AL JOUF CEMENT COMPANY:

A Cradle-to-gate Life Cycle Assessment of Al Jouf Cement Products - Sulphate Resistant Cement (SRC)

Prepared by: Urban Lab – King Abdullah University of Science and Technology (KAUST)

Prepared for: Al Jouf Cement Company | Initial Submission Date: 24 April 2024

Latest update: v1.2 (August 2024)

Glossary of Terms

Based on ISO 14040:2006/Amd1:2020 /44:2006 – Terms and Definition Section.

Allocation: Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems.

Life Cycle: Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal.

Life Cycle Assessment (LCA): Compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle.

Life Cycle Impact Assessment (LCIA): Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product.

Life Cycle Interpretation: Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations.

Life Cycle Inventory (LCI): Phase of Life Cycle Assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle.

Product system: Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product.

System boundary: Set of criteria specifying which unit processes are part of a product system. Note: the term system boundary is not used in this International Standard in relation to LCIA.

System expansion: Expanding the product system to include the additional functions related to the co-products, taking into account the requirements of 4.2.3.3.

Based on ISO 14021:1999(E)- Clause 7.8 Recycled content

Pre-consumer material: Material diverted from the waste stream during a manufacturing process. Excluded is the reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it.

Post-consumer material: Material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product that can no longer be used for its intended purpose. This includes returns of material from the distribution chain.

Based on ISO 14025:2006- Clause 3 Terms and definitions

Type III Environmental Product Declaration (EPD): providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information

Note 1 the predetermined parameters are based on the ISO 14040 series of standards.

Note 2 the additional environmental information may be quantitative or qualitative.

Product Category Rules (PCR): set of specific rules, requirements and guidelines for developing Type III environmental declarations for one or more product categories.

Based on ISO 21930:2017- Clause 3 Terms and definitions

Building product: goods or services used during the life cycle of a building or other construction works.

Declared unit: quantity of a building product for use as a reference unit in an EPD, based on LCA, for the expression of environmental information needed in information modules.

Information module: compilation of data to be used as a basis for a type III environmental declaration, covering a unit process or a combination of unit processes that are part of the life cycle of a product.

Reference service life: service life of a building product that is known or expected under a particular set, i.e., a reference set, of in-use conditions and that may form the basis of estimating the service life under other in-use conditions.

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1 General Study Aspects

Commissioner of the LCA project report and EPD	أسمنت الجوف AL JOUF CEMENT
External LCA Practitioner	Sami G. Al-Ghamdi, Anissa Nurdiawati, Glenda Terán-Cuadrado, and Mohammed Al-Humaiqani جامعة الملك عبدالله للعلوم والتقنية King Abdullah University of Science and Technology مختبر العمران Urban Lab
Date/version	August 2024 Version 1.2

Product Identification

Product name	Sulphate Resistant Cement (SRC)
Additional label(s)	
Product number/reference	ASTM C150-Type V
Place(s) of production	Gurayat-Turaif Road Crossing, Turaif, Northern Region Province-KSA
CPC code	374 – Plaster, lime and cement

This study has been conducted in accordance with the requirements of the International EPD System Product Category Rule (PCR) for Construction products 2019:14 version 1.3.4 [1], EN 15804:2012+A2:2019/AC:2021, Sustainability of construction works [2]. The CEN standard EN15804 serves as the core PCR. This LCA study was also conducted in accordance with ISO 14040:2006/Amd1:2020 [3], 14044:2006/Amd1:2017/Amd2:2020 [4]. This study also complies with the latest General Program Instructions for the International EPD System version 5.0.0 [5].

This LCA project report was critically reviewed as per ISO 14040:2006/Amd1:2020 /14044:2006/Amd1:2017/Amd2:2020 and the reference PCR requirements by International EPD system.

This life cycle assessment was independently verified in accordance with ISO 14044 and the reference PCR by:	Name and affiliation: Agnieszka Pikus, Greenwise

2 Company and Product Information

2.1 Company Profile

Manufacturer	Al Jouf Cement Company
Address	Turaif, Saudi Arabia
Contact details	Eng. Adel Awad Al Enaizy pmadel@joufcem.com.sa
Website	https://joufcem.com.sa/

Al Jouf Cement Company was established in 2007 to be a Saudi joint stock company specialized in the production of Ordinary Portland Cement (OPC), Super 20 cement, Sulfate Resistant cement (SRC) and Finishing Cement (FC). It follows a strategic approach that ensures the sustainability of matter, energy, and the economy in general. The company's latest factories, with a total production capacity of 10,000 tons per day, are located in the northwest of the Kingdom of Saudi Arabia, close to the Saudi-Jordanian and Iraqi border.

Over the course of nearly two decades, the company has achieved the highest quality standards in its production processes in accordance with Saudi standard specifications that conform to American and European standards. Its products have successfully passed all necessary checks from the Royal Society of Jordan and the Iraqi Central Organization for Standardization and Quality Control. On this path, Al Jouf Cement has maintained an advanced level of development in its sector by providing its products inside and outside the Kingdom and its partnerships with locally and internationally accredited suppliers to support achieving the goals of Vision 2030 and creating a sustainable future for the industry.

2.2 Product Information

Al Jouf Cement Company has focused on producing three core products: OPC, SRC and Super 20 cement. Recently, the company introduced a new finishing product (FC), expanding its product spectrum. The scope of this study is limited to the SRC product only.

2.2.1 Product Name

Sulphate Resistant Cement - ASTM C150 Type-V.

2.2.2 *Product Description*

Sulfate Resistant cement (SRC) is manufactured by grinding clinker, which is produced through the burning of raw materials such as limestone, clay, and iron ore, in specific proportions. Additionally, a predetermined amount of retarder, typically gypsum, is added to achieve the desired properties of the cement mixture.

This type is produced in accordance with the Gulf specifications GSO 1914/2009 (E) and the American standard ASTM C150 Type V, and is used in places where the concrete is in contact with soil, groundwater, seawater or is exposed to the sea coast, as the concrete in these circumstances is exposed to attack by sulfates present in large quantities, which leads to damage to the structure.

This type of cement many characteristics, such as:

- Prevent cracking.
- Prevent sulfate attack.
- High pressure resistance.
- Maintaining concrete strength and high performance and ensuring structural integrity in acidic and sulfurous environment.

2.2.3 *Technical Specifications*

Table 1 lists the technical characteristics according to the Saudi standards, metrology, and quality organization (SASO) and the gulf cooperation council standardization organization (GSO) under the SASO-GSO 1914/2009, which aligns with ASTM C150 Type V specifications.

