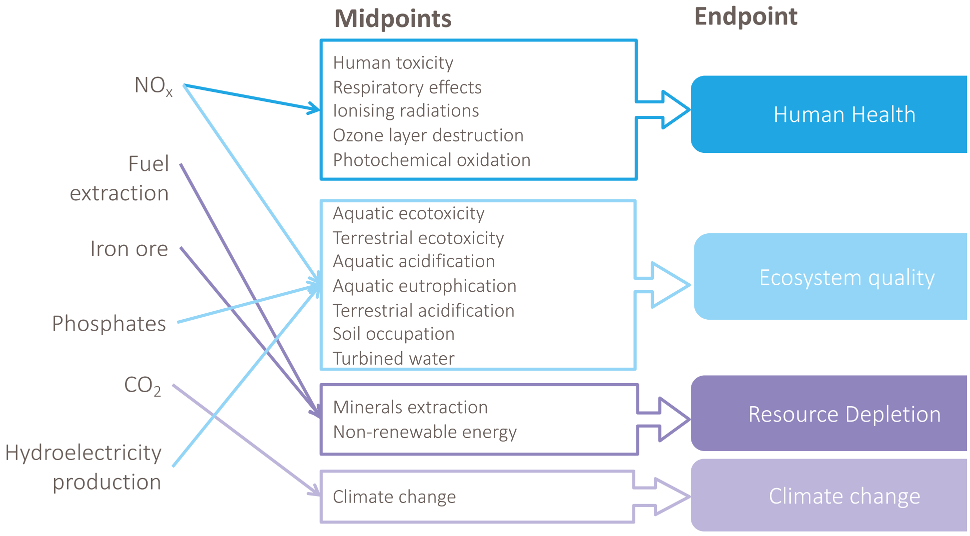

Figure 2 - Impact assessment framework

The method used here to evaluate the environmental impact of cement production with carbon capture is the Environmental Footprint (EF) method (European Commission 2017). This method assesses 16 different potential impact categories (midpoint). It is the result of a project for the European Commission that analyzed several life cycle impact assessment (LCIA) methodologies to reach consensus. It is the official method to be used in the Product Environmental Footprint (PEF) context of the Single Market for Green Products (SMGP) initiative (European Commission 2013).

In this screening LCA only the impact of climate change will be assessed due to a lack of data on clinker production emissions other than CO_2. In the final LCA 3 midpoint and 2 endpoint indicators will be used.

Table 1 describes the models used for each of the 3 midpoint indicators.

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Table 4 - Indicators and related assessment models used

Impact category or LCI indicator	Model	Unit	Source
Climate change	Bern model – Global Warming potentials (GWP) over a 100-year time horizon	kg CO_2 eq	(IPCC 2013)
Non-renewable energy resource depletion	CML 2002 model (abiotic depletion – fossil)	MJ	(Guinee 2002; van Oers et al 2002)
Water scarcity footprint	AWARE 100 model	m^3 water deprived eq	(Boulay et al 2017)

In addition, two endpoint indicators will be assessed to provide a more comprehensive overview of environmental impacts: human health and ecosystem quality (Jolliet et al 2003).

Figure 3 summarizes the key indicators included in this study

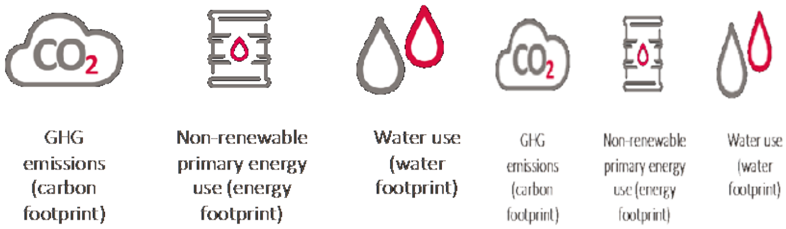

Figure 3 - Key indicators assessed in the environmental study

3. RESULTS

3.1 Comparison of the different scenarios

The LCA shows that cement produced with the integrated CaL process has a climate change impact 73% lower than that of the reference cement plant without CO_2 capture (Figure 4). Compared to the other carbon capture technologies it has a climate change impact 16% lower than that of Full Oxyfuel and 37% lower than that of Partial Oxyfuel, equivalent to that of Tail-End CaL with 50%-IL and higher than that Tail-End CaL with 20%-IL (+10%).

