Life Cycle Assessment Report

Draft

Life Cycle Assessment Study

Sagar Cements Limited, Mattampally

By Confederation of Indian Industry, Hyderabad, March 2023

B20 India Secretariat

Confederation of Indian Industry

CII-Sohrabji Godrej Green Business Centre

Cradle to Gate
Life Cycle Assessment Study Report
(Draft)

Sagar Cements Limited, Mattampally

2021 – 2022

Acknowledgement

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About Sagar Cements Limited

Sagar Cements is a prominent player in the field of cement in Andhra Pradesh & Telangana for over 3 decades adopting progressive manufacturing practices, whether it relates to maintaining high standards of quality of its products or development of its highly valued human resources or the need to keep the pollution to the barest minimum. ISO 9001:2015, ISO 14001:2015, OHSAS 18001:2007 and ISO 50001:2018 certified Company.

The Company manufactures various varieties of cement like Ordinary Portland Cement (OPC) of 53 grade, 43 grade, Portland Pozzolana Cement (PPC) and Sulphate Resistant Cement (SRC) to suit different needs of customers and all these products are being sold under the Brand Name “Sagar” which has already become popular in Andhra Pradesh, has now found its acceptance among the customers in the neighboring States as well.

The Company employs modern technology in each of its process of manufacture at its plant and has adopted progressive manufacturing practices, whether it relates to maintaining high standards of quality of its products or development of its highly valued human resources or the need to keep the pollution to the barest minimum.

The Company has been operating with a Clinker capacity of 2.65 MTPA, Cement capacity of 3.30 MTPA, WHR based power plant of 8.8 MW and Thermal based Captive power plant of 18 MW.

About CII

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the development of India, partnering industry, Government, and civil society, through advisory and consultative processes. For 126 years, CII has been working on shaping India's development journey and, this year, more than ever before, it will continue to proactively transform Indian industry's engagement in national development.

CII is a non-government, not-for-profit, industry-led and industry-managed organization, with about 9100 members from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 300,000 enterprises from 288 national and regional sectoral industry bodies.

CII charts change by working closely with Government on policy issues, interfacing with thought leaders, and enhancing efficiency, competitiveness, and business opportunities for industry through a range of specialized services and strategic global linkages. It also provides a platform for consensus-building and networking on key issues.

Extending its agenda beyond business, CII assists industry to identify and execute corporate citizenship programs. Partnerships with civil society organizations carry forward corporate initiatives for integrated and inclusive development across diverse domains including affirmative action, livelihoods, diversity management, skill development, empowerment of women, and sustainable development, to name a few.

As India completes 75 years of Independence in 2022, it must position itself for global leadership with a long-term vision for India@100 in 2047. The role played by Indian industry will be central to the country's progress and success as a nation. CII, with the Theme for 2022-23 as Beyond India@75: Competitiveness, Growth, Sustainability, Internationalization has prioritized 7 action points under these 4 sub-themes that will catalyze the journey of the country towards the vision of India@100.

With India assuming G20 presidency as of 2023, CII is elected to be the B20 secretriate to lead the business agenda during India's G20 Presidency. The B20 represents the voice of the entire G20 business community.

1. Background

Sagar Cements Limited has initiated a life-cycle assessment (LCA) to evaluate the environmental impact of various types of cement produced. With such an LCA study, Sagar Cements Limited can assist others in understanding and communicating the environmental footprint and impact of various type of cement and at the same time, this study helps describe the environmental impacts of cement's different life-cycle stages in relation to overall environmental performance, and the potential environmental benefits of process improvements.

This study is reference to the LCA study for Sagar Cements Limited, Mattampally unit. The unit is integrated plant and produces Ordinary Portland Cement (OPC) and Portland Pozzolana Cement (PPC).

1.1 Introduction to LCA

An LCA is a standardized, scientific method for systematic analysis of flows (e.g., mass and energy) associated with the life cycle of a specific product, technology, service, or manufacturing process system. In the case of a product system, the life cycle includes raw materials acquisition, manufacturing, use and end-of-life (EoL) management. According to the International Organization for Standardization (ISO) 14040/44 standards, an LCA study consists of four phases:

1. Goal and scope (framework and objective of the study)
2. Life-cycle inventory (input/output analysis of mass and energy flows from operations along the product's value chain)
3. Life-cycle impact assessment (evaluation of environmental relevance, e.g., global warming potential)
4. Interpretation (e.g., optimization potential).

LCA addresses potential environmental impacts throughout a product's lifecycle from raw material extraction through production, use, end of life treatment recycling and final disposal. There are multiple approaches possible for LCA, namely,

- Cradle to gate
- Cradle to grave
- Cradle to cradle

Cradle to gate includes raw material extraction, transportation, and emissions during different processing stages, until the product exits the factory gate. Cradle to grave includes raw material extraction, transportation, emissions during different processing stages, product use and disposal, until the product reaches its end of useful life (i.e., grave). Cradle to cradle includes raw material extraction, transportation, emissions during different processing stages, product use and disposal, until the product reaches its end of useful life and is either reused or recycled (i.e., cradle).

The goal and scope stage outline the rationale of the study, anticipated use of study results, boundary conditions, data requirements and assumptions to analyse the product system under consideration, and other similar technical specifications for the study. The goal of the study is based upon specific questions that the study seeks to answer, the target audience and stakeholders involved and the intended use for the study's results. The scope of the study defines the systems boundary in terms of technological, geographical, and temporal coverage of the study; attributes of the product system; and the level of detail and complexity addressed.

1.2 Functional Unit

The functional unit is a key element of LCA which must be clearly defined. The functional unit is a measure of the function of the studied system, and it provides a reference to which the inputs and outputs can be related. This enables comparison of two essential different systems.

1.3 System Boundaries

The system that will be studied in the LCA should be clearly described. Flow diagrams can be used to show the different subsystems, processes and material flows that are part of the system model.

The system boundaries determine which unit processes to be included in the LCA study. Defining system boundaries is partly based on a subjective choice, made during the scope phase when the boundaries are initially set. The following boundaries can be considered: Boundaries between the technological system and nature. A life cycle usually begins at the extraction point of raw materials and energy carriers from nature. Final stages normally include waste generation and/or heat production.

In System boundaries the geographical areas are also to be defined. Geography plays a crucial role in most LCA studies, e.g., infrastructures, such as electricity production, waste management and transport systems, vary from one region to another. Moreover, ecosystems sensitivity to environmental impacts differs regionally too. Time horizon. Boundaries must be set not only in space, but also in time. Basically, LCAs are carried out to evaluate present impacts and predict future scenarios. Limitations to time boundaries are given by technologies involved, pollutants lifespan, etc.

1.4 Inventory analysis

The inventory analysis involves data collection and calculation procedures to quantify the inputs and outputs that are associated with the product system(s) under study. This includes use of resources, releases to air, water, and land. Procedures of data collection and calculation should be consistent with the goal and the scope of the study. The results of the inventory analysis may constitute the input for the life cycle assessment as well as an input for the interpretation phase.

1.5 Allocation

A special issue related to the inventory analysis is the so-called allocation problem. This refers to the allocation of environmental inputs and outputs of a process to different products. Examples of processes where allocation is needed are:

1.6 Impact assessment

In the impact assessment, the results of the inventory analysis are linked to specific environmental damage categories (e.g., CO_2 emissions are related to global warming and climate change, SOx emissions are related to damages to the ecosystem caused by acidification, etc.). The impact assessment predicts potential environmental damages (impacts) related to the system under study. More details on the methodology of impact assessment please refer the annexure.

1.7 Interpretation

According to ISO 14043, in the interpretation phase of an LCA, the results of the inventory analysis and the impact assessment are critically analyzed and interpreted in line with the defined goal and scope of the study. The findings of this interpretation may take the form of conclusions and recommendations to decision makers. It may also take the form of an improvement assessment, i.e., an identification of opportunities to improve the environmental performance of products or processes.

1.8 LCA Benefits

LCA offers the following benefits:

- A systematic evaluation of the environmental impacts associated with the products.
- Analyzing the key issues and areas of improvement within the life cycle of the product.
- Comparing alternatives to determine the more sustainable choice in material selection.
- Helps in communicating environmental performance to customers and consumers through Environment Product Declaration (EPD).
- Development and optimization of production processes.

2. Objective of the study

Lifecycle assessment study for Sagar Cements Limited, Mattampally unit was aimed to establish the environmental impacts produced due to the manufacture of various types of cement. The following are the major objectives of the study:

- To monitor the environment impacts caused due to the manufacturing of types of cement.
- Establish environmental profiles for OPC and PPC.
- To determine hot spots and key environmental parameters between cradle to gate operation in the manufacturing process.
- Compare the processes to establish the one with least potential environment impacts.

2.1 Goal & Scope

2.1.1 Goal

The goal of the study is to assess life cycle of the various cement manufactured by Sagar Cements Limited in Mattampally unit and use results to identify hotspots to minimize the environmental impact. The products manufactured by Sagar Cements Limited, Mattampally unit are OPC and PPC. The study is based on the latest inventory data collected for the year 2021-22.

2.1.2 Scope

The study will try to include all the major components which would have significant impact. However, components that are small and have negligible mass and/or volume will be excluded from the study unless they have significant toxicity or human health impacts on account of the materials used in them or the processing of the materials contained in it. Capital and infrastructure goods will be excluded for impact analysis. The impact analysis will include non-renewable energy use, freshwater use, smog, acidification, ecotoxicity, global warming, eutrophication, and human health impacts.

2.1.3 Functional Unit

The functional unit for the study is one ton of OPC and one ton of PPC.

2.1.4 System boundaries

The boundary considered for the LCA study is Cradle to Gate which includes raw material extraction, transportation, and emissions during different processing stages, until the product exits the factory gate.

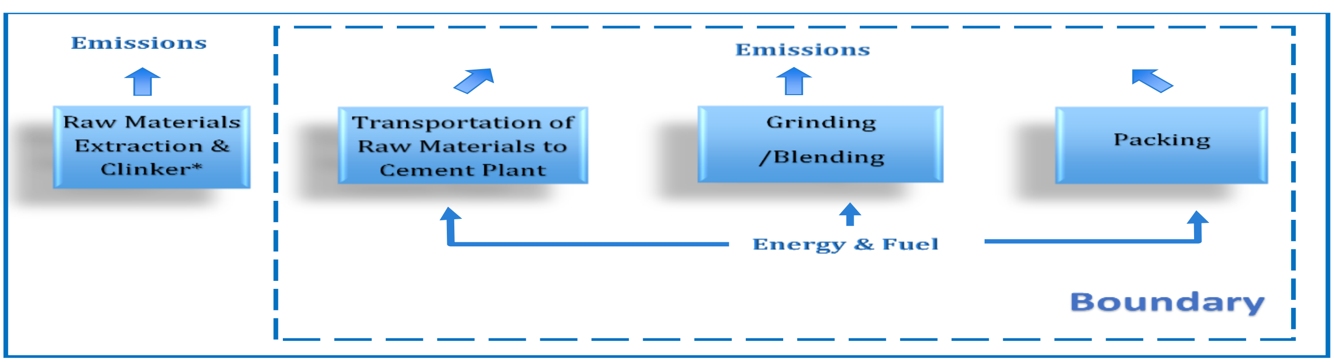

Figure 1: LCA – Boundary

2.2 Cut-off Criteria

Cut-off criteria were employed to include all the environmental impact sources while ensuring the study to be complete, relevant, accurate and consistent. Cut-off criteria considered for this study are below:

- **Mass** – For mass flow less than 1% of the total mass flow environmental impact source may be eliminated with the stipulation that impact would be marginal.
- **Energy** – For energy flow less than 1% of the total energy flow environmental impact source may be eliminated under that condition that environmental impact is not a concern.
- **Environment** – For those flows (mass or energy flow) less than 1% of the total respective flow with significant environmental concern impact source must be included for the study.

2.3 Allocation

The rule pertaining to allocation applies only when there are two or more by-products produced from a single stream. In this study allocation rule was not considered, as the operation in Sagar Cements Limited, Mattampally unit resulted in no more than one product from each stream.

2.4 Assumptions

Cradle to gate study approach was adopted, all the data considered for this study was obtained from primary sources. Hence, the need for assumptions was eliminated completely.

3 LCI Methodology & Analysis

Life cycle inventory analysis is a phase of life cycle assessment which involves quantification & compilation of inputs and outputs for a product throughout its life cycle.

3.1 Methodology

Lifecycle Assessment study carried out for Sagar Cements Limited, Mattampally unit was carried out in different phases as follows:

3.1.1 Initial Discussion

An online discussion was conducted to understand the operations and major impact sources of Sagar Cements Limited, Mattampally unit. During the discussion, major impact sources were recorded with the consensus of the team.

3.1.2 Development of Inventory Metrics

Following the initial discussion, metrics for LCA study was established after collaborating with the Sagar Cements Limited, Mattampally unit and established metrics would help to carry out data collection activity in the future, whilst maintaining the data accuracy. The software used for carrying out this study was SimaPro v9.4 and the datasets used were from Ecoinvent. Ecoinvent is an independent association consisting of the five institutes as active members. With this step, Ecoinvent has become a not-for-profit organization whose goal is to ensure the further development of a consistent, transparent and trustworthy database for the LCA community as well as for creators of eco-design tools, decision-makers, industry and scientific research. The data was modelled using SimaPro and the results obtained were explained in detail in section 8.

3.1.3 Data Collection

System boundary was set after consulting Sagar Cements Limited, Mattampally unit. Having set the boundary data collection process was initiated. Since the accuracy of LCA study depends on the data availability caution was exercised during the data collection process. A questionnaire has been designed to collect the required data. It is attached as an annexure.

3.1.4 Data Authentication

As a part of the study data authentication was carried out to understand the assurance level provided by the collected data. This authentication process enabled Sagar Cements Limited, Mattampally unit, to avoid any ambiguities that may encircle in the future.

3.1.5 In-House Calculation

Following the data collection and authentication process calculations were performed to evaluate and analyze the significance of different impact categories associated with the production of 1 tonne of cement and 1 tonne of equivalent product (average cement), considering cradle to gate boundary.