Table 1. Technical specifications according to SASO-GSO 1914/2009

Properties	Unit	Value
Mechanical properties	3 days compressive strength (MPa)	24.40
	7 days compressive strength (MPa)	3.90
	28 days compressive strength (MPa)	41.80
Chemical properties	Sulfate content (SO3, % w/w)	2.07
	Loss of Ignition (% w/w)	1.62
	Insoluble residue (%)	1.23
Physical properties	Initial setting time (min)	142
	Final Setting Time (min)	179
	Autoclave expansion (%)	0.17
	Soundness (Le Chatelier) (mm)	1.16
	Specific Surface Area (m2/kg) - Blaine	360

2.2.4 *Product Composition*

Table 2 lists the product composition of Sulphate Resistant Cement (SRC).

Table 2. Product mass composition of Sulphate Resistant Cement (SRC)

Product components	Weight percentage (%)
Clinker	92.86
Pozzolana	3.14
Gypsum	4.00

2.3 Brief Process Description: Manufacturing and Packing (A1-A3)

The Al Jouf Cement Plant operates through a designed production which begins with mining and quarrying of clinker feedstock and culminating in storage & packaging of cement through various essential steps. These include extraction, crushing, stacking, pre-blending, and raw grinding of raw materials, followed by the formation of clinker in the pyroprocessing stage (pre-heating and pre-calcination, sintering, and clinkerization, along with clinker cooling), and finalizing with cement grinding [6].

The production process for Al Jouf company's SRC cement involves utilizing various raw materials, including limestone, clay, and iron ore during the initial clinker production stage. After those materials are crushed and blended into a homogenous stockpile, this mixture is adjusted with corrective additives and then ground into raw meal in the mill. The raw meal is pre-heated and then transferred to the rotary kiln for sintering, where clinker is formed. After rapid cooling, specific proportions of clinker are ground and blended with additives such as gypsum based on the desired SRC product. The finalized product is then stored in silos for packing or bulk transportation. This systematic approach is decribed in Figure 1.

3 Goal of the Study

The goal of this study is to provide information to support the development of an EPD for Sulphate Resistant Cement (SRC) Product.

3.1 Intended Applications

The LCA was designed to evaluate and understand the overall environmental performance of the cement production process perfomed by Al Jouf company and the associated supply chain, identifying critical processes and potential improvements in each stage. The EPD developed from this study is intended for use in Business to Business (B-to-B) communication.

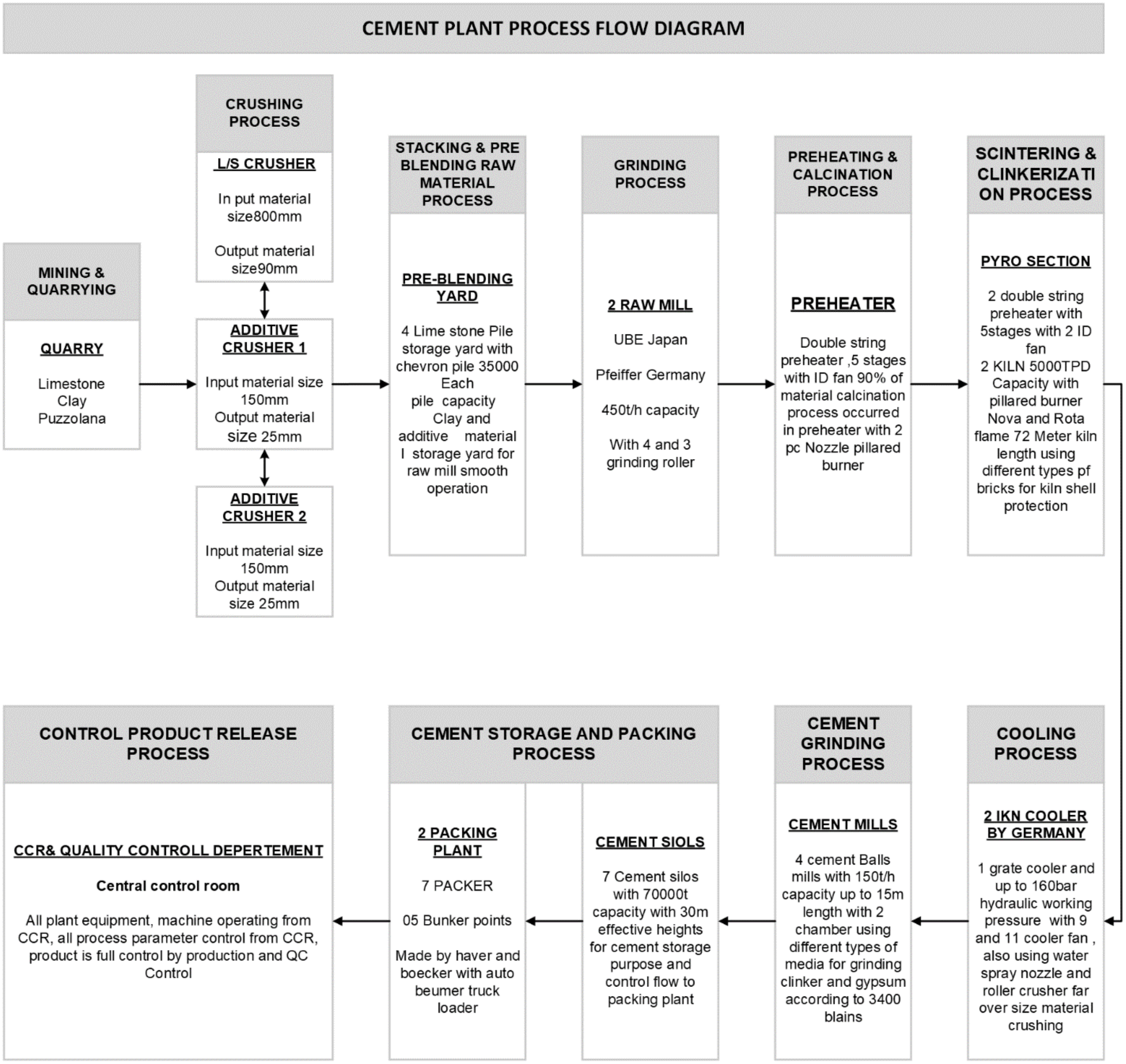

Figure 1.Cement production chain in Al Jouf cement company

3.2 Intended Audience

The intended audience for this LCA project report is Al Jouf cement company and the verifier of the subsequent EPD. The intended audience for the EPD, for which this LCA project report serves as the reference document, include their suppliers, architectural, engineering, and specifying professionals, LCA practitioners and tool developers, academia, governmental organizations, policy makers and other interested value chain parties who require reliable information on SRC product.