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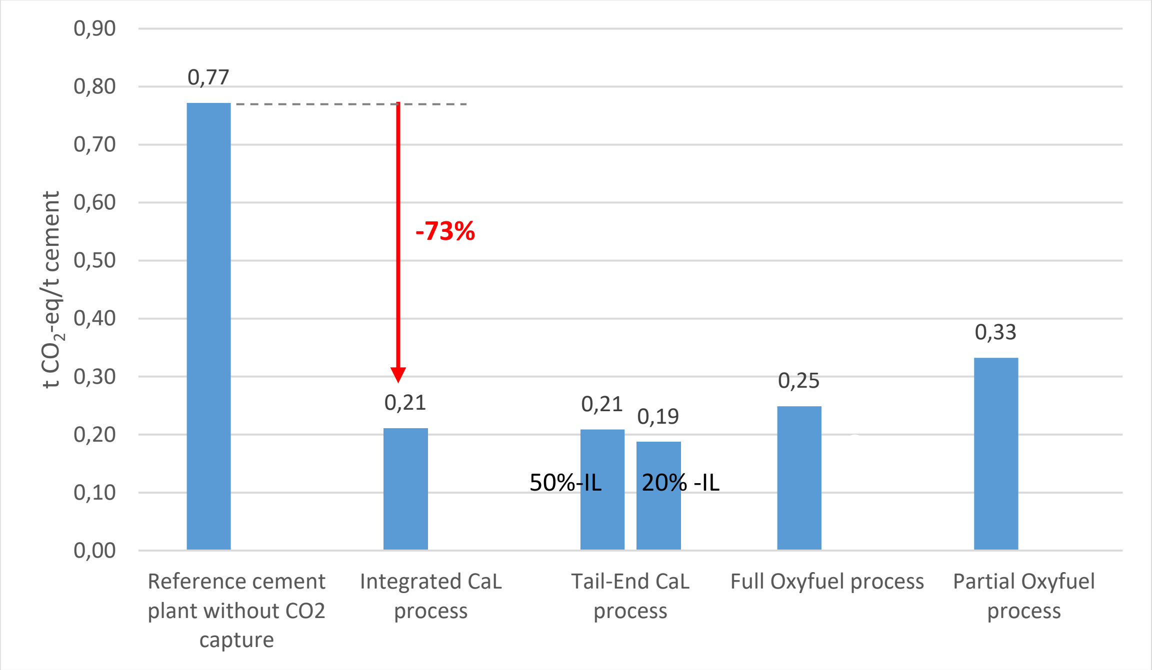

Figure 4 – Climate change impact of 1 t of cement in the different scenarios

Since data for cement production from clinker are the same in all the scenarios when comparing 1 t of clinker (Figure 5) the trend is the same as that shown in Figure 4.

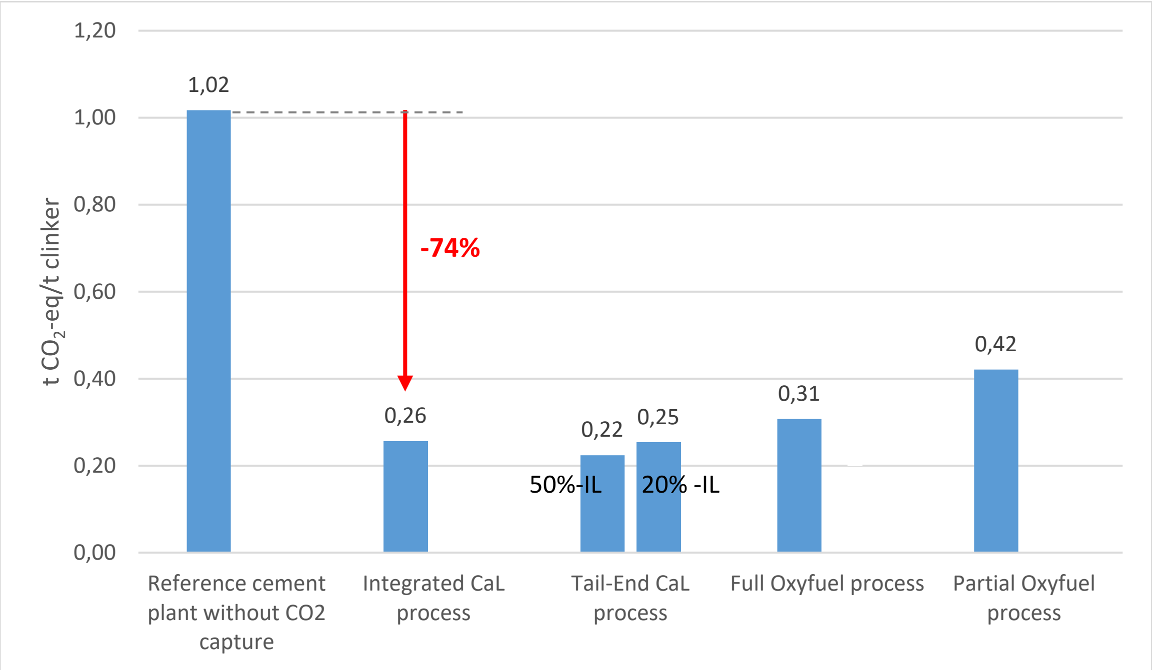

Figure 5 – Climate change impact of 1 t of clinker in the different scenarios

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In Figure 6 the differences between the scenarios with carbon capture and the reference scenario is shown to understand what are the costs (more energy consumption) and the benefits (CO_2 captured) in terms of climate change impact of the difference technologies.