3.2 Life Cycle Inventory

The following is the process flow diagram of the cement manufacturing process in Mattampally unit of Sagar Cements Limited.

- **Mining**: For mining process fuel, water and material are the inputs, whereas emissions, solid waste and wastewater are the output.
- **Clinkerisation**: The inputs for clinkerisation process are fuel, water and material whereas emissions, solid waste and wastewater are the output.
- **OPC**: The inputs for manufacturing OPC are water, material, clinker, and fuel. The outputs are emissions & solid waste.
- **PPC**: The inputs are clinker, Flyash, mineral gypsum, fuel, water, and the outputs are PPC, emissions and solid waste.

All the finished products are input for the packing process and output is the packaged product along with solid waste.

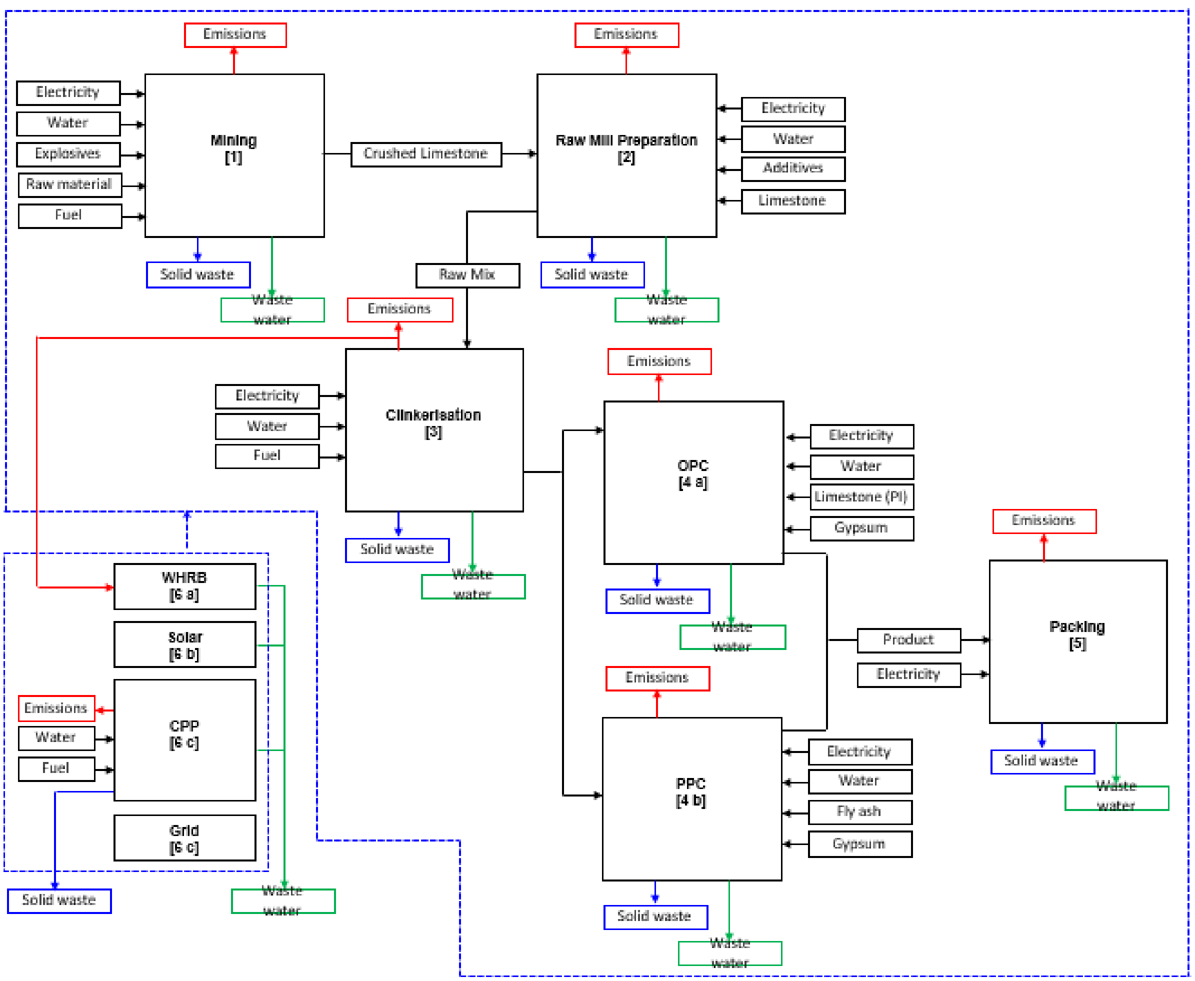

Figure 2 Life Cycle Inventory Details

Life cycle inventory involves compilation of all the inputs and outputs of the manufacturing process. Inputs and outputs include all the material and energy flows across each of the unit process within the plant boundary. The following section provides highlight on the data collection process for compilation of inventory along with the life cycle inventory of the functional unit under study. Data used for this study covers time horizon of 2021-22. Primary data for this study includes the following, the operation was split into different blocks based on the operations. Broadly the operations were divided into six blocks:

1. Mining operations
2. Clinkerisation
3. Ordinary Portland Cement
4. Portland Pozzolana cement
5. Captive Power Plant

For all these sections two sets of data were collected. Data collected was classified into input and outputs and the further classified into fuels, materials and water in the input side and product, waste, emissions, wastewater in the output side.

3.3 Life cycle inventory – Process wise

Functional unit for each block is defined as output, all input and output for each process was recorded. Life cycle Inventory is the data collection part of LCA. It is accounting all the major operations in the system and detailed tracking of all the inputs and outputs in the process. For instance, including raw resources or materials, energy by type, water, and emissions to air, water, and land by specific substance.

3.3.1 Limestone Mining

The functional unit for mining operation was considered as tonne of limestone, inputs and outputs for this operation has been listed below.

Table 1: Limestone Inventory Data

S.No.	Particulars	Basis	Unit	Mine 1	Mine 2
Inputs					
1.1	**Resources**				
a	Land Use		Hectares	6.69	0.46
b	Water	Annum	KL	13,249	5,940
1.2	**Material/Fuel**				
a	Explosive		Ton	240.06	0
b	Diesel for equipment	Annum	KL	9,15,058	1,53,500
		Density	kg/l	0.83	0.83
c	Transport		ton	25,25,000	4,00,000
d	Distance (Mine to crusher)		km	0.96	3.25
1.3	**Electricity/Heat**				
a	Electricity	Annum	kWh	50,91,888	0
Output					
1.1	**Material**				
a	Limestone	Annum	Ton	25,25,000	4,00,000

3.3.2 Clinkerisation

The functional unit for clinkerisation operation was considered as tonne of clinker, inputs and outputs for this operation has been listed below:

Table 2: Inventory Data - Clinker

S.No.	Particulars	Basis	Unit	Unit-I	Unit-II
Inputs					
1.1	**Resources**				
a	Water	Annum	KL	38,564	
1.2	**Material/Fuel**				
a	Limestone	Annum	Ton	6,17,577	22,68,810
b	Alu-Laterite	Annum	Ton	2,627	9,651
c	Fe.Lat/Flue Dust	Annum	Ton	40,212	1,47,726
d	Iron ore	Annum	Ton	1,305	4,796
e	Iron sludge	Annum	Ton	415	1,526
f	Plastic waste	Annum	Ton	10	310
i	RDF	Annum	Ton		
k	Agri waste	Annum	Ton	128	4,500
l	Coal (Indian)	Annum	Ton	13,952	88,595
m	Coal (Imported)	Annum	Ton	16,483	42,539
n	Pet coke	Annum	Ton	27,486	77,307
o	Hazardous Liquid Waste	Annum	Ton	908	9,696
p	Hazardous Solid Waste	Annum	Ton	570	9,853
q	Other wastes	Annum	Ton	3	10
r	LDO	Annum	KL	48	111
1.3	**Electricity/Heat**				
a	Electricity	Annum	kWh	1,07,17,889	4,30,42,368
Output					
1.1	**Material**				
a	Clinker	Annum	Ton	4,39,965	16,16,312
1.2	**Waste**				
a	Waste oil	Annum	KL	3	
b	Waste Grease	Annum	Ton	2.16	

3.3.3 OPC Grinding

The functional unit for OPC operation was considered as tonne of OPC. The input and output materials considered for the analysis are stated below for the year 2021-2022. The inputs are resources, material & electricity and output is OPC.

Table 3: Inventory Data – OPC Grinding

S.No.	Particulars	Basis	Unit	CM-2	CM-3	CM-4
Inputs						
1.1	**Resources**					
a	Water	Annum	KL	1,526	7,828	9,837
1.2	**Material/Fuel**					
a	Clinker	Annum	Ton	26,630	4,17,287	4,46,399
b	Gypsum	Annum	Ton	1,075	17,622	18,851
c	Limestone as PI	Annum	Ton	0	19,046	20,375
1.3	**Electricity/Heat**					
a	Electricity	Annum	kWh	9,70,926	1,61,92,647	1,83,21,714
Output						
1.1	**Material**					
a	OPC	Annum	Ton	27,705	4,53,955	4,85,625

3.3.4 PPC Grinding

The functional unit for PPC operation was considered as tonne of PPC. The input and output materials considered for the analysis are stated below for the year 2021-2022. The inputs are resources, material & electricity and output is PPC.

Table 4: Inventory Data: PPC

S.No.	Particulars	Basis	Unit	CM-3	CM-4
Inputs					
1.1	**Resources**				
a	Water	Annum	KL	2,480	4,329
1.2	**Material/Fuel**				
a	Clinker	Annum	Ton	1,63,121	2,43,570
b	Gypsum	Annum	Ton	10,290	15,365
c	Flyash	Annum	Ton	91,669	1,36,880
1.3	**Electricity/Heat**				
a	Electricity	Annum	kWh	71,12,515	1,13,84,453
Output					
1.1	**Material**				
a	PPC	Annum	Ton	2,65,080	3,95,815

3.3.4 CPP Data

The functional unit for CPP operation was considered as 1 kWh of electricity. The input and output materials considered for the analysis are stated below for the year 2021-2022. The inputs are resources, material & electricity and output is kWh.

Table 5: CPP Inventory Data

S.No.	Particulars	Basis	Unit	Value
Input				
1.1	**Resources**			
a	Water	Annum	KL	38,425
1.2	**Material/Fuel**			
a	Coal (Indian)	Annum	Ton	1,03,777
b	Coal (Imported)	Annum	Ton	3,235
c	Diesel	Annum	KL	4
Output				
1.1	**Material**			
a	Electricity	Annum	kWh	10,89,48,092
b	Flyash	Annum	Ton	42,250
c	Bottom Ash	Annum	Ton	1,191
1.2	**Waste**			
a	Treated Effluent water consumption	Annum	KL	11,921
1.3	**Electricity Generation**			
a	Gross Generation	Annum	kWh	12,16,39,973
b	Net Generation	Annum	kWh	10,89,48,092
c	Used by Plant	Annum	kWh	10,89,41,352
d	Sold to Grid (if any) (Free cost Power export)	Annum	kWh	6,740

3.3.5 Emission Data

As cement plant one of the major pollutants generated are NOx, SOx, and Particulate matter. For Sagar Cements Limited, specific data pertaining to process was collected – Preheater, Cooler, Cement mill and Coal mill. Following data was collected from plant for LCA analysis (Primary).

Table 6: Unit 1 – Emissions Data

Unit-1			
Clinkerisation			
1	**Kiln/Bag House**		
No		**Quantity**	**Unit**
1	NOx	-	mg/Nm^3
2	SOx	-	mg/Nm^3
3	SPM	-	mg/Nm^3
4	CO_2		
5	Temperature	-	°C
6	Quantity	-	m^3/h
2	**Coal Mill Stack**		
No		**Quantity**	**Unit**
1	SPM	21.91	mg/Nm^3
2	CO_2	0.185	Kg/Nm^3
3	Temperature	67	°C
4	Quantity	8,882	Nm^3/h

3	**Cooler Vent**		
No		**Quantity**	**Unit**
1	SPM	12.99	mg/Nm^3
2	Temperature	168	°C
3	Quantity	66,843	Nm^3/h

Table 7: Unit 2 - Emission Data

Unit-2			
Clinkerisation			
1	**Kiln/Bag House**		
No		**Quantity**	**Unit**
1	NOx	433	mg/Nm^3
2	SOx	23	mg/Nm^3
3	SPM	13.3	mg/Nm^3
4	CO_2	0.28	Kg/Nm
5	Temperature	124	°C
6	Quantity	6,31,294	m^3/H
2	**Coal Mill Stack**		
No		**Quantity**	**Unit**
1	SPM	14.18	mg/Nm^3
2	CO_2	0.185	
3	Temperature	70	°C
4	Quantity	14536	m^3/h
3	**Cooler Vent**		
No		**Quantity**	**Unit**
1	SPM	19.02	mg/Nm^3
2	Temperature	152	C
3	Quantity	2,45,328	m^3/h

Table 8: Cement Mill Emissions Data

Cement Mill -2			
S.No.		**Quantity**	**Unit**
1	NOx	-	mg/Nm^3
2	SOx	-	mg/Nm^3
3	SPM	26.09	mg/Nm^3
4	CO_2	-	
5	Temperature	80	°C
6	Quantity	2,169	Nm^3/h
Cement Mill -3			
S.No.		**Quantity**	**Unit**
1	NOx	-	mg/Nm^3
2	SOx	-	mg/Nm^3
3	SPM	15.7	mg/Nm^3
4	CO_2	-	
5	Temperature	73	°C
6	Quantity	12,702	Nm^3/h
Cement Mill -4			
S.No.		**Quantity**	**Unit**
1	NOx	-	mg/Nm^3
2	SOx	-	mg/Nm^3
3	SPM	19.1	mg/Nm^3
4	CO_2	-	
5	Temperature	77	°C
6	Quantity	14,430	Nm^3/h

3.3.6 Other data

In addition to the above-mentioned data, GHG emissions, energy consumption, transport data and coal quality data were also collected for the year 2021-22.