3.3 Comparative Assertions

This LCA project report does not include comparative assertions.

4 Study Scope

4.1 Product Standard

This type of cement is produced according to Gulf Standard GSO 1914/2009 for SRC, American Standard ASTM C150 Type V and European Standard EN 197-1 2011, CEM-I 42.5N SR5.

4.2 System Boundary

According to EN 15804 Section 5.2, the type of EPD for OPC product in this study is a type (d) Cradle to gate (A1-A3). This includes raw material mining and quarrying, transport to manufacturing site, and the manufacturing stage (A1-A3, EN 15804 A2+) as presented in Figure 2. The environmental impacts assessed during the product stage encompass the extraction and processing of raw materials utilized in production, along with packaging materials and ancillary resources. Additionally, it accounts for the transportation, generation of electricity, steam and heat from primary energy resources, also including their extraction, refining and transport and the management of waste generated during manufacturing processes at the facilities.

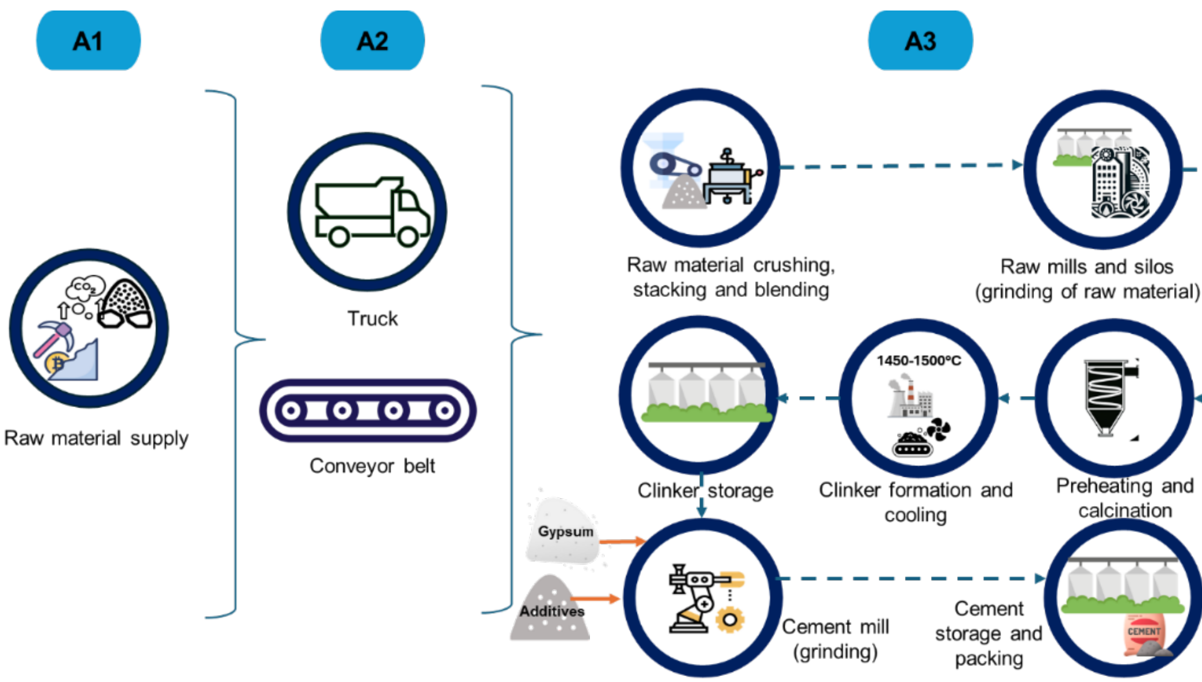

Figure 2. Flow diagram of the processes included in the LCA, divided into life cycle stages A1-A3

A1. Raw materials supply

This phase encompasses the extraction and pre-treatment of raw materials prior to production. The primary materials utilized in the production of OPC include limestone, iron oxide, aluminum oxide (bauxite), clay, pozzolana, and gypsum. Additionally, mill scale, a byproduct of the steelmaking industry, is incorporated to enhance the iron oxide content in the cement mixture. Furthermore, the production processes for fuels, such as heavy fuel oil and diesel, are also considered in this stage.

A2. Transportation until cement plant gate

This step covers the transportation-related impacts of materials necessary for producing OPC. The transport distances, which are specific to each supplier, are provided by the manufacturer.

A3. Manufacturing (core process)

The production-related environmental impacts of the product are derived from the following unit operations:

1. Raw material preparation. Transported raw materials undergo an initial crushing process, reducing particles to smaller sizes for subsequent stacking and blending. At AlJouf Cement Plant, this process involves three crushers—one for limestone and two for additives. The resulting mixture, called raw meal, is homogenized and stored before being transferred to a pre-heater and pre-calciner.
2. Pyro-processing and cooling. After approximately 90% of the calcination process is completed in the calciner, the raw meal is transformed into clinker using two rotary kilns, each with a daily capacity of 5,000 tons. The clinker is then cooled using two reciprocating grate coolers.
3. Cement milling/blending- packaging & transport. In this step, the clinker, gypsum, and pozzolana are ground to meet the technical specifications for OPC. The finished cement is then stored in silos before being packaged in bags. The quality control and production teams, in conjunction with the central control room, oversee the entire cement manufacturing process, ensuring its correct development from cradle to gate.

The LCA model perfomed by this report considers the minimum requirements of the EN 15804:2012+A2:2019 where the construction (transport and installation) (A4-A5), use, and end of life stages were disregarded since cement, as intermediate material, complies with the rules to omit a cradle to grave analysis (seeTable 3). Those requirements are [7]:

- If the product is physically integrated with other products during installation so it cannot be physically separated from them at the end-of-life
- It is no longer identifiable at the end-of-life as a result of a physical transformation processes (e.g., mixing with other aggregates and building material components)
- It does not contain biogenic carbon.

Moreover, the production and end-of-life processes of infrastructure or capital goods used in the product system were excluded, align with PCR 2019:14 Section 4.3.

Table 3. Life cycle modules selected for portland cement from EN 15804:2012+A2:2019

	Product stage			Construction process stage		Use stage							End of life stage				Resource recovery stage
	Raw material supply	Transport	Manufacturing	Transport	Construction installation	Use	Maintenance	Repair	Replacement	Refurbishment	Operational energy use	Operational water use	De-construction demolition	Transport	Waste processing	Disposal	Reuse-Recovery-Recycling-potential
Module	**A1**	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**C1**	**C2**	**C3**	**C4**	**D**
Modules declared	X	X	X	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Geography	SA	SA	SA	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Specific data used*	>90%			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Variation – products	Not relevant			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Variation – sites	Not relevant			-	-	-	-	-	-	-	-	-	-	-	-	-	-

More information: X=included, ND=module not declared

**The share of primary data is calculated based on GWP-GHG results. It is a simplified indicator for data quality that do not capture all relevant aspects of data quality. The indicator is not comparable across product categories.*

4.3 Geographical and temporal boundary

The present analysis focuses solely on the local context of Saudi Arabia, specifically examining the cement production processes conducted by Al Jouf company in 2023. Country specific boundaries wherever possible have been adapted and others dataset were chosen from EU and GLO if no regional datasets were available. The data collection is related to one year of operation, and the year of the data is indicated in the questionnaire for each data point. The data is collected from year January 2023 - December 2023. For the background system, this study leverages the GaBi Sphera Managed LCA database v2023.2, which is considered relevant and up-to-date until the end of 2024, as well as Ecoinvent v3.9.1.

4.4 Declared/Functional Unit

The declared unit is 1 tonne (t) of Sulphate Resistant Cement (SRC). This study covers the production stage information (from A1 to A3) of the product. As no use stage is declared, the reference service life (RSL) for cement is irrelevant.

4.5 Cut-off Criteria

The study does not exclude any modules or processes which are stated mandatory in the EN 15804:2012+A2:2019 and the applied PCR. The study does not exclude any hazardous materials or substances. The analysis incorporates every input and output from unit processes for which data are available. No unit process contributing more than 1% to the overall mass or energy flows is disregarded. Furthermore, the total disregarded input and output flows specific to each module do not exceed 5% of energy usage or mass.

5 Life Cycle Inventory (LCI) Analysis

The material and unit process data underlying this study and the resultant EPD were derived from various sources. Primary data for the LCA were collected to detail the process inputs—including material and energy inputs, as well as transport data—and to document direct emissions. Secondary LCI data sources were utilized to account for the energy and materials supplied to the foreground system, drawing from comprehensive LCI background databases and relevant literature. This section qualitatively and quantitatively describes the various data sources used to compile the life cycle inventory metrics and subsequent life cycle impact assessment (LCIA) indicator results for the SRC product.

5.1 Primary Data Sources

Al Jouf Cement Factory provided the most accurate and representative data for SRC production. Where feasible, the study prioritizes the use of primary data, grounded in information gathered throughout 2023. This includes comprehensively updated data on production volume, processes, raw material quantity, as well as fuel-related input flows. Additionally, the study incorporates information on the mode of transport and distances for the transportation of raw materials and fuels. The materials and fuels includes limestone, clay, bauxite, iron ore, mill scale, shredded tires, heavy fuel oil (HFO), and diesel.

While an environmental measurement report for exhaust gas from kiln and power generator is available, it lacks detailed information on the measurement conditions necessary to convert these measurements into the amount of emissions per unit of cement produced. Therefore, to address this shortfall, the direct measurement report is triangulated with engineering calculations based on both stoichiometric and thermodynamic principles. Emissions resulting from limestone decarbonization are estimated based on the composition of the raw meal, particularly the content of $CaCO_3$ (calcium carbonate) and $MgCO_3$ (magnesium carbonate), which serve as primary data. These estimates also take into account the degree of calcination and the volume of cement production. The calculations are performed using stoichiometric principles, which allow for the quantification of CO_2 emissions released during the calcination process, where $CaCO_3$ and $MgCO_3$ decompose to release CO_2. This approach ensures a detailed estimation of the total emissions from the decarbonization of limestone, grounded in the primary data of raw material composition, raw meal-to-clinker ratio and clinker-to-cement factor.

5.2 Secondary Data Sources

All upstream material, resource and energy carrier inputs have been sourced from GaBi Sphera version 2023.2 and Ecoinvent v3.9.1. In the data matching, the data come from two or more different sets of data should have common identifiers in terms of geographies, product, technology, and unit matching to ensure that data are coherent and compatible. Datasets specific to Saudi Arabia, particularly those related to electricity production and heat generation by fuel type, are obtained from the Sphera database. Although the generic datasets available at present may sometimes lack temporal, technological and geographical representativeness, modifications have been made to the foreground system of those datasets by adapting the electricity and thermal energy specific to Saudi Arabia datasets.

Table 4, Table 5, and Table 6 describe each LCI data source for raw materials (A1), transportation by mode (A2) and the SRC core manufacture process (A3) as well as an assessment of data quality. The share of primary data is calculated based on GWP-GHG results. It is a simplified indicator for data quality that do not capture all relevant aspects of data quality. The detail of LCI data in terms of material quantities, transportation distance, energy requirements and emissions are presented on a 1 t of SRC cement basis and presented in Appendices (Table A. 1 and Table A. 2).

Table 4. A1 – Raw Material Supply

Materials	LCI Data Source	Database Reference Year*/Region	Data Quality Assessment	Data Category	Share of primary data
Limestone production	Ecoinvent 3.9.1 - RoW: Limestone quarry operation This dataset was modified with Saudi Arabia electricity grid mix.	2022 World/ Saudi Arabia	• Technology: very good • Time: very good • Geography: very good • Completeness: very good • Reliability: very good	Secondary data	0%

Clay production	Ecoinvent 3.9.1 - RoW: Clay pit operation	2022 World	• Technology: good • Time: very good • Geography: good • Completeness: very good • Reliability: good	Secondary data	0%
Iron ore production	Ecoinvent 3.9.1 - Iron ore mine operation, 46% Fe, Glo	2022 World	• Technology: good • Time: very good • Geography: good • Completeness: very good • Reliability: very good	Secondary data	0%
Bauxite production	Ecoinvent 3.9.1 - GLO: Bauxite mine operation. This dataset was modified with Saudi Arabia electricity grid mix.	2022 World/ Saudi Arabia	• Technology: very good • Time: very good • Geography: good • Completeness: very good • Reliability: very good	Secondary data	0%
Mill scale recovery	None, no incoming burden, only transport is considered	N/A	• N/A • Recovered material	Secondary data	0%
Natural pozzolana production	The model for pozzolana mining incorporates the diesel consumption and combustion emissions associated with excavation processes [8].	N/A	• Technology: good • Time: fair • Geography: fair • Completeness: good • Reliability: good	Secondary data	0%
Gypsum production	Sphera SA: Gypsum stone (CaSO4-Dihydrate)	2022 Saudi Arabia	• Technology: very good • Time: very good • Geography: very good • Completeness: very good • Reliability: very good	Secondary data	0%
Shredded tires	None, the recycling process for tyres is modeled to include the electricity consumption required for shredding and granulation.	N/A	• N/A • Recycled material	Secondary data	0%
Diesel production	Sphera CN: Diesel mix at refinery	2020 China	• Technology: very good • Time: very good	Secondary data/Proxy	0%

			• Geography: fair • Completeness: very good • Reliability: good		

*The year in the table refers to the reference year for the datasets retrieved from the Ecoinvent and Gabi Sphera databases. The primary data reference year is 2023 (See Section 5.1).

Table 5. A2 – Transportation

Process	LCI Data Source	Year/Region	Data Quality Assessment	Data Category	Share of primary data
Road transportation	Sphera GLO: Truck, Euro 5, 28-32 gross weight	2022 World	• Technology: very good • Time: very good • Geography: good • Completeness: good • Reliability: good	Primary data	3.6%

Table 6. A3 – Manufacturing

Process	LCI Data Source	Year/Region	Data Quality Assessment	Data Category	Share of primary data
Thermal/ Heavy fuel oil (combustion)	Gabi Sphera SA: Thermal energy from from heavy fuel oil	2019 Saudi Arabia	• Technology: very good • Time: very good • Geography: very good • Completeness: very good • Reliability: very good	Primary data	27.2%
Limestone decompositio n (process emissions)	None, measured and based on stoichometric calculation	2023 Saudi Arabia	• N/A	Primary data	53.3%
Shredded tires (combustion)	None, the combustion emissions was stoichiometric ally calculated considering elemental composition and heating value.	N/A	• N/A • Recycled material	Primary data	4.2%
Diesel (combustion)	USLCI/Spher a US: diesel combusted in industrial	2009 US	• Technology: very good • Time: poor • Geography: fair • Completeness: very good • Reliability: good	Primary data	0.12%

Lubricating oil	Ecoinvent 3.9.1 RER: market for lubricating oil	2022 Europe	• Technology: very good • Time: very good • Geography: good • Completeness: very good • Reliability: very good	Secondary data	0%
HFO-based electricity generation	Sphera SA: Electricity from heavy fuel oil Sphera	2019 Saudi Arabia	• Technology: very good • Time: very good • Geography: very good • Completeness: good • Reliability: good	Primary data	10.35%
Water	Sphera SA: Groundwater SA: Brackish water reverse osmosis GLO: Municipal wastewater treatment	2022 Saudi Arabia	• Technology: good • Time: very good • Geography: good • Completeness: good • Reliability: good	Secondary data	0%
Packaging material production	Ecoinvent 3.9.1 RER: market for kraft paper	2022 Europe	• Technology: very good • Time: very good • Geography: good • Completeness: very good • Reliability: very good	Secondary data	0%
Solid waste	Sphera UA: Landfill (Municipal household waste)	2022 UAE	• Technology: very good • Time: very good • Geography: good • Completeness: very good • Reliability: very good	Secondary data	0%
Used oil	Gabi Sphera DE: Used oil Sphera	2022 Germany	• Technology: very good • Time: very good • Geography: fair • Completeness: very good • Reliability: very good	Secondary data	0%
Wastewater	Ecoinvent 3.9.1 RoW: treatment of wastewater, unpolluted,wastewater treatment	2022 World/Region	• Technology: very good • Time: very good • Geography: good • Completeness: very good • Reliability: very good	Secondary data	0%

5.3 Allocation

- The production process was divided into two distinct sub-processes: clinker production and cement manufacturing. Input and output data related to each sub-process were documented. The allocation has been avoided wherever possible. However, the allocation could not be avoided for raw, ancillary material, energy use and waste generation as some information was only measured on a plant level. In the factory, several kinds of cement are produced; since the production processes of these products are similar, the annual production percentages are taken into consideration for allocation. Additionally, the clinker-to-cement ratio for each cement product was considered during allocation of raw materials and fuels. Ancillary materials, water and waste streams were physically allocated to the studied product (SRC) based on annual production volume (mass), and are assumed to be the same for all types of products, regardless of the products formulation.
- Allocation used in generic environmental data sources follow the requirements of the EN 15804 standard. Allocation method 'allocation, cut-off by classification' has been used for Ecoinvent 3.9.1 data, which complies with EN 15804.
- The polluter pays principle is met. The product category rules for this EPD recognize mill scale as recovered materials and thus the environmental impacts allocated to these materials are limited to the treatment and transportation required to use as a raw material input. No by-products occur during clinker and cement production; therefore, there is no need for allocations in by-products.
- Processing of waste materials generated in A1- A3 (e.g. wastewater) is included in the product system.

5.4 Data Quality

Data quality requirements, as specified in EN 15804 and ISO 14044:2006, are applied and reported in Table 4, Table 5, and Table 6. Data quality is judged on the basis of its representativeness (technological, temporal, and geographical), completeness (e.g., unreported emissions), consistency and reliability. All LCI data (Table 4, Table 5, and Table 6) underwent evaluation based on five data quality indicators. For each indicator, we analyze relevant data parameters to ensure a transparent assessment process.

• ***Technical representativeness***: *The degree to which the data reflects the actual technology(ies) used.*

The core technology for the manufacturing process is based on the most recent annual data provided by the cement manufacturer. The production of electricity and heat specifically employs technologies from Saudi Arabia, as detailed in the Sphera database. While some of the background material and process data originate from global, European, US sources, these are considered comparable to the technologies employed in Saudi Arabia or the broader Middle East, ensuring relevance and applicability of the data to local contexts.

Overall quality - Good to very good

• ***Temporal representativeness***: *The degree to which the data reflects the actual time (e.g. year) or age of the activity.*

Core manufacturing process is up-to-date, based on 2023 data. Secondary data sets range in age from 3 to 7 years.

Overall quality - Good to very good

• ***Geographical representativeness***: *The degree to which the data reflects the actual geographic location of the activity (e.g. country or site).*

Geographical coverage of core manufacturing processes is specific to Saudi Arabia. Majority energy profiles reflect Saudi Arabia conditions such as for electricity and heat. Some materials such as bauxite, iron ore, limestone, and clay are based on Global and Rest of the world (RoW) (not including global, China, India, and Canada average production) average data, respectively. Emissions from transportation (trucks) were calculated from global data. Due to the lack of specific LCI data for diesel production in Saudi Arabia, diesel produced in China was selected as a proxy for the transport fuel datasets. This selection was based on the representativeness of technology, energy efficiency benchmarking, and the fact that both countries' crude oil supplies are sourced from their domestic supply chains.

Overall quality - Fair to very good

• ***Completeness***: *The degree to which the data are statistically representative of the relevant activity.*

All relevant, specific processes, including inputs (raw materials, energy and ancillary materials) and outputs (emissions and production volume) were taken into account and modeled to represent the specified and declared SRC product. The relevant background materials and processes were taken from the Gabi Sphera 2023.2 and ecoinvent v3.9.1 LCI databases and modeled in Sphera LCA FE software. Efforts were made to ensure that all data used was as complete as reasonably possible.

Overall quality - Good to very good

• ***Reliability***: *The degree to which the sources, data collection methods and verification procedures used to obtain the data are dependable*.

The reliability of information and data for core manufacturing processes is considered very high, as these were obtained through a survey and close engagement with the cement producer and subsequently subjected to a thorough plausibility review. All missing process data (dummies) associated with the Saudi LCI data have been consistently filled. All other LCI data have been incorporated in accordance with the default PCR requirements or derived from Sphera and Ecoinvent databases, which have been verified by those companies.

Overall quality - Good to very good

Moreover, the data quality is evaluated on the basis the precision, consistency and reproducibility.

Precision:

The cement company collected primary data on their annual production of Sulphate Resistant Cement (SRC) and other cement products through both measurement and calculation. To ensure accuracy, the LCA team verified these plant gate-to-gate input and output data.

Consistency: To ensure consistency, the data sources for inputs and outputs, including raw materials, energy consumption, and emissions, were carefully aligned in terms of quality, time frame, and geographical relevance across the different phases of cement production. Additionally, data for all relevant processes were collected and analyzed using comparable units and methodologies. Crosschecks concerning the plausibility of mass and energy flows were continuously conducted. The LCA team conducted mass and energy balances at the plant and selected process levels to maintain a high level of consistency. Furthermore, the assumptions made—regarding technology, system boundaries, or operational conditions—were made coherently and uniformly applied throughout all processes analyzed. Where possible, this data was compared with industry benchmarks or data from similar studies to assess consistency and identify any discrepancies.

Reproducibility: Internal reproducibility is achievable because both the data and models are preserved and accessible in a database (Sphera LCA FE). The report offers a significant degree of transparency by detailing the specifications and material composition of the specified SRC product, and by providing summaries of the primary and secondary LCI data sources in Table 4, Table 5, and Table 6.

6 Life Cycle Impact Assessment (LCIA)

The Life Cycle Impact Assessment (LCIA) phase involves further processing and interpreting the inventory analysis results, in terms of environmental impacts and resource use inventory metrics. This is in line with the specifications in the PCR 2019:14 v1.3.4 and EN 15804:2012+A2:2019/AC:2021 for construction products. EN 15804 reference package based on EF 3.1 was utilized for the impact categories. EN 15804:2012+A2:2019/AC:2021 specifies additional environmental indicators that shall be declared in the LCA report and may be declared in the EPD, as detailed in Table 7. In addition, the results of a supplementary indicator for climate impact is declared: GWP-GHG, which is is identical to GWP-total except that the characterisation factor (CF) for biogenic CO_2 is set to zero. LCA is performed using Sphera LCA FE (GaBi) software v10.8.0.14.

Electricity used in the A3 manufacturing process is generated by a heavy fuel oil (HFO) power generator located within the facility. The datasets specific to Saudi Arabia's HFO-based electricity production were sourced from the Sphera database version 2023.2. The climate impact of HFO-based electricity used in A3, measured using the GWP-GHG indicator in accordance with EN 15804 EF 3.1, is 0.846 kg CO_2 eq. per kWh.

Table 7.Life Cycle Category Indicators and Inventory Metrics (Methods: EN 15804 reference package based on EF 3.1)

Indicators	Abbreviation	Unit
Mandatory Impact Indicator		
Global Warming Potential, total	GWP- total	kg CO_2 eq.
Global Warming Potential fossil fuels	GWP-fossil	kg CO_2 eq.
Global Warming Potential biogenic	GWP-biogenic	kg CO_2 eq.
Global Warming Potential land use and land use change	GWP- luluc	kg CO_2 eq.
All greenhouse gases except biogenic carbon dioxide uptake and emissions and biogenic carbon stored in the product	GWP-GHG	kg CO_2 eq.
Depletion potential of the stratospheric ozone layer	ODP	kg CFC 11 eq.
Acidification potential, Accumulated Exceedance	AP	mol H+ eq.
Eutrophication potential, fraction of nutrients reaching freshwater end compartment	EP- freshwater	kg P eq.
Eutrophication potential, fraction of nutrients reaching marine end compartment	EP- marine	kg N eq.
Eutrophication potential, Accumulated Exceedance	EP- terrestrial	mol N eq.
Formation potential of tropospheric ozone	POCP	kg NMVOC eq.
Abiotic depletion potential for non-fossil resources	ADP - minerals&metals	kg Sb eq.
Abiotic depletion for fossil resources potential	ADP – fossil	MJ
Water (user) deprivation potential, deprivation-weighted water consumption	WDP	m^3
Resource Use Indicators		
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	PERE	MJ
Use of renewable primary energy resources used as raw materials	PERM	MJ
Total use of renewable primary energy resources	PERT	MJ
Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials	PENRE	MJ
Use of non-renewable primary energy resources used as raw materials	PENRM	MJ
Total use of non-renewable primary energy resources	PENRT	MJ
Use of secondary material	SM	kg
Use of renewable secondary fuels	RSF	MJ
Use of non-renewable secondary fuels	NRSF	MJ
Use of net fresh water	NFW	m^3
Indicators Describing Waste		

Hazardous waste disposed	HWD	kg
Non-hazardous waste disposed	NHWD	kg
Radioactive waste disposed	RW	kg
Components for re-use	CRU	kg
Material for recycling	MR	kg
Materials for energy recovery	MER	kg
Exported energy, electricity	EE	MJ
Optional indicators		
Particulate matter		Disease incidences
Ionizing, radiation human health		kBq U235 eq.
Ecotoxicity, freshwater		CTUe
Human toxicity, cancer		CTUh
Human toxicity, non-cancer		CTUh
Land Use		Pt

7 LCIA Results

This section presents the inventory metrics and life cycle impact indicator results for the Al Jouf SRC product. These results are a function of LCI modeling and LCA as performed using Sphera LCA FE (Gabi) v10.8.0.14 with the LCI data sets as described in Section 5 and Appendices of this report. Environmental performance has been calculated with EF 3.1 EN15804+A2 method. Characterization factors from EF 3.1 have been used for estimating the potential environmental impacts, as required by PCR 2019:14 v1.3.4.

Table 8, Table 9, Table 10, Table 11, and Table 12 summarize the LCA results for 1 t of SRC product. The results are presented as an aggregated A1-A3 scope due to the aggregation of the datasets from Sphera, such as for thermal and electricity LCI data for Saudi Arabia. The estimated impact results are only relative statements which do not indicate the end points of the impact categories, exceeding threshold valued, safety margins or risks. Emerging LCA impact categories and inventory items are still under development and can have high levels of uncertainty that preclude international acceptance pending further development. Use caution when interpreting data in these categories.

Table 8. Mandatory impact category indicators according to EN 15804 (Results per functional or declared unit)

Indicator	Unit	A1-A3
GWP- total	kg CO_2 eq.	9.34E+02
GWP-fossil	kg CO_2 eq.	9.34E+02
GWP-biogenic(1)	kg CO_2 eq.	0.00E+00
GWP- luluc	kg CO_2 eq.	1.88E-02
GWP-GHG (2)	kg CO_2 eq.	9.34E+02
ODP	kg CFC 11 eq.	1.24E-07
AP	mol H^+ eq.	1.06E+01

EP- freshwater	kg P eq.	6.36E-03
EP- marine	kg N eq.	5.25E-01
EP- terrestrial	mol N eq.	5.76E+00
POCP	kg NMVOC eq.	1.99E+00
ADP - minerals&metals*	kg Sb eq.	9.59E-05
ADP - fossil*	MJ	5.31E+03
WDP*	m^3	9.34E+00

Acronyms:

GWP-fossil = Global Warming Potential fossil fuels; GWP-biogenic = Global Warming Potential biogenic; GWP-luluc = Global Warming Potential land use and land use change; ODP = Depletion potential of the stratospheric ozone layer; AP = Acidification potential, Accumulated Exceedance; EP-freshwater = Eutrophication potential, fraction of nutrients reaching freshwater end compartment; EP-marine = Eutrophication potential, fraction of nutrients reaching marine end compartment; EP-terrestrial = Eutrophication potential, Accumulated Exceedance; POCP = Formation potential of tropospheric ozone; ADP-minerals&metals = Abiotic depletion potential for non-fossil resources; ADP-fossil = Abiotic depletion for fossil resources potential; WDP = Water (user) deprivation potential, deprivation-weighted water consumption

[1] This indicator is negative due to an uptake of biogenic carbon in packaging materials. Considering that module A5 is not declared, the correlated emissions due to end-of-life of packaging, are balanced-out already in Module A1-A3, hence resulting in a total value of zero.

[2] This indicator accounts for all greenhouse gases except biogenic carbon dioxide uptake and emissions and biogenic carbon stored in the product. As such, the indicator is identical to GWP-total except that the CF for biogenic CO_2 is set to zero.

** Disclaimer: The results of this environmental impact indicator shall be used with care as the uncertainties of these results are high or as there is limited experience with the indicator.*

Table 9. Resource use indicators (Results per functional or declared unit)

Indicator	Unit	A1-A3
PERE	MJ	1.08E+02
PERM	MJ	0.00E+00
PERT	MJ	1.08E+02
PENRE	MJ	5.31E+03
PENRM	MJ	0.00E+00
PENRT	MJ	5.31E+03
SM	kg	0.00E+00
RSF	MJ	0.00E+00
NRSF	MJ	0.00E+00
FW	m^3	3.19E-01

Acronyms:

PERE = Use of renewable primary energy excluding renewable primary energy resources used as raw materials; PERM = Use of renewable primary energy resources used as raw materials; PERT = Total use of renewable primary energy resources; PENRE = Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials; PENRM = Use of non-renewable primary energy resources used as raw materials; PENRT = Total use of non-renewable primary energy re-sources; SM = Use of secondary material; RSF = Use of renewable secondary fuels; NRSF = Use of non-renewable secondary fuels; FW = Use of net fresh water

Table 10. Waste indicators (Results per functional or declared unit)

Indicator	Unit	A1-A3
Hazardous waste disposed	kg	1.44E-08
Non-hazardous waste disposed	kg	6.41E-01

Radioactive waste disposed	kg	2.49E-04

Table 11.Output flow indicators (Results per functional or declared unit)

Indicator	Unit	A1-A3
Components for re-use	kg	0.00E+00
Material for recycling	kg	0.00E+00
Materials for energy recovery	kg	0.00E+00
Exported energy, electricity	MJ	0.00E+00
Exported energy, thermal	MJ	0.00E+00

Table 12. Optional impact category indicators (Results per functional or declared unit)

Indicator	Unit	A1-A3
Particulate matter	Disease incidences	8.84E-05
Ionizing, radiation human health	kBq U235 eq.	5.62E-01
Ecotoxicity, freshwater	CTUe	3.53E+03
Human toxicity, cancer	CTUh	2.18E-07
Human toxicity, non-cancer	CTUh	1.94E-06
Land Use	Pt	6.49E+02

8 Interpretation

With a clinker-to-cement ratio of 0.93, SRC exhibited an climate impact of 931 kg CO2-eq per each tonne produced. The environmental burdens on climate change mainly stems from the limestone decarbonization and heavy fuel oil (HFO) combusted in the kiln during the clinker production. On-site electricity produced from HFO (EL-HFO) was identified as the third main emitter of greenhouse gases (GHG) emissions as can be observed inFigure 3. Correspondingly, the contribution to overall GWP from limestone decomposition, HFO combustion, and EL-HFO (A3 activities) was 53%, 27%, and 10.3%, respectively. The emissions from raw materials supply (A1) and their transportation (A2) from the extraction site to the cement plant gate account for 4.45% of the total emissions contributing to GWP.

Table 8 also presents non-climate change-related impact categories representing the complete environmental performance of SRC. Power and thermal energy generation using HFO are the main responsable processes for the emissions that contribute to AP, EP-marine and terrestrial, POCP, ADP-F, ADP-minerals & metals. They account for 96, 80, 87, 87, and 86%, respectively. For the WDP category, EL-HFO alone accounted for 43% of the total water consumed during SRC production process. On the other hand, the emissions stemming from clay mining, manufacturing, and transportation of packing materials to the cement plant gate account for 95 and 97% of total emissions that deplete stratospheric ozone and increase eutrophication in freshwater bodies, respectively.