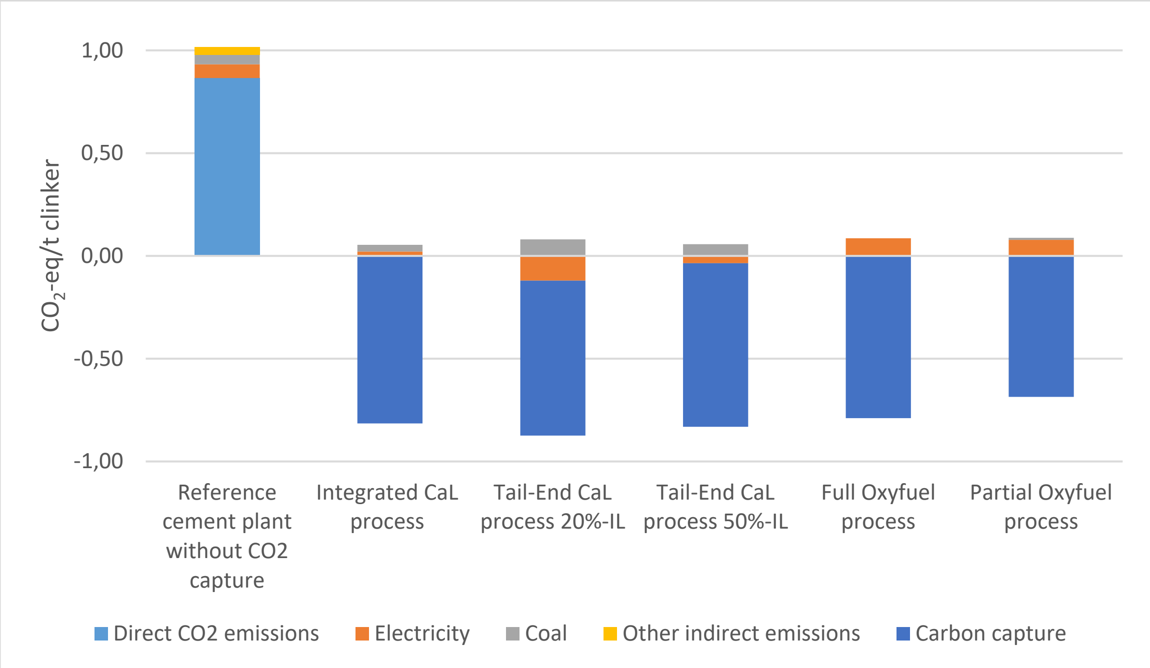

Figure 6 – Differences between the scenarios with carbon capture and the reference scenario

3.2 Hotspot identification

Cement climate change impact (Figure 7) is mostly caused by clinker production (including fuel and electricity used in this stage) (89%) and electricity used for cement production (7%), while production of other raw materials (2%), transportation of raw materials (1%) and the cement plant infrastructure (1%) are less relevant.

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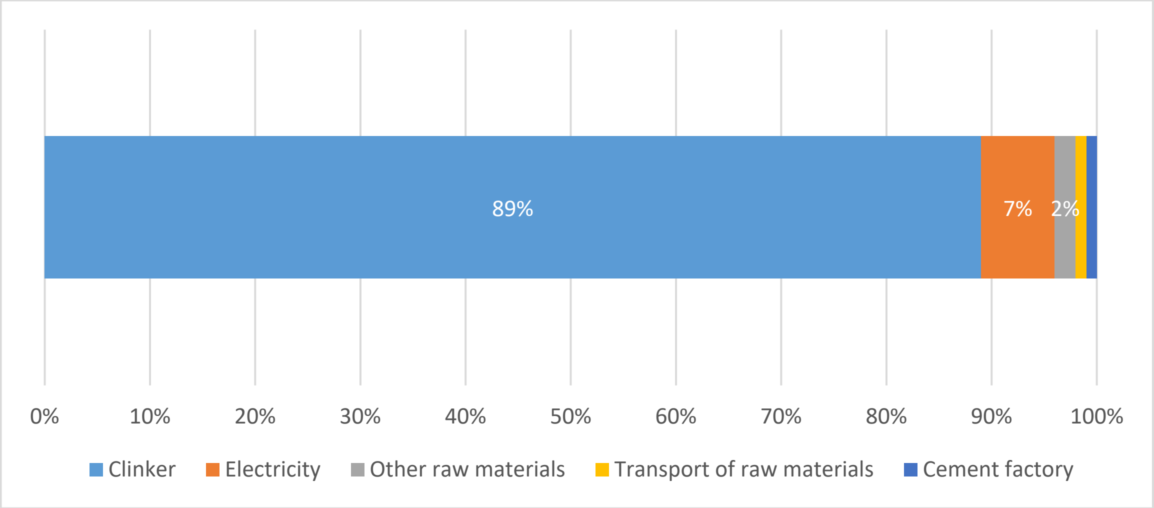