Table 9: Electricity Mix

Electricity Consumption 2021-22				
S.No.	**Particulars**	**Basis**	**Unit**	**Value**
1	Electricity from Grid for Cement Plant	Annum	kWh	1,23,44,002
2	Mini Hydel Power	Annum	kWh	6,88,244
3	Electricity from Grid for CPP Light up	Annum	kWh	86,470
4	Electricity from CPP	Annum	kWh	10,89,48,092
5	Electricity from Open Access (IEX Power)	Annum	kWh	--
6	Onsite Renewable Energy	Annum	kWh	13,53,377

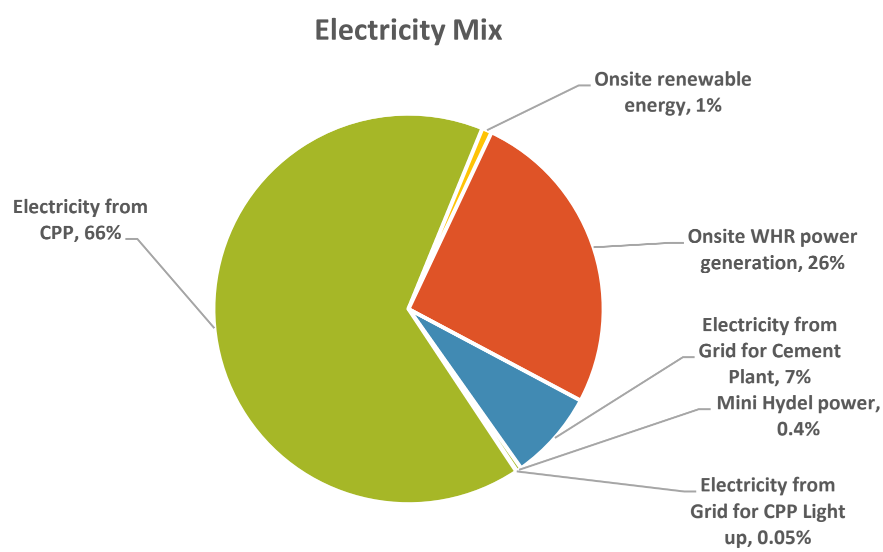

Figure 3: Electricity Mix FY2021-22

4 Life Cycle Impact Assessment

4.1 LCA Tool - About SimaPro

SimaPro is a well-recognized professional tool to collect, analyse and monitor the sustainability performance data of the company's products and services. Using SimaPro, the user can model and analyse complex life cycles in a systematic and transparent way, following ISO 14040 series recommendations. The software can be used for a variety of applications, such as sustainability reporting, carbon and water foot printing, product design, generating environmental product declarations and determining key performance indicators. It helps to make conscious decisions throughout the analysis, to ensure the accuracy of the results.

SimaPro requires the user to build a life cycle of product and fill details in each stage of product life cycle such as material, process, transport, recycle, reuse and disposal; and then, the results of product life cycle network and ecological impact are presented. In data collection stage, the user can input the amount of material, processes, and relative data available in the huge databases built in the package, which are collected from a large number of sources related to variety of assessment methods.

Furthermore, the database can be modified and extended based on customer's requirement. The user can add new material or process into the database and use it in his/her application. Function equations are also supported by SimaPro when the user adds new parameters or elements.

SimaPro has clear and precise presentation of results. The breakdown network of processes and materials are represented at the right side of each element of the presentation network, ecological impact indicator is illustrated in color bar. The size of the color bar indicates the scale of the impact, the larger one represents larger ecological impact of the element. This function is helpful for designer to compare the LCIA of different products, which is useful for eco-design optimization. SimaPro v9.4 is used for this study.

4.2 Impact Assessment Methodology

In life cycle assessment (LCA), environmental impacts are classified according to the methodology used. Several life cycle impact assessment (LCIA) methods are currently used, and the method selected, and the particulars thereof may influence the results obtained.

This is the step where the LCI list that contains the corresponding materials and consumed energy quantities related to the studied product is interpreted and transformed into understandable impact indicators. These indicators express the severity of the contribution of the impact categories to the environmental load. These indicators are concluded through a series of steps recommended by the ISO standards 14042, where some of these steps are obligatory and others are optional. The obligatory steps are definition and classification of impact categories, and characterization.

The impact categories are defined and selected to describe the impacts caused by the emissions and the consumption of natural resources that are induced during the production, use and disposal of the considered product or process.

4.3 ReCiPe Method

ReCiPe is a method for the life cycle impact assessment (LCIA). The primary objective of the ReCiPe method is to transform the long list of life cycle inventory results into a limited number of indicator scores. These indicator scores express the relative severity on an environmental impact category.

In ReCiPe we determine indicators at two levels:

- 18 midpoint indicators
- 3 endpoint indicators

Each method (midpoint, endpoint) contains factors according to the three cultural perspectives. These perspectives represent a set of choices on issues like time or expectations that proper management or future technology development can avoid future damages.

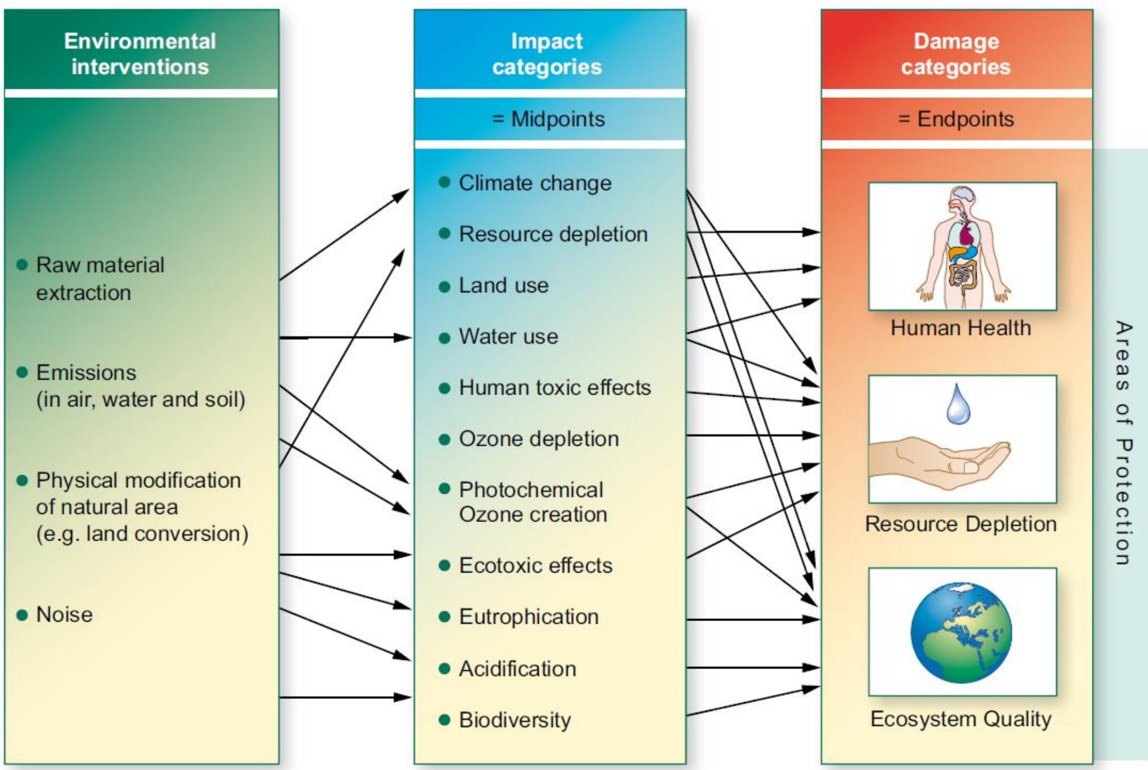

Figure 4: ReCiPe Method – Impact

Individualist: Short term, optimism that technology can avoid many problems in future.

Hierarchist: consensus model, as often encountered in scientific models, this is often considered to be the default model.

Egalitarian: long term based on precautionary principle thinking.

Some of the advantages of the ReCiPe framework relative to other approaches include:

The broadest set of midpoint impact categories. Where possible, it uses impact mechanisms that have global scope. Unlike other approaches (Eco-Indicator 99, EPS Method, LIME, and Impact 2002+) it does not include potential impacts from future extractions in the impact assessment but assumes such impacts have been included in the inventory analysis.

4.4 Analysis

After entering the inputs into the software, the analysis is run to obtain the results. The results obtained are in the form of graph which determines the kg CO_2 equivalent for one ton of the product. The characterization & normalization graphs are obtained from which the impact analysis can be drawn. It has 18 indicators each represented with different colors to analyse the impact of each indicator.

4.5 Impact Categories

Table 10: Impact Categories – ReCiPe Method

Impact Categories	Units	Description
Global warming potential	kg CO_2 equivalent	Alteration of global temperature caused by Greenhouse gases this causes disturbances in global temperature and climatic phenomenon.
Ozone layer depletion	kg CFC-11 equivalent	Diminution of the stratospheric ozone layer due to anthropogenic emissions of ozone depleting substances. This causes increase of ultraviolet UV-B radiation and number of cases of skin illnesses.
Ionizing radiation	kBq Co-60 to air	It is related to the damage to human health and ecosystems that are linked to the emissions of radionuclides throughout a product or building lifecycle. The effects of radiation are health decline, cancer, illness etc.
Photochemical oxidant formation potential	kg NOx to air	Type of smog created from the effect of sunlight, heat and NMVOC (non-methane volatile organic compounds) & NOx. It causes increase in summer fog.
Particulate matter	(PM2.5 equivalent) kg particulate matter	Suspended extremely small particles originated from anthropogenic processes such as combustion, resource extraction, etc. This causes increase in different sized particles suspended on air leading to multitude of health problems especially of the respiratory tract.
Acidification	kg SO_2 equivalent	Reduction of pH due to the acidifying effects of anthropogenic emissions such as NH_3, SOx, NOx this causes increase in the acidity of water & soil systems.
Eutrophication	kg PO_4^{3-} equivalent, kg N equivalent	Eutrophication is the build-up of a concentration of chemical nutrients in an ecosystem which leads to abnormal productivity this causes excessive plant growth like algae in rivers which causes severe reductions in water quality and animal populations.
Land use	Potentially Disappeared Fraction of species/m^2, m^2a	Impact on the land due to agriculture, anthropogenic settlement, and resource extractions. This causes Species loss, soil loss, amount of organic dry matter content, etc.
Depletion of abiotic resources	kg antimony equivalent, kg of minerals, MJ of fossil fuels, m^3 water consumption	Consumption of non-biological resources such as fossil fuels, minerals, metals, water etc. this causes decrease of resources.
Ecotoxicity	kg 1,4-DB equivalent	Environmental toxicity refers to toxic effects of chemicals on three separate impact categories which examine freshwater, marine and land. This causes biodiversity loss and/or extinction of species.

5 Life Cycle Impact Analysis (LCIA)

This chapter analyses the impacts arising from the production of ton of OPC, PPC and average cement at Sagar Cements Limited, Mattampally unit. Comparative analysis was done for the environmental profiles of the three types of cement. The method used for this LCA study was ReCiPe and the impacts categories considered were global warming potential, acidification, eutrophication, ozone depletion potential, ecotoxicity etc. The lifecycle assessment was done for all the products at Sagar Cements Limited, Mattampally unit and below is the product mix:

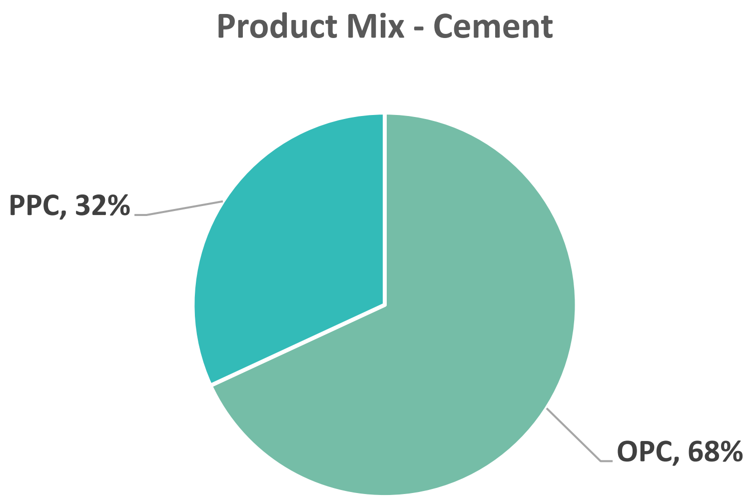

Figure 5: Product Mix – Cement (2021-22)

Table 11: Cement Production (2021-22)

Particulars	UOM	Value
Clinker production	MT	20,56,277
Clinker consumption	MT	12,97,007
Gypsum	MT	63,203
Fly Ash	MT	2,28,549
Limestone as Performing improver in OPC	MT	39,421
Cement production	MT	16,28,180
Clinker to cement ration	%	0.8
Cement equivalent	-	**25,81,319**
Cementitious products	-	**23,87,450**

5.1 Ordinary Portland Cement - LCIA

For the 2021-22, the environmental impacts for one ton of OPC production is highlighted in the table below:

Table 12: Environment Impact - OPC

Impact category	Unit	OPC
Global warming	kg CO_2 eq	873.38
Stratospheric ozone depletion	kg CFC-11 eq	0.00005
Ionizing radiation	kBq Co-60 eq	1.34
Ozone formation, Human health	kg NOx eq	1.28
Fine particulate matter formation	kg PM2.5 eq	0.05
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.28
Terrestrial acidification	kg SO2 eq	0.98
Freshwater eutrophication	kg P eq	0.14
Marine eutrophication	kg N eq	0.009
Terrestrial ecotoxicity	kg 1,4-DCB	131.23
Freshwater ecotoxicity	kg 1,4-DCB	4.72
Marine ecotoxicity	kg 1,4-DCB	1.63
Human carcinogenic toxicity	kg 1,4-DCB	0.05
Human non-carcinogenic toxicity	kg 1,4-DCB	1.10
Land use	m^2a crop eq	4.26
Mineral resource scarcity	kg Cu eq	1.89
Fossil resource scarcity	kg oil eq	104.95
Water consumption	m^3	0.45

The following table highlights that the impact from the **clinker production** is a major contributor to the environment impact among all the other process.

Table 13: Environment Impact Contribution Different Process – OPC

Contribution (%)			
Impact Category	**Clinker**	**Grinding**	**Gypsum**
Global warming	94.2	0.02	0.4
Stratospheric ozone depletion	88.2	0.9	2.4
Ionizing radiation	81.8	0.1	3.4

Ozone formation, Human health	92.3	0.03	1.2
Fine particulate matter formation	75.7	0.1	8.3
Ozone formation, Terrestrial ecosystems	92.2	0.03	1.2
Terrestrial acidification	83.8	0.1	1.1
Freshwater eutrophication	83.8	0.04	0.2
Marine eutrophication	84.5	0.04	0.2
Terrestrial ecotoxicity	79.2	0.2	13.3
Freshwater ecotoxicity	81.2	0.1	0.99
Marine ecotoxicity	80.3	0.1	1.2
Human carcinogenic toxicity	83.1	0.1	1.4
Human non-carcinogenic toxicity	81.7	0.1	3.8
Land use	82.6	0.1	3.1
Mineral resource scarcity	96.3	0.02	3.2
Fossil resource scarcity	84.1	0.1	1.04
Water consumption	75.1	0.2	1.96

The following graph summaries the impact of various processes in production of one tone of OPC,

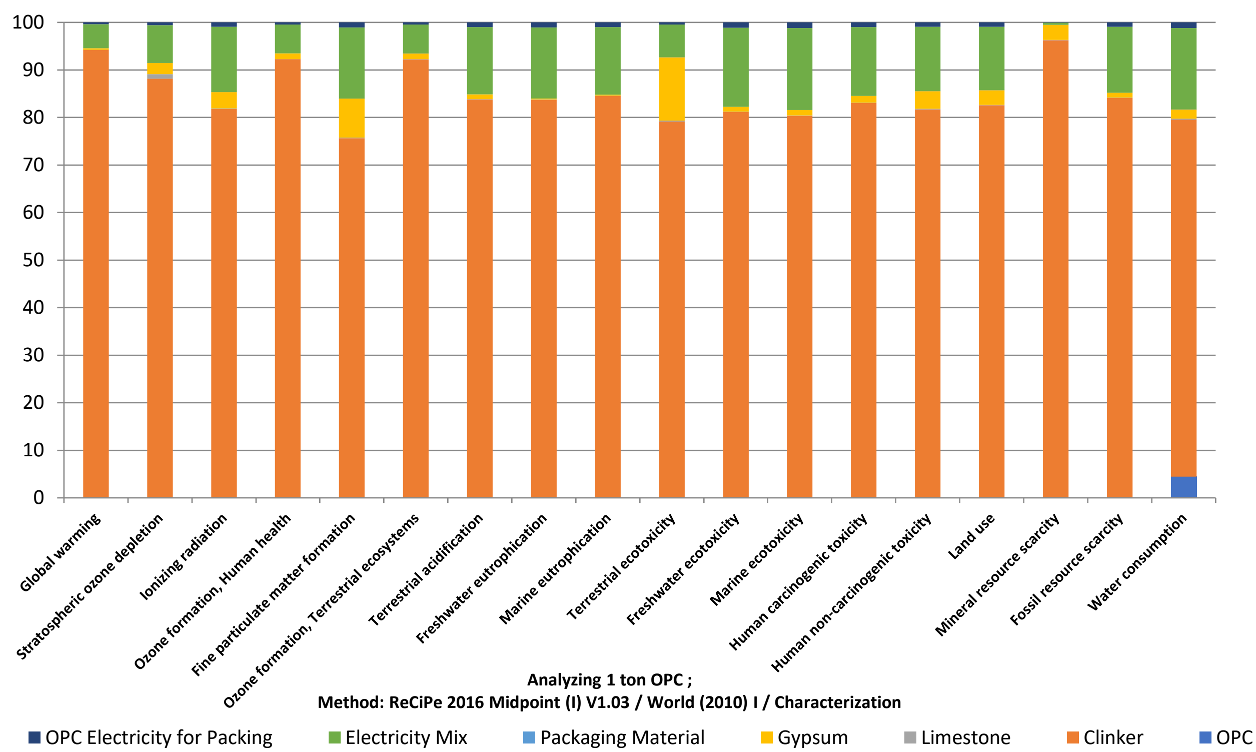

Figure 6: Impact Assessment – Characterization OPC

5.2 Portland Pozzolana Cement - LCIA

For the 2021-22, the environmental impacts for one ton of PPC production is highlighted in the table below:

Table 14: Environment Impact - PPC

Impact category	Unit	PPC
Global warming	kg CO_2 eq	598.68
Stratospheric ozone depletion	kg CFC-11 eq	0.00004
Ionizing radiation	kBq Co-60 eq	1.04
Ozone formation, Human health	kg NOx eq	0.90
Fine particulate matter formation	kg PM2.5 eq	0.04
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.91
Terrestrial acidification	kg SO2 eq	0.70
Freshwater eutrophication	kg P eq	0.10
Marine eutrophication	kg N eq	0.01
Terrestrial ecotoxicity	kg 1,4-DCB	135.42
Freshwater ecotoxicity	kg 1,4-DCB	3.39
Marine ecotoxicity	kg 1,4-DCB	1.18
Human carcinogenic toxicity	kg 1,4-DCB	0.03
Human non-carcinogenic toxicity	kg 1,4-DCB	0.87
Land use	m^2a crop eq	3.27
Mineral resource scarcity	kg Cu eq	1.29
Fossil resource scarcity	kg oil eq	75.13
Water consumption	m^3	0.33

The following table highlights that the impact from the **clinker production** and **electricity consumption** is a major contributor to the environment impact among all the other process.

Table 15: Environment Impact Contribution Different Process – PPC

Contribution (%)					
Impact Category	**Clinker**	**Gypsum**	**Flyash from CPP**	**Flyash**	**Electricity**
Global warming	91.88	0.54	0.003	1.22	5.62
Stratospheric ozone depletion	80.97	3.23	0.01	6.3	8.39
Ionizing radiation	70.81	4.45	0.02	9.4	13.54
Ozone formation, Human health	87.31	1.72	0.01	3.53	6.57

Fine particulate matter formation	65.84	10.76	0.01	6.6	14.84
Ozone formation, Terrestrial ecosystems	87.23	1.75	0.01	3.57	6.58
Terrestrial acidification	78.43	1.47	0.01	3.02	15.09
Freshwater eutrophication	80.55	0.27	0.002	0.57	16.46
Marine eutrophication	81.29	0.33	0.002	0.71	15.61
Terrestrial ecotoxicity	51.29	12.9	0.05	30.02	5.08
Freshwater ecotoxicity	75.57	1.38	0.01	3.09	17.63
Marine ecotoxicity	74.14	1.63	0.01	3.68	18.15
Human carcinogenic toxicity	76.62	1.87	0.01	4.24	15.26
Human non-carcinogenic toxicity	69.42	4.78	0.02	10.97	13.09
Land use	71.99	4.02	0.01	8.94	13.29
Mineral resource scarcity	93.99	4.68	0.003	0.74	0.52
Fossil resource scarcity	78.56	1.46	0.01	3.3	14.74
Water consumption	68.26	2.67	0.01	5.9	17.77

The following graph summaries the impact of various processes in production of one tone of PPC,

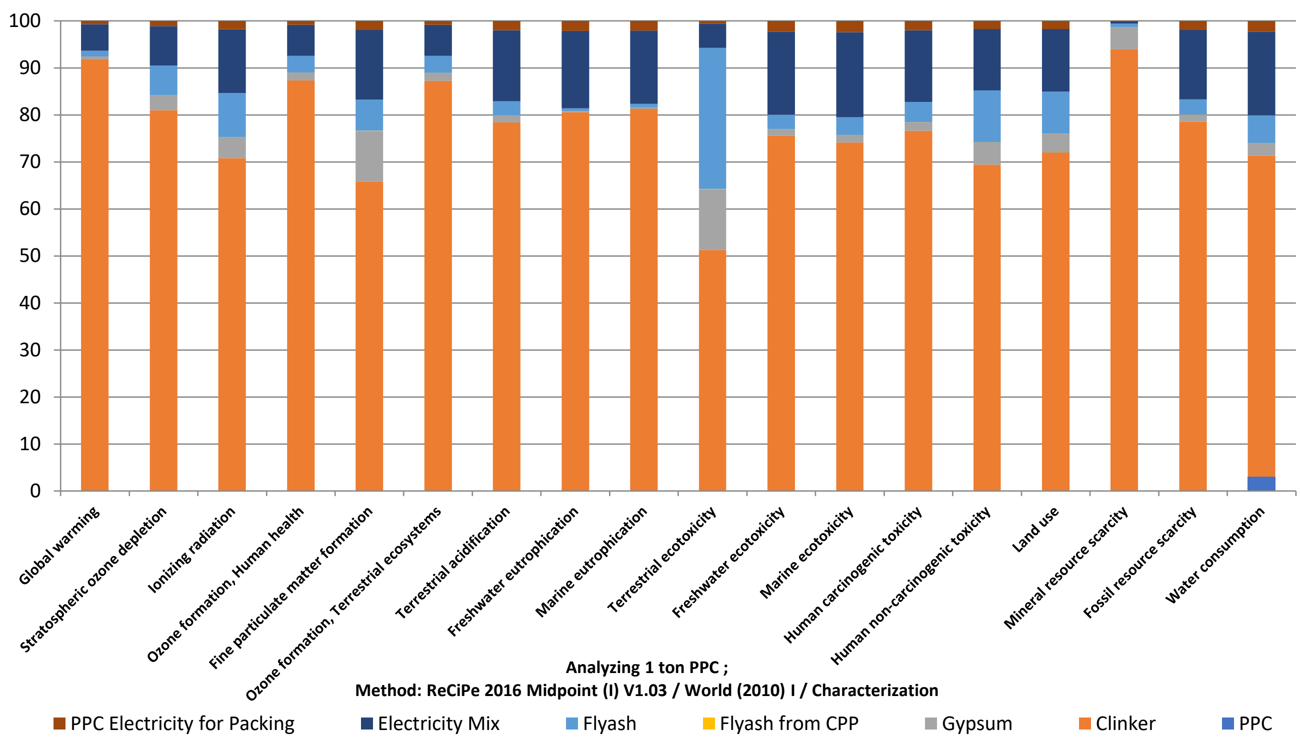

Figure 7: Impact Assessment – Characterization PPC

5.3 Average Cement - LCIA

For the 2021-22, the environmental impacts for one ton of average cement are highlighted in the table below:

Table 16: Environment Impact – Average Cement

Impact category	Unit	Average Cement
Global warming	kg CO_2 eq	763.64
Stratospheric ozone depletion	kg CFC-11 eq	0.00004
Ionizing radiation	kBq Co-60 eq	1.23
Ozone formation, Human health	kg NOx eq	1.13
Fine particulate matter formation	kg PM2.5 eq	0.05
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.13
Terrestrial acidification	kg SO2 eq	0.87
Freshwater eutrophication	kg P eq	0.13
Marine eutrophication	kg N eq	0.01
Terrestrial ecotoxicity	kg 1,4-DCB	133.30
Freshwater ecotoxicity	kg 1,4-DCB	4.21
Marine ecotoxicity	kg 1,4-DCB	1.46
Human carcinogenic toxicity	kg 1,4-DCB	0.04
Human non-carcinogenic toxicity	kg 1,4-DCB	1.01
Land use	m^2a crop eq	3.88
Mineral resource scarcity	kg Cu eq	1.65
Fossil resource scarcity	kg oil eq	93.43
Water consumption	m^3	0.40

The following table highlights that the impact of various types of cement and it can be seen as the share of **OPC** is more currently in overall product mix and thus is a major contributor in all type of environment impacts.

Table 17: Environment Impact Contribution – Different Type of Cement

%Contribution		
Impact Category	**OPC**	**PPC**
Global warming	91.88	0.54
Stratospheric ozone depletion	80.97	3.23
Ionizing radiation	70.81	4.45
Ozone formation, Human health	87.31	1.72

Fine particulate matter formation	65.84	10.76
Ozone formation, Terrestrial ecosystems	87.23	1.75
Terrestrial acidification	78.43	1.47
Freshwater eutrophication	80.55	0.27
Marine eutrophication	81.29	0.33
Terrestrial ecotoxicity	51.29	12.9
Freshwater ecotoxicity	75.57	1.38
Marine ecotoxicity	74.14	1.63
Human carcinogenic toxicity	76.62	1.87
Human non-carcinogenic toxicity	69.42	4.78
Land use	71.99	4.02
Mineral resource scarcity	93.99	4.68
Fossil resource scarcity	78.56	1.46
Water consumption	68.26	2.67

The following graph summaries the comparison of various cement and average cement produced at Sagar Cements Limited, Mattampally unit. On comparison, PPC has lower impact.

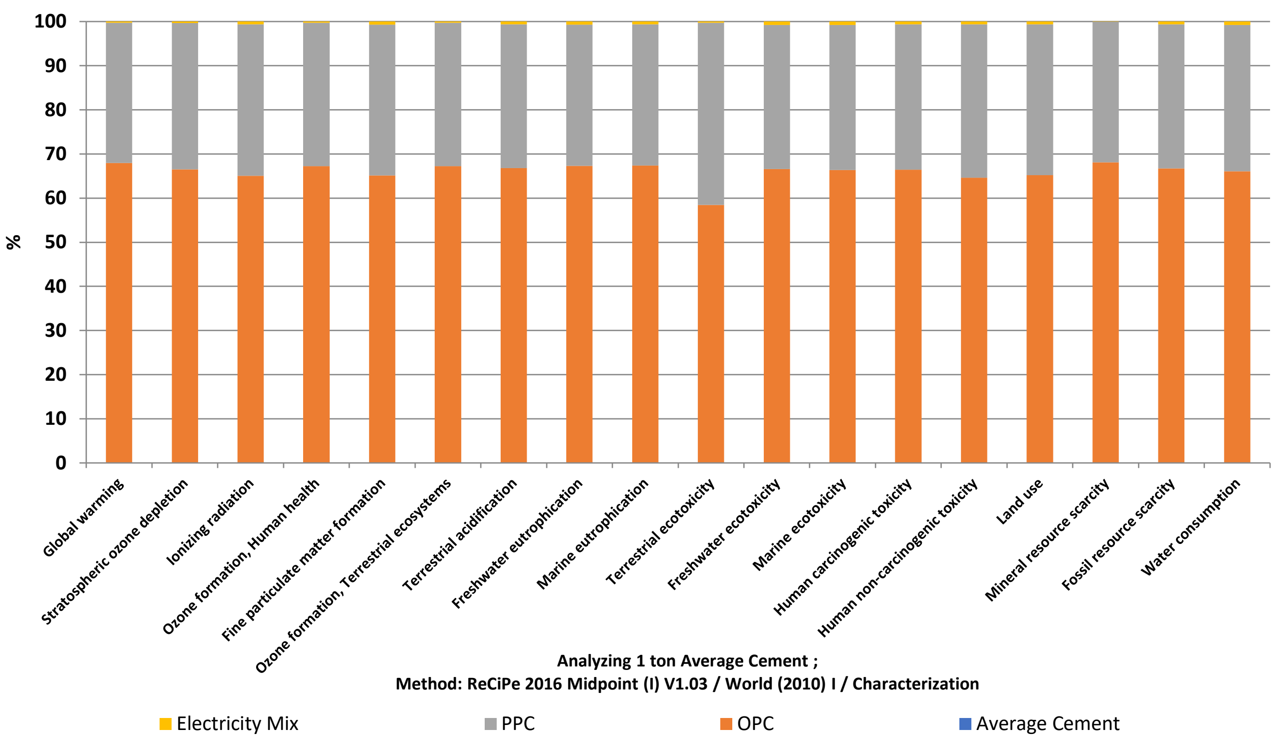

Figure 8: Environment Impact Comparison – Different Type of Cement

5.5 LCA Comparison – OPC vs. PPC

Sagar Cements Limited, Mattampally unit manufactures two types of cement mainly – OPC and PPC. Each type of cement has different mix of clinker, flyash, and gypsum because of which they have different environmental impacts and hotspots in their life cycle.

Global Warming

The OPC and PPC are compared on global warming environment impact in terms of its GHG emission intensity (kg CO_2 eq/ton of cement). The OPC emission intensity is 873 kg CO_2 eq/ton of OPC and the emission intensity of PPC is 599 kg CO_2 eq/ton of PPC. The primary reason for reduction is lower clinker factor for PPC as compared to OPC.

"PPC has 20% lower global warming impact as compared to OPC"

Acidification

The OPC and PPC are compared on acidification environment impact in terms of acidification potential (kg SO_2/ton of cement). The OPC emission intensity is 0.98 kg SO_2/ton of OPC and the impact of PPC is 0.7 kg SO_2/ton of PPC. The primary reason for reduction is lower clinker factor for PPC as compared to OPC, which has resulted in lower coal consumption, electricity consumption etc.

"PPC has 29% lower acidification impact as compared to OPC"

Terrestrial Ecotoxicity

The OPC and PPC are compared on their environment impact on terrestrial ecotoxicity in terms of kg 1,4-DCB/ton of cement). The terrestrial ecotoxicity potential of OPC is 131 kg 1,4-DCB/ton of OPC and the impact of PPC is 135 kg 1,4-DCB/ton of PPC. Here, PPC has a higher environmental impact than OPC because of the use of flyash.

OPC has 3% lower terrestrial ecotoxicity impact as compared to PPC"

Fossil Fuel Scarcity

The OPC and PPC are compared on their environment impact on fossil fuel scarcity in terms of kg oil eq/ton of cement). The scarcity of fossil fuel due to OPC is 104.95 kg oil eq/ton of OPC and the impact of PPC is 75.13 kg oil eq/ton of PPC. The primary reason for reduction is lower clinker factor for PPC as compared to OPC, which has resulted in lower coal consumption and electricity consumption.

"PPC has 28% lower impact on fossil fuel scarcity as compared to OPC"

6 Critical Review and Conclusion

The primary goal of critical review chapter is to discuss on various parameters like completeness of the data, sensitivity analysis and consistency check. In addition, this chapter provides quick insights on maximization of this study in future.

6.1 Completeness

LCA study for Sagar Cements Limited, Mattampally unit was carried out in accordance with the ISO 14044 standard. Data collection process was designed to cover all major impact sources considering the cut off criteria assigned for this study. Assumptions taken for the study are rationalized.

6.2 Consistency check

To check the consistency of data used for calculation, CII – Godrej GBC team has carried out the authentication and cross checked the numbers submitted with the publicly declared data available in open domain.

6.3 Way forward

Environmentally friendly manufacturing practice has been the contemporary vogue among industries. With ever increasing consciousness on environmental impacts among various stakeholders of industries, a need to understand the performance of a product arises. This LCA study will assist Sagar Cements Limited, Mattampally unit to develop a comprehensive model to eliminate the environmental risk associated with its production practices. Also, a study like this will create a platform to highlight the environmental performance of the product.

Going a step ahead, it will act as a strong communication tool in exhibiting the energy efficiency and environmental management practices. Indeed, this exposition would help Sagar Cements Limited, Mattampally unit to gain favorable advantage among its competitors and venture into new markets. Various scenarios have been modelled to understand the reduction in impacts.

6.3.1 Increasing Share of Renewable Energy (Non-Fossil Fuel Energy)

At present, the share of CPP in overall electricity consumption is 66% and Grid share is around 7% and use of non-renewable energy is round 1.4%. Sagar Cements Limited, Mattampally unit has already a sustainability plan in place and already targeting the increasing the share of Renewable energy including WHR that currently meets 26% of the electricity demand. Increasing the renewable energy (including WHR) share would result in reduction of grid share and CPP, thereby reducing the environmental impact. Following table summarizes the ideal case scenario if the unit reduces the grid & CPP dependency completely and switches to renewable energy.

Table 18: Increasing Share of Renewable Energy

Impact category	Unit	OPC Current Mix	OPC Proposed Mix	% impact reduction (OPC)	PPC Current Mix	PPC Proposed Mix	% impact reduction (PPC)
Global warming	kg CO_2 eq	873.38	800.17	-8%	598.68	545.17	-9%
Stratospheric ozone depletion	kg CFC-11 eq	0.00005	0.00004	-20%	0.00004	0.00003	-25%

Ionizing radiation	kBq Co-60 eq	1.34	1.23	-8%	1.04	0.97	-7%
Ozone formation, Human health	kg NOx eq	1.28	1.15	-10%	0.90	0.81	-10%
Fine particulate matter formation	kg PM2.5 eq	0.05	0.04	-20%	0.04	0.03	-25%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.28	1.16	-9%	0.91	0.82	-10%
Terrestrial acidification	kg SO2 eq	0.98	0.76	-22%	0.70	0.54	-23%
Freshwater eutrophication	kg P eq	0.14	0.11	-21%	0.10	0.07	-30%
Marine eutrophication	kg N eq	0.009	0.01	11%	0.01	0.005	-50%
Terrestrial ecotoxicity	kg 1,4-DCB	131.23	143.14	9%	135.42	153.56	13%
Freshwater ecotoxicity	kg 1,4-DCB	4.72	3.97	-16%	3.39	2.85	-16%
Marine ecotoxicity	kg 1,4-DCB	1.63	1.31	-20%	1.18	0.95	-19%
Human carcinogenic toxicity	kg 1,4-DCB	0.05	0.04	-20%	0.03	0.03	0%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.10	0.95	-14%	0.87	0.78	-10%
Land use	m^2a crop eq	4.26	4.21	-1%	3.27	3.29	1%
Mineral resource scarcity	kg Cu eq	1.89	1.91	1%	1.29	1.31	2%
Fossil resource scarcity	kg oil eq	104.95	80.68	-23%	75.13	57.38	-24%
Water consumption	m^3	0.45	0.4	-11%	0.33	0.30	-9%

"The major impact reduction would be seen in acidification, fossil fuel scarcity and fine partivulate formation due to less dependency on coal

However, due to high RE share, the land use and mineral resource scarcity increases for the installation of solar panels or construction of wind farms"

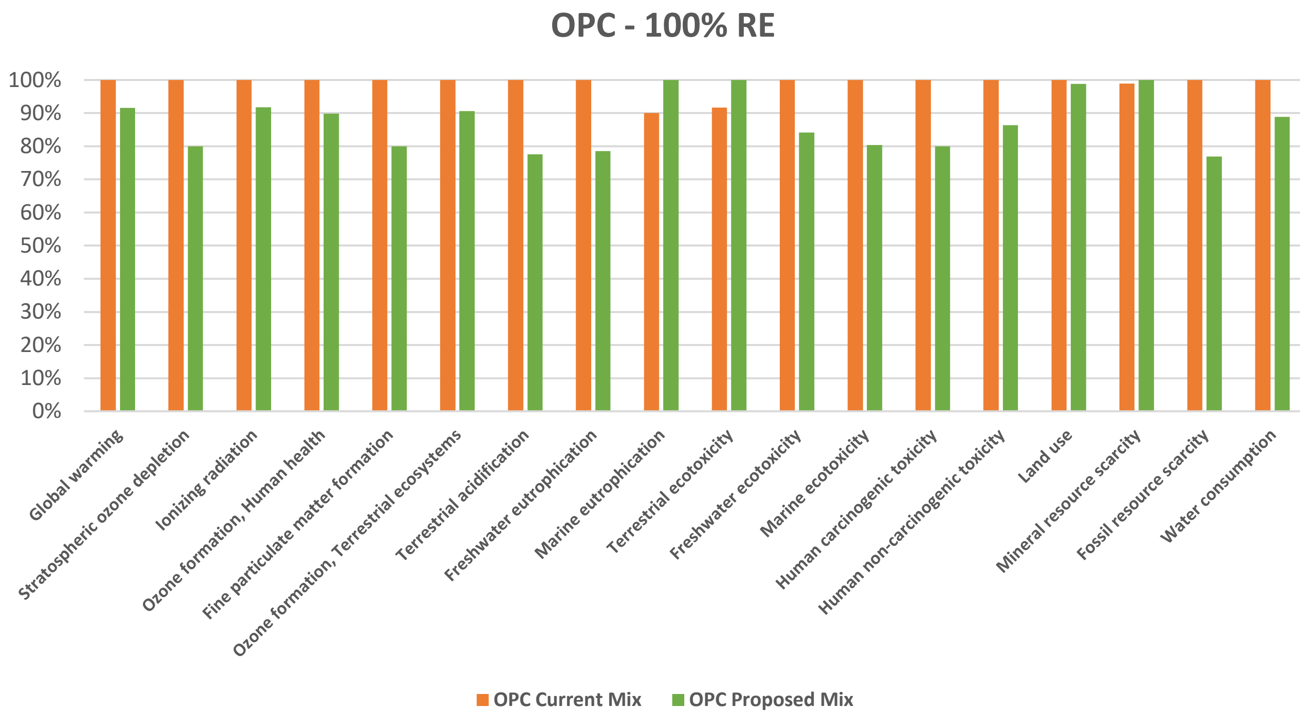

Figure 9: Impact of Increasing Share of RE in overall power mix for OPC

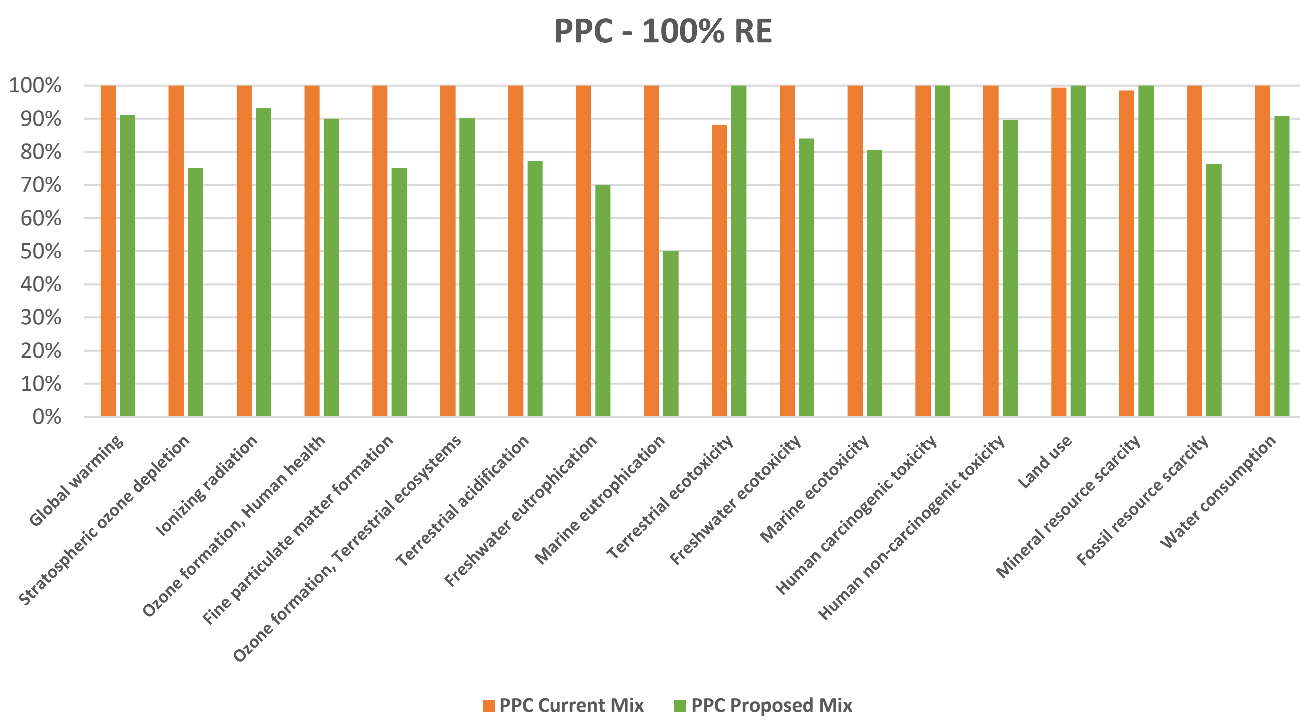

Figure 10: Impact of Increasing Share of RE in overall power mix for PPC

6.3.2 Energy Efficiency

At present the unit requires 112 kWh of electricity to produce 1 ton of cement (either OPC or PPC). Therefore, energy efficiency is an important area for energy and cost reduction. The unit can target improving the energy efficiency by implementing various energy conservation measures (separator performance, grinding media, VFD, fan efficiency, etc.). Improving the energy efficiency by 10%, 20% & 30% can result in reducing the environmental impact and following tables highlights the improvement for key environment impact category for OPC & PPC is summarized:

Table 19: Electrical Energy Efficiency – Improvement for OPC

Impact category	Unit	OPC Current Mix	OPC – 10% EE	OPC – 20% EE	OPC – 30% EE	% impact reduction (OPC)		
						10% EE	20% EE	30% EE
Global warming	kg CO_2 eq	873.38	868.97	864.56	860.15	-1%	-1%	-2%
Stratospheric ozone depletion	kg CFC-11 eq	0.00005	0.00005	0.00005	0.00005	0%	0%	0%
Ionizing radiation	kBq Co-60 eq	1.34	1.33	1.31	1.29	-1%	-2%	-4%
Ozone formation, Human health	kg NOx eq	1.28	1.27	1.26	1.25	-1%	-2%	-2%
Fine particulate matter formation	kg PM2.5 eq	0.05	0.05	0.05	0.05	0%	0%	0%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.28	1.27	1.27	1.26	-1%	-1%	-2%
Terrestrial acidification	kg SO2 eq	0.98	0.97	0.96	0.94	-1%	-2%	-4%
Freshwater eutrophication	kg P eq	0.14	0.14	0.14	0.14	0%	0%	0%
Marine eutrophication	kg N eq	0.009	0.01	0.01	0.01	11%	11%	11%
Terrestrial ecotoxicity	kg 1,4-DCB	131.23	130.33	129.43	128.53	-1%	-1%	-2%
Freshwater ecotoxicity	kg 1,4-DCB	4.72	4.64	4.56	4.49	-2%	-3%	-5%
Marine ecotoxicity	kg 1,4-DCB	1.63	1.60	1.57	1.54	-2%	-4%	-6%
Human carcinogenic toxicity	kg 1,4-DCB	0.05	0.05	0.05	0.05	0%	0%	0%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.10	1.09	1.07	1.06	-1%	-3%	-4%
Land use	m^2a crop eq	4.26	4.21	4.15	4.09	-1%	-3%	-4%
Mineral resource scarcity	kg Cu eq	1.89	1.89	1.89	1.88	0%	0%	-1%

Fossil resource scarcity	kg oil eq	104.95	103.50	102.05	100.60	-1%	-3%	-4%
Water consumption	m^3	0.45	0.44	0.43	0.42	-2%	-4%	-7%

Table 20: Electrical Energy Efficiency – Improvement for PPC

Impact category	Unit	PPC Current Mix	PPC – 10% EE	PPC – 20% EE	PPC – 30% EE	% impact reduction (PPC)		
						10% EE	20% EE	30% EE
Global warming	kg CO_2 eq	598.68	595.31	591.95	588.58	-1%	-1%	-2%
Stratospheric ozone depletion	kg CFC-11 eq	0.00004	0.00004	0.00004	0.00004	0%	0%	0%
Ionizing radiation	kBq Co-60 eq	1.04	1.02	1.01	1.00	-2%	-3%	-4%
Ozone formation, Human health	kg NOx eq	0.90	0.90	0.89	0.88	0%	-1%	-2%
Fine particulate matter formation	kg PM2.5 eq	0.04	0.04	0.04	0.04	0%	0%	0%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.91	0.90	0.89	0.89	-1%	-2%	-2%
Terrestrial acidification	kg SO2 eq	0.70	0.69	0.68	0.67	-1%	-3%	-4%
Freshwater eutrophication	kg P eq	0.10	0.10	0.10	0.09	0%	0%	-10%
Marine eutrophication	kg N eq	0.01	0.01	0.01	0.01	0%	0%	0%
Terrestrial ecotoxicity	kg 1,4-DCB	135.42	134.73	134.05	133.36	-1%	-1%	-2%
Freshwater ecotoxicity	kg 1,4-DCB	3.39	3.33	3.27	3.21	-2%	-4%	-5%
Marine ecotoxicity	kg 1,4-DCB	1.18	1.16	1.14	1.11	-2%	-3%	-6%
Human carcinogenic toxicity	kg 1,4-DCB	0.03	0.03	0.03	0.03	0%	0%	0%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.87	0.86	0.85	0.83	-1%	-2%	-5%
Land use	m^2a crop eq	3.27	3.23	3.18	3.14	-1%	-3%	-4%
Mineral resource scarcity	kg Cu eq	1.29	1.29	1.29	1.29	0%	0%	0%
Fossil resource scarcity	kg oil eq	75.13	74.02	72.91	71.80	-1%	-3%	-4%
Water consumption	m^3	0.33	0.32	0.32	0.31	-3%	-3%	-6%

Table 21: Electrical Energy Efficiency – Improvement for Average Cement

Impact category	Unit	Average Cement Current Mix	Average Cement – 20% EE	% impact reduction
Global warming	kg CO_2 eq	763.64	755.67	-1%
Stratospheric ozone depletion	kg CFC-11 eq	0.00004	0.00004	0%
Ionizing radiation	kBq Co-60 eq	1.23	1.19	-3%
Ozone formation, Human health	kg NOx eq	1.13	1.11	-2%
Fine particulate matter formation	kg PM2.5 eq	0.05	0.05	0%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.13	1.12	-1%
Terrestrial acidification	kg SO2 eq	0.87	0.85	-2%
Freshwater eutrophication	kg P eq	0.13	0.12	-8%
Marine eutrophication	kg N eq	0.01	0.01	0%
Terrestrial ecotoxicity	kg 1,4-DCB	133.30	131.67	-1%
Freshwater ecotoxicity	kg 1,4-DCB	4.21	4.07	-3%
Marine ecotoxicity	kg 1,4-DCB	1.46	1.41	-3%
Human carcinogenic toxicity	kg 1,4-DCB	0.04	0.04	0%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.01	0.99	-2%
Land use	m^2a crop eq	3.88	3.78	-3%
Mineral resource scarcity	kg Cu eq	1.65	1.64	-1%
Fossil resource scarcity	kg oil eq	93.43	90.81	-3%
Water consumption	m^3	0.40	0.39	-3%

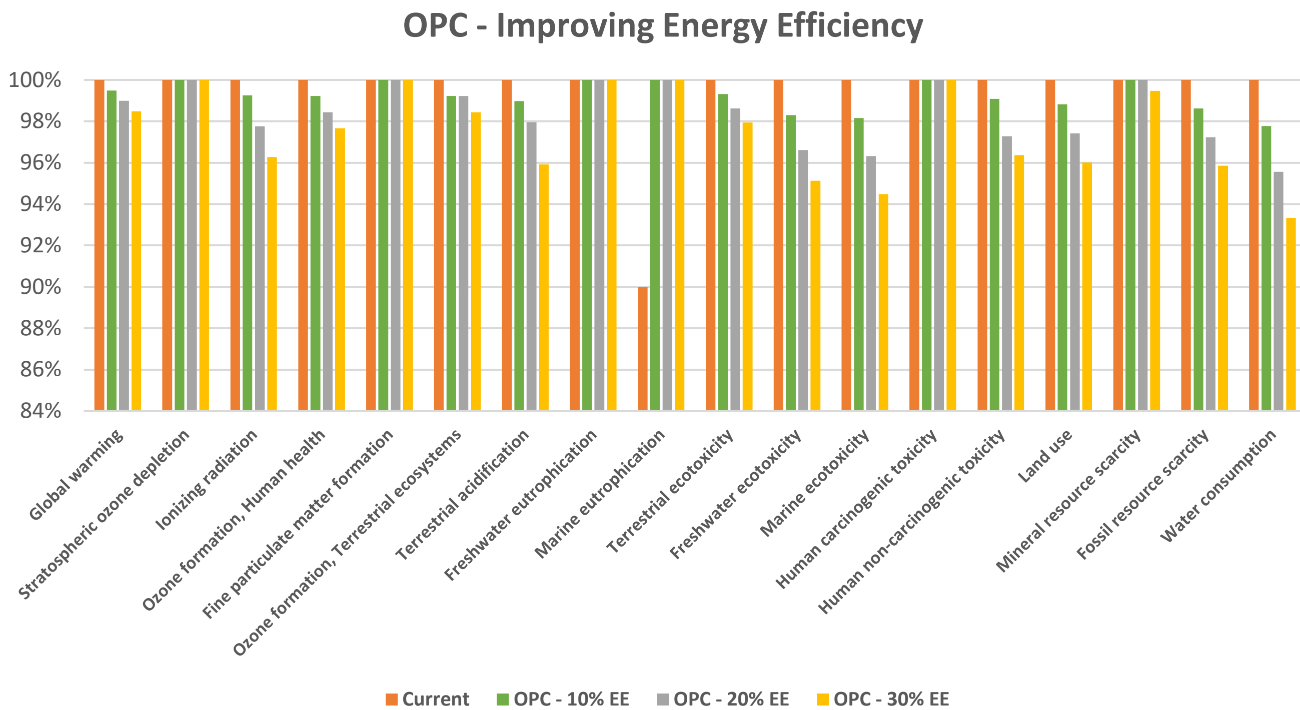

Figure 11: Impact of improving EE on OPC Production

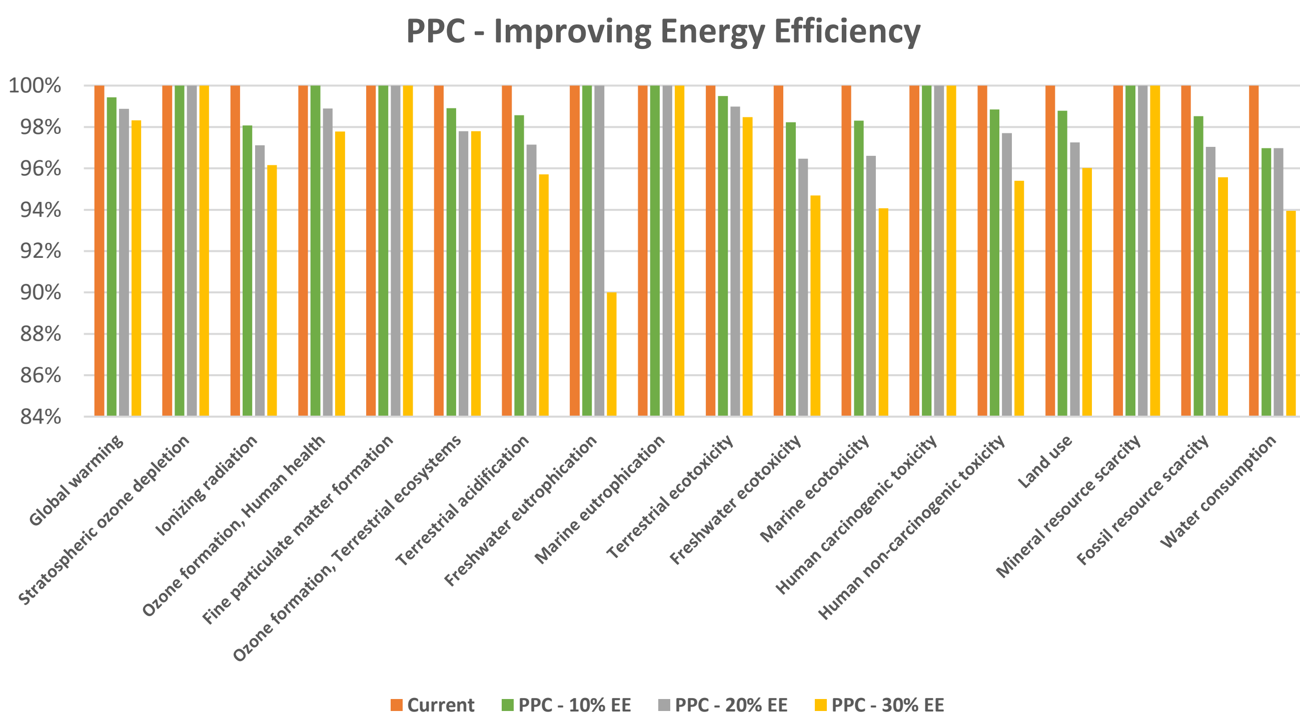

Figure 12: Impact of improving EE on PPC Production

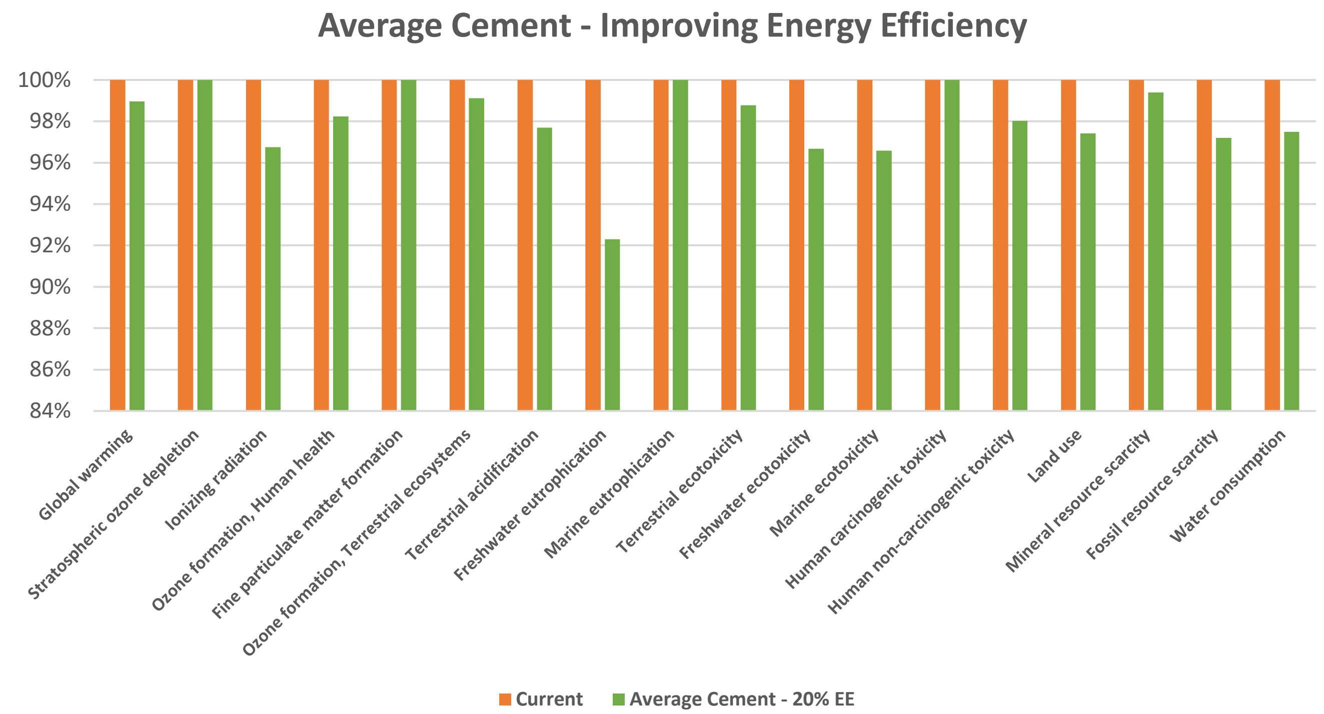

Figure 13: Impact of improving EE on Average Cement Production

"Every 10% increasing in energy efficiency would result in reduction of key environment impact in range of 1-3%, thus resulting in overall reduction of environment impact through energy efficiency in electrical systems"

6.3.3 Increasing Manufacturing of PPC

At present, Sagar Cements Limited, Mattampally unit is manufacturing three type of cement – OPC and PPC. Based on current production mix, the share of OPC is on the higher side compared to PPC.

OPC cement utilizes more natural resources such as limestone, fuel, minerals, and additives as compared to PPC which utilizes flyash. Utilization of more flyash would result in reduction of clinker consumption, thus resulting in lower environmental impact, as flyash comes without many environmental burdens as they are considered as waste in their main process.

With increasing the share of PPC and reducing the share of OPC in overall product mix, it can reduce the environment impact significantly. Increasing PPC production by 5% can result in significant environment impact reduction and following table summarizes the impact.

Table 22: Impact Reduction - Proposed Product Mix

Impact category	Unit	Average Current Mix	Average Cement Proposed Mix	% impact reduction
Global warming	kg CO_2 eq	763.64	757.87	-1%
Stratospheric ozone depletion	kg CFC-11 eq	0.00004	0.00004	0%

Ionizing radiation	kBq Co-60 eq	1.23	1.22	-1%
Ozone formation, Human health	kg NOx eq	1.13	1.12	-1%
Fine particulate matter formation	kg PM2.5 eq	0.05	0.05	0%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.13	1.13	0%
Terrestrial acidification	kg SO2 eq	0.87	0.87	0%
Freshwater eutrophication	kg P eq	0.13	0.13	0%
Marine eutrophication	kg N eq	0.01	0.01	0%
Terrestrial ecotoxicity	kg 1,4-DCB	133.30	133.39	0%
Freshwater ecotoxicity	kg 1,4-DCB	4.21	4.18	-1%
Marine ecotoxicity	kg 1,4-DCB	1.46	1.45	-1%
Human carcinogenic toxicity	kg 1,4-DCB	0.04	0.04	0%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.01	1.01	0%
Land use	m^2a crop eq	3.88	3.86	-1%
Mineral resource scarcity	kg Cu eq	1.65	1.63	-1%
Fossil resource scarcity	kg oil eq	93.43	92.81	-1%
Water consumption	m^3	0.40	0.40	0%

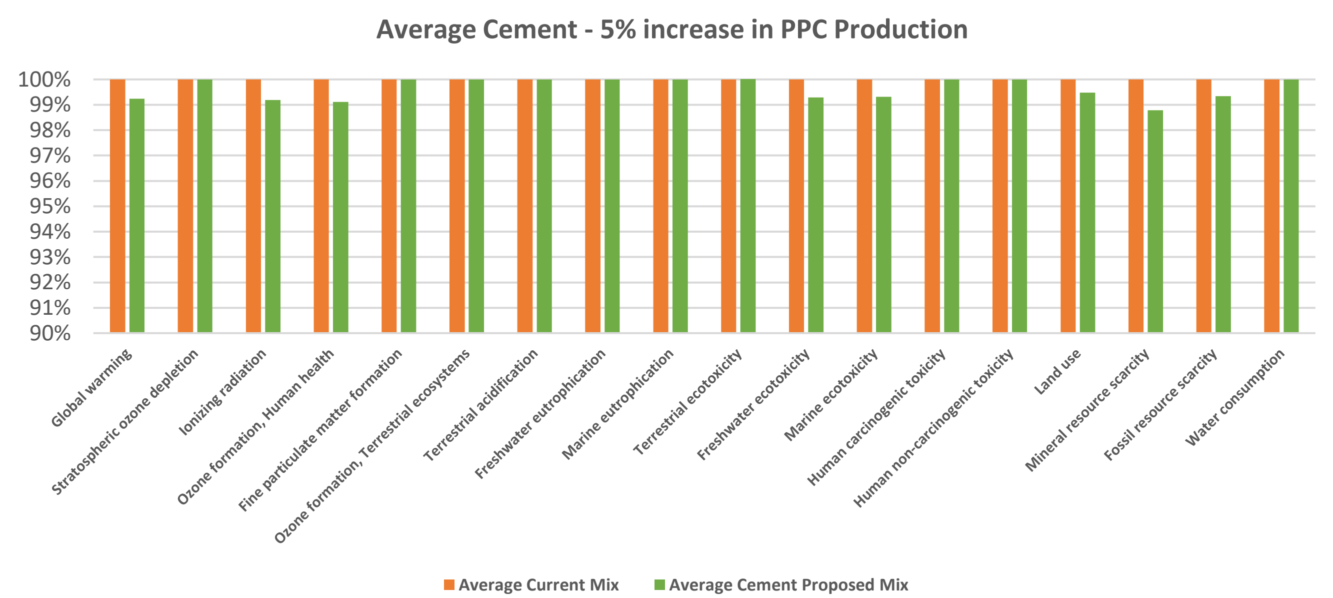

Figure 14: Impact of increasing PPC production in the product mix

6.3.4 Increasing RE share & Improving Energy Efficiency

As seen from previous sections, increasing RE share in the electricity mix and improving energy efficiency of the electrical utilities has significant improvement in the environmental impact of OPC, PPC & average cement. Following table summarizes the impact of increasing RE share by 50% and by improving the energy efficiency by 15%.

Table 23: Impact Reduction – Increase in RE share & Improving EE - OPC

Impact category	Unit	OPC Current Mix	OPC Proposed Mix	% impact reduction
Global warming	kg CO_2 eq	873.38	829.00	-5%
Stratospheric ozone depletion	kg CFC-11 eq	0.00005	0.00005	0%
Ionizing radiation	kBq Co-60 eq	1.34	1.11	-17%
Ozone formation, Human health	kg NOx eq	1.28	1.20	-6%
Fine particulate matter formation	kg PM2.5 eq	0.05	0.04	-20%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.28	1.20	-6%
Terrestrial acidification	kg SO2 eq	0.98	0.85	-13%
Freshwater eutrophication	kg P eq	0.14	0.12	-14%
Marine eutrophication	kg N eq	0.009	0.01	11%
Terrestrial ecotoxicity	kg 1,4-DCB	131.23	124.79	-5%
Freshwater ecotoxicity	kg 1,4-DCB	4.72	4.14	-12%
Marine ecotoxicity	kg 1,4-DCB	1.63	1.40	-14%
Human carcinogenic toxicity	kg 1,4-DCB	0.05	0.04	-20%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.10	0.98	-11%
Land use	m^2a crop eq	4.26	3.74	-12%
Mineral resource scarcity	kg Cu eq	1.89	1.89	0%
Fossil resource scarcity	kg oil eq	104.95	90.67	-14%
Water consumption	m^3	0.45	0.38	-16%

Table 24: Impact Reduction – Increase in RE share & Improving EE - PPC

Impact category	Unit	PPC Current Mix	PPC Proposed Mix	% impact reduction
Global warming	kg CO_2 eq	598.68	566.88	-5%
Stratospheric ozone depletion	kg CFC-11 eq	0.00004	0.00003	-25%
Ionizing radiation	kBq Co-60 eq	1.04	0.89	-14%
Ozone formation, Human health	kg NOx eq	0.90	0.85	-6%

Fine particulate matter formation	kg PM2.5 eq	0.04	0.03	-25%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.91	0.85	-7%
Terrestrial acidification	kg SO2 eq	0.70	0.60	-14%
Freshwater eutrophication	kg P eq	0.10	0.08	-20%
Marine eutrophication	kg N eq	0.01	0.01	0%
Terrestrial ecotoxicity	kg 1,4-DCB	135.42	139.72	3%
Freshwater ecotoxicity	kg 1,4-DCB	3.39	2.98	-12%
Marine ecotoxicity	kg 1,4-DCB	1.18	1.02	-14%
Human carcinogenic toxicity	kg 1,4-DCB	0.03	0.03	0%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.87	0.79	-9%
Land use	m^2a crop eq	3.27	2.94	-10%
Mineral resource scarcity	kg Cu eq	1.29	1.30	1%
Fossil resource scarcity	kg oil eq	75.13	64.90	-14%
Water consumption	m^3	0.33	0.28	-15%

Table 25: Impact Reduction – Increase in RE share & Improving EE – Average Cement

Impact category	Unit	Average Cement Current Mix	Average Cement Proposed Mix	% impact reduction
Global warming	kg CO_2 eq	763.64	723.41	-5%
Stratospheric ozone depletion	kg CFC-11 eq	0.00004	0.00004	0%
Ionizing radiation	kBq Co-60 eq	1.23	1.02	-17%
Ozone formation, Human health	kg NOx eq	1.13	1.06	-6%
Fine particulate matter formation	kg PM2.5 eq	0.05	0.04	-20%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.13	1.06	-6%
Terrestrial acidification	kg SO2 eq	0.87	0.75	-14%
Freshwater eutrophication	kg P eq	0.13	0.11	-15%
Marine eutrophication	kg N eq	0.01	0.01	0%
Terrestrial ecotoxicity	kg 1,4-DCB	133.30	131.09	-2%
Freshwater ecotoxicity	kg 1,4-DCB	4.21	3.69	-12%
Marine ecotoxicity	kg 1,4-DCB	1.46	1.25	-14%

Human carcinogenic toxicity	kg 1,4-DCB	0.04	0.04	0%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.01	0.91	-10%
Land use	m^2a crop eq	3.88	3.42	-12%
Mineral resource scarcity	kg Cu eq	1.65	1.65	0%
Fossil resource scarcity	kg oil eq	93.43	80.49	-14%
Water consumption	m^3	0.40	0.34	-15%

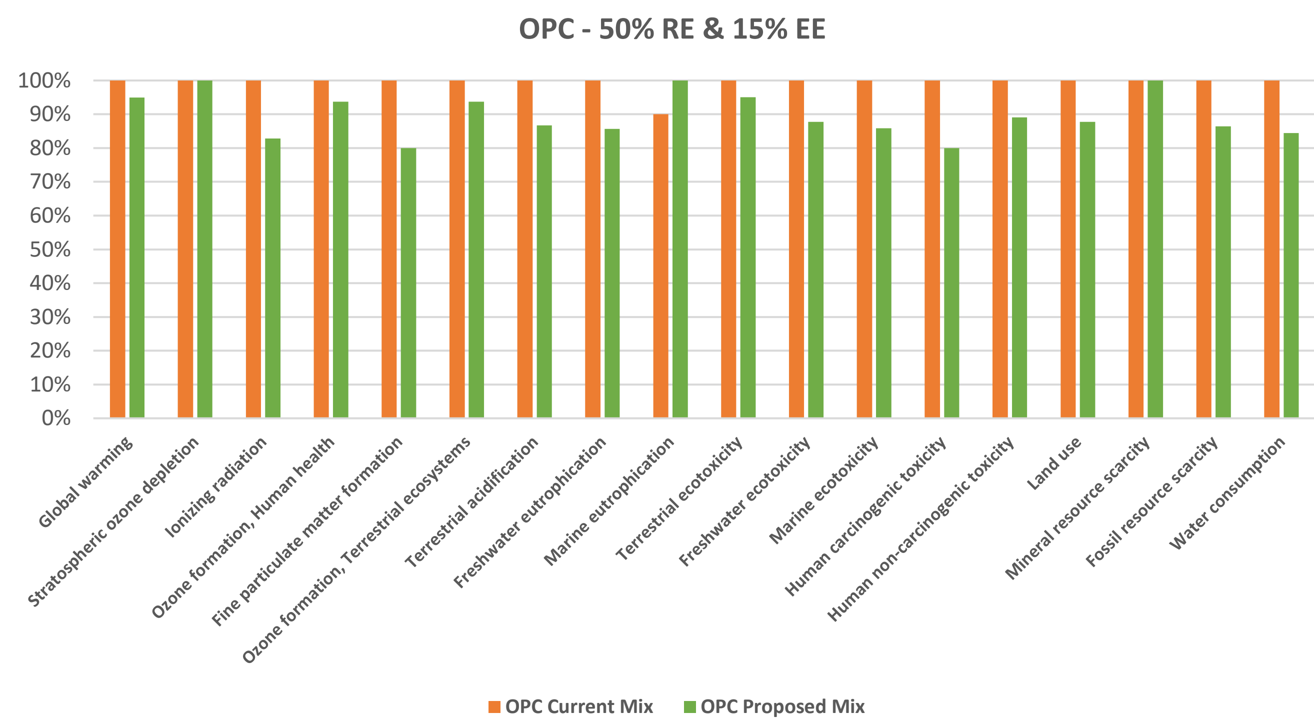

Figure 15: Impact of increasing RE Share to 50% and improving energy efficiency by 15% - OPC

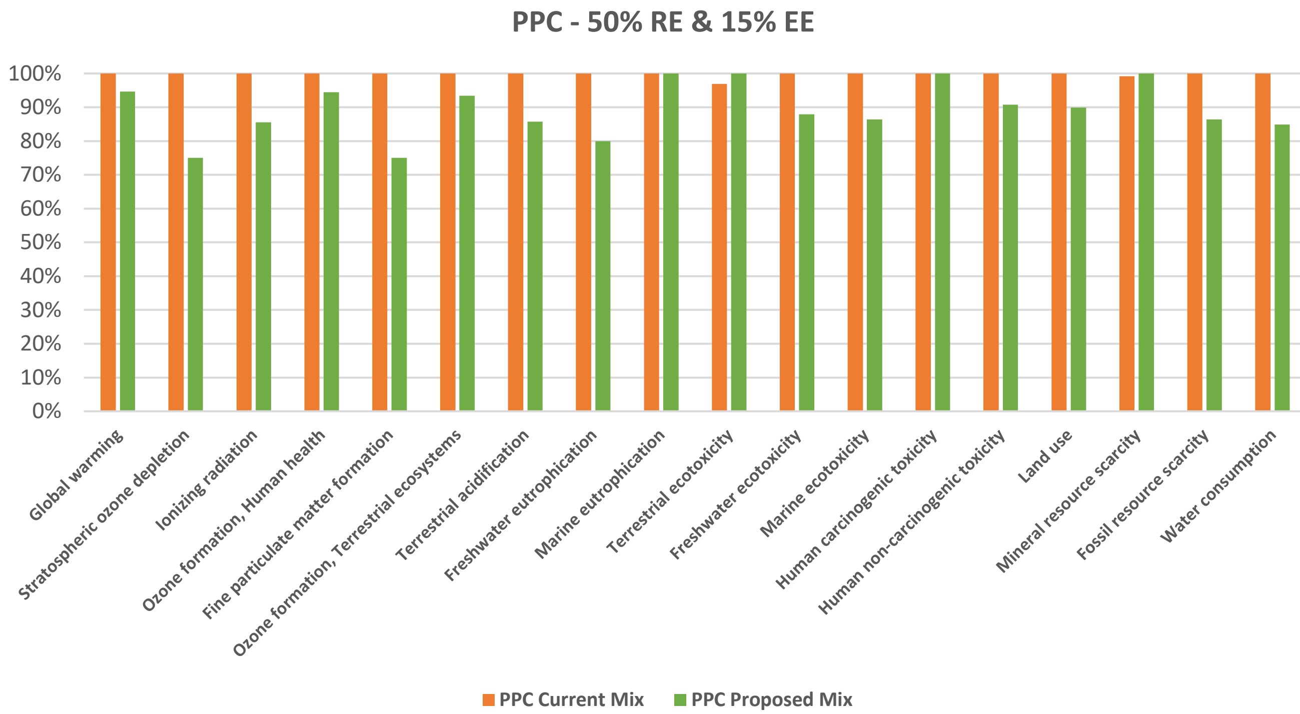

Figure 16: Impact of increasing RE Share to 50% and improving energy efficiency by 15% - PPC

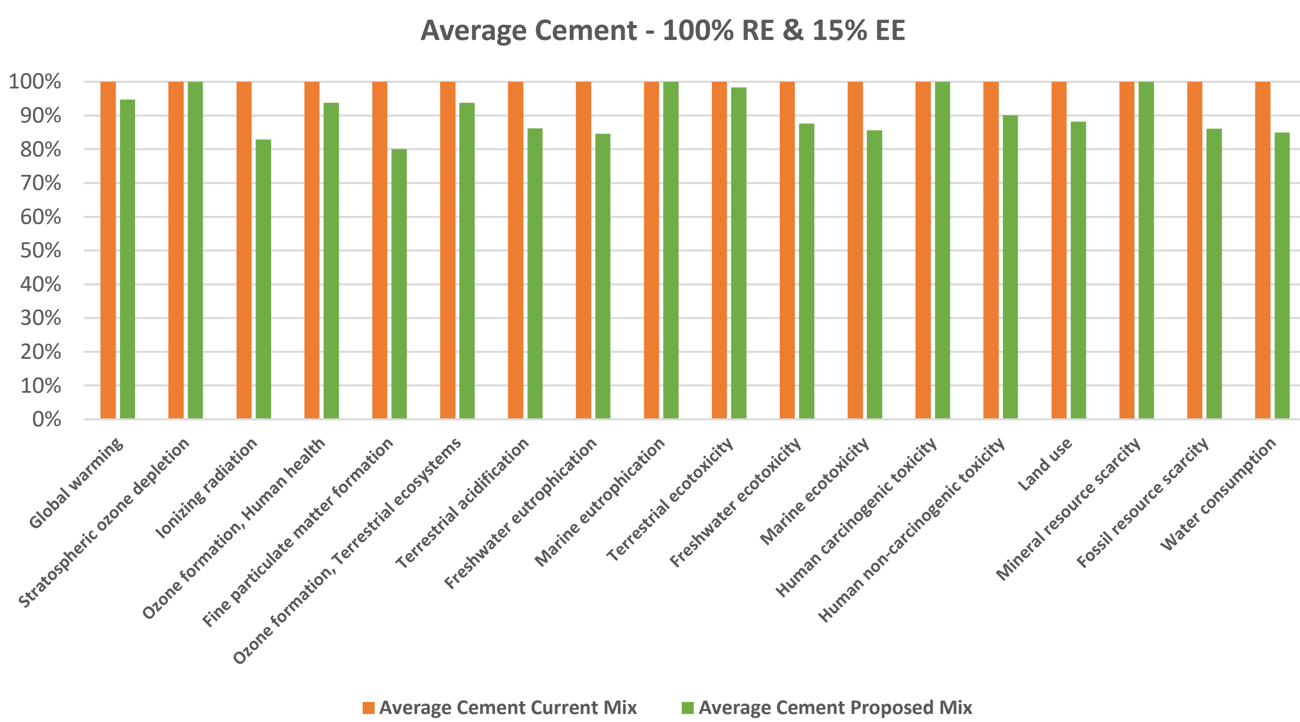

Figure 17: Impact of increasing RE Share to 50% and improving energy efficiency by 15% - Average Cement

6.3.5 Thermal Energy Efficiency

Cement production requires raw materials to be heated to 1450°C, making it an energy-intensive process, even though thermal energy accounts for just around 35% of the cement industry's CO_2 emissions. The highest energy efficiency today - about 3,300 MJ/t clinker - may be attained with preheater kilns with precalciners under optimised and consistent conditions (PH-PC). Newer PH-PC kilns offer a larger output capacity than earlier installations, which adds to increased energy efficiency in the sector. Waste Heat Recovery is another area where improvement may be achieved (WHR). The biggest disadvantage of employing WHR is the initial expenditure and the lengthy payback time, which is depending on local electricity cost. Following tables summarizes the environmental impact of improving thermal energy efficiency by 5% & 10% for OPC & PPC production.

Table 26: Impact of improving thermal energy efficiency - OPC

Impact category	Unit	OPC Current Mix	OPC – 5% red in TE	OPC – 10% red in TE	%impact reduction	
					OPC – 5% red in TE	OPC – 10% red in TE
Global warming	kg CO_2 eq	873.38	864.57	717.10	-1%	-17%
Stratospheric ozone depletion	kg CFC-11 eq	0.00005	0.00005	0.00005	0%	0%
Ionizing radiation	kBq Co-60 eq	1.34	1.32	1.30	-2%	-1%
Ozone formation, Human health	kg NOx eq	1.28	1.27	1.26	-1%	-1%
Fine particulate matter formation	kg PM2.5 eq	0.05	0.053	0.052	5%	-1%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.28	1.27	1.27	-1%	-1%
Terrestrial acidification	kg SO2 eq	0.98	0.97	0.96	-1%	-1%
Freshwater eutrophication	kg P eq	0.14	0.14	0.13	-2%	-3%
Marine eutrophication	kg N eq	0.009	0.01	0.01	-6%	-3%
Terrestrial ecotoxicity	kg 1,4-DCB	131.23	129.54	128.51	-1%	-1%
Freshwater ecotoxicity	kg 1,4-DCB	4.72	4.54	4.43	-4%	-2%
Marine ecotoxicity	kg 1,4-DCB	1.63	1.57	1.53	-4%	-2%
Human carcinogenic toxicity	kg 1,4-DCB	0.05	0.05	0.04	-9%	-3%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.10	1.07	1.05	-3%	-2%
Land use	m^2a crop eq	4.26	4.12	4.03	-3%	-2%
Mineral resource scarcity	kg Cu eq	1.89	1.89	1.88	0%	0%
Fossil resource scarcity	kg oil eq	104.95	101.02	98.51	-4%	-2%
Water consumption	m^3	0.45	0.44	0.43	-3%	-1%

Table 27: Impact of improving thermal energy efficiency - PPC

Impact category	Unit	PPC Current Mix	PPC – 5% red in TE	PPC – 10% red in TE	%impact reduction	
					PPC – 5% red in TE	PPC – 10% red in TE
Global warming	kg CO_2 eq	598.68	592.79	494.21	-1%	-17%
Stratospheric ozone depletion	kg CFC-11 eq	0.000036	0.000036	0.000035	-2%	-3%
Ionizing radiation	kBq Co-60 eq	1.04	1.02	1.01	-2%	-3%
Ozone formation, Human health	kg NOx eq	0.90	0.89	0.89	-1%	-1%
Fine particulate matter formation	kg PM2.5 eq	0.041	0.040	0.040	-1%	-2%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.91	0.90	0.89	-1%	-1%
Terrestrial acidification	kg SO2 eq	0.70	0.69	0.68	-2%	-3%
Freshwater eutrophication	kg P eq	0.10	0.10	0.09	-4%	-7%
Marine eutrophication	kg N eq	0.01	0.01	0.01	-4%	-7%
Terrestrial ecotoxicity	kg 1,4-DCB	135.42	134.29	133.60	-1%	-1%
Freshwater ecotoxicity	kg 1,4-DCB	3.39	3.27	3.19	-4%	-6%
Marine ecotoxicity	kg 1,4-DCB	1.18	1.14	1.11	-3%	-6%
Human carcinogenic toxicity	kg 1,4-DCB	0.03	0.03	0.03	-4%	-6%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.87	0.85	0.83	-2%	-4%
Land use	m^2a crop eq	3.27	3.17	3.11	-3%	-5%
Mineral resource scarcity	kg Cu eq	1.29	1.29	1.29	0%	0%
Fossil resource scarcity	kg oil eq	75.13	72.49	70.82	-4%	-6%
Water consumption	m^3	0.33	0.32	0.32	-2%	-3%

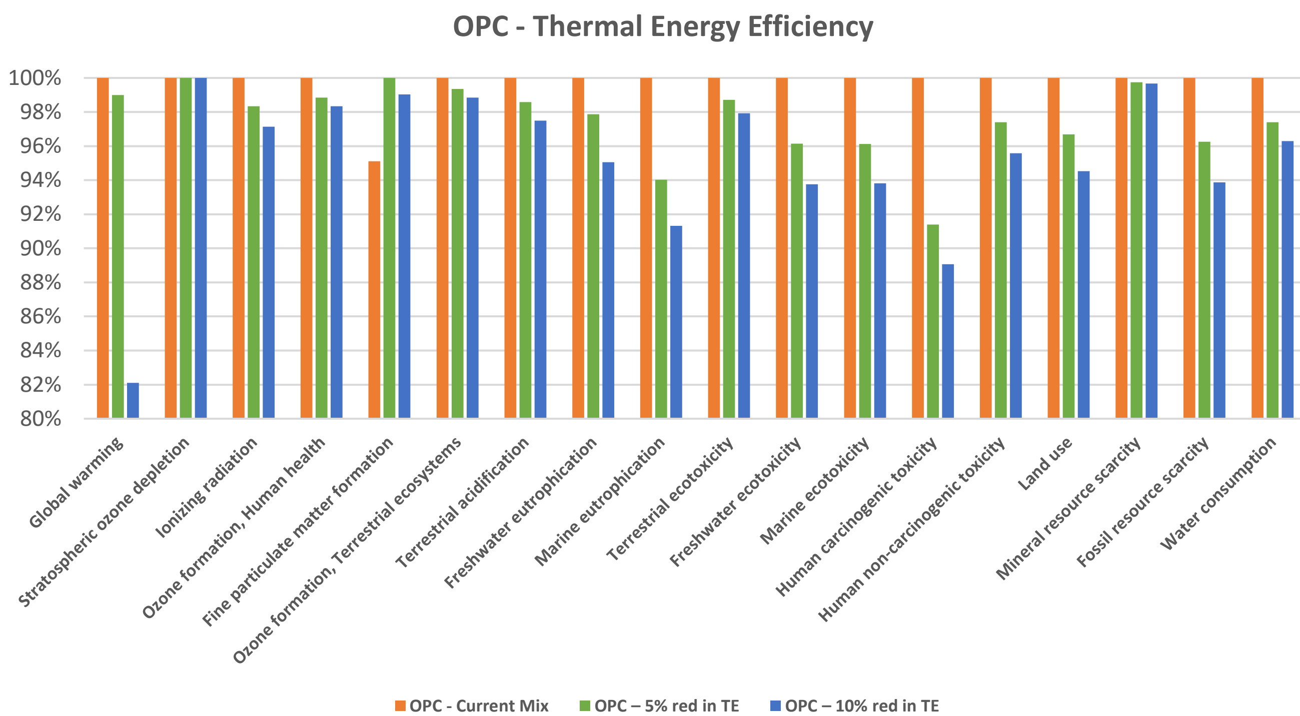

Figure 18: Impact of improving thermal energy efficiency – OPC