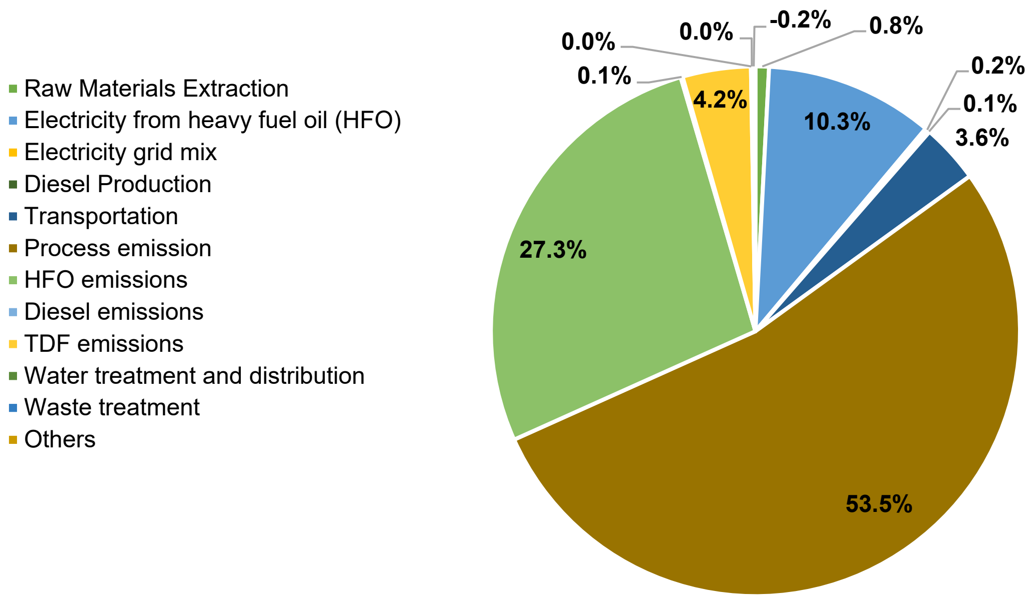

Figure 3. Process contribution to Global Warming Potential (GWP) for SRC production

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10 Appendices

10.1 Life cycle inventory data

Table A. 1. Technology matrix (energy and material inputs) for the production of 1 t of Sulphate Resistant Cement (SRC) in Al Jouf company.

Material	Vehicle type/payload size (Ton)	Quantity	Unit	Dataset	Comments
A1. Raw materials extraction for clinker production					
Limestone	-	1.062	t	RoW: Limestone quarry operation ecoinvent 3.9.1 This dataset was modified with Saudi Arabia's electricity grid mix.	
Clay	-	0.312	t	RoW: Clay pit operation ecoinvent 3.9.1	
Iron ore	-	0.104	t	GLO: Iron ore mine operation, 46% Fe ecoinvent 3.9.1. This dataset was modified with Saudi Arabia's electricity grid mix.	
Bauxite	-	0	t	GLO: Bauxite mine operation ecoinvent 3.9.1. This dataset was modified with Saudi Arabia's electricity grid mix.	
Mill scale	-	0.007	t	-	Following the *Polluter Pays* Principle, as a recycled material (by-product) in the steelmaking process, no environmental burden is associated to its production/treatment. It represents 6% of the total iron ore mixture to increase the iron oxide content.

Pozzolana		0.0314	t	The model for pozzolana mining incorporates the diesel consumption associated with excavation processes [8].	
Gypsum		0.05	t	SA: Gypsum stone ($CaSO_4$-Dihydrate)	
Shredded tires (secondary fuel)	-	9.92	MJ	SA: Electricity grid mix Sphera	Following the Polluter Pays Principle, no environmental burden will be associated to the production of waste materials. Transportation and treatment emissions were included in the LCA model [9]. The recycling process for tyres is modeled to include the electricity consumption required for shredding and granulation, which amounts to 212 kWh/ t tyres [10].
A2. Transportation from the raw materials extraction site to the cement plant					
Limestone	Euro 5 truck/32	2	km	GLO: Truck, Euro 5. 28-32 gross weight	
Clay	Euro 5 truck/32	55	km	GLO: Truck, Euro 5. 28-32 gross weight	
Pozzolana	Euro 5 truck/32	5	km	GLO: Truck, Euro 5. 28-32 gross weight	
Iron ore	Euro 5 truck/32	1600	km	GLO: Truck, Euro 5. 28-32 gross weight	
Bauxite	Euro 5 truck/32	1000	km	GLO: Truck, Euro 5. 28-32 gross weight	

Gypsum	Euro 5 truck/32	300	km	GLO: Truck, Euro 5. 28-32 gross weight	
Mill scale	Euro 5 truck/32	1400	km	GLO: Truck, Euro 5. 28-32 gross weight	
Shredded tires	Euro 5 truck/32	1250	km	GLO: Truck, Euro 5. 28-32 gross weight	
Heavy fuel oil (HFO)	Euro 5 truck/32	1500	km	GLO: Truck, Euro 5. 28-32 gross weight	
Diesel	Euro 5 truck/32	400	km	GLO: Truck, Euro 5. 28-32 gross weight	
A3. Manufacturing					
a. Clinker					
Heavy fuel oil		0.083	t	SA: Thermal energy from heavy fuel oil Sphera	Source of heat for calciner and kiln. Low heating value(LHV): 40.52 MJ/kg.
Shredded tires combusted in the kiln		0.013	t	-	The emissions profile of shredded tires is modeled based on the assumed composition of the tires and stoichiometric calculations provided in [11]. Shredded tires contribute with 14% of the total energy delivered by HFO in the kiln. LHV: 32 MJ/kg
Diesel		0.22	kg	US: diesel combusted in industrial	Used in the boilers of the thermal oil to heat up the HFO lines
Water		0.045[1]	m^3	-	Treated wastewater and brine water from reverse-osmosis plant are used as spray water within process

				systems of raw Mill, crusher, and kiln for cooling purposes.
Lubricating oil	0.16	kg	RER: market for lubricating oil ecoinvent	Used for maintance/lubrication of equipments used durin the cement production process
b. Cement				
Electricity/Heavy fuel oil	0.010	t	SA: Electricity from heavy fuel oil Sphera	Source of electricity for the production process, generated on-site the plant. 114 kWh was assumed as the total electricity demanded to produce 1 t of cement.
Packaging material (kraftpaper)	2.92	kg	RER: market for kraft paper ecoinvent 3.9.1	

[1]The water source originates from groundwater, which then undergoes treatment to remove impurities and reduce hardness at the reverse osmosis plant. The water treatment process, along with the corresponding wastewater treatment, was simulated using Gabi Sphera datasets, with modifications made to account for electricity usage. Electricity consumption figures were obtained from primary data, which specify that 0.00432 kWh is needed to pump and treat each liter of groundwater.

Table A. 2. Waste generated during the cement production process in Al Jouf company (FU=1 t of OPC)

Waste type	Quantity	Unit	Datasource
Sewage water, liquid industrial wastewater	0.04923	m^3	GLO: Municipal wastewater treatment (sludge landfill, for regionalization) Sphera
Solid municipal wastes	0.12	kg	UA: Landfill(Municipal household waste) Sphera
Used oil	0.05	kg	DE: Used oil Sphera