Figure 7 - Contribution of the different inputs and emissions to the climate change impact of cement made with clinker produced with the integrated CaL process

If we look at clinker climate change impact (Figure 8), we can see that is mostly caused by electricity generation (35%) coal production (31%), net CO_2 emissions at stack including carbon capture (20%) and transportation of raw materials (8%).

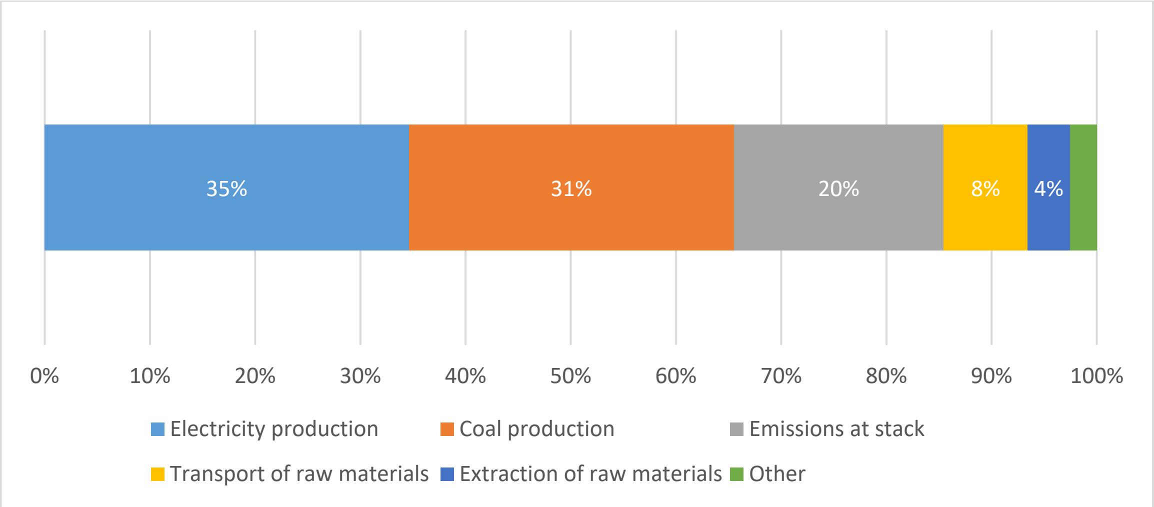

Figure 8 - Contribution of the different inputs and emissions to the climate change impact of clinker produced with the integrated CaL process

Net electricity consumption, fuel (coal) input and net CO_2 emissions at stack are therefore the 3 main key parameters that influences the climate change impact of the clinker and thus also the cement production.

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Other than by optimising the performances of the different carbon capture technologies, a further reduction in climate change impact is possible by shifting from coal to less impacting fuels (e.g. bio-based fuels instead of coals) and by using electricity from renewable sources instead that electricity with a standard mix. Data on these alternative solutions will be collected in the second part of the project and results presented in the final LCA.

4. NEXT STEPS

At month 36 an assessment of data availability and quality to conduct a robust final LCA will be done. 90% of all primary data required should be available at that time (milestone MS17).

In the final environmental LCA (month 45, deliverable D6.5):

- the latest available data on the CLEANKER technology will be used;
- the calcium looping technology environmental performance will be compared to other carbon capture technologies (e.g. direct separation, post-combustion capture with amine chemical absorption)
- all the environmental impacts described in paragraph 2.7 will be assed;
- both the functional units described in paragraph 2.2 will be used;
- sensitivity analyses on different energy sources will be performed (e.g. on the use of bio-fuels for thermal energy and of electricity from renewable sources).

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This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 764816. This work is supported by the China Government (National Natural Science Foundation of China) under contract No.91434124 and No.51376105.

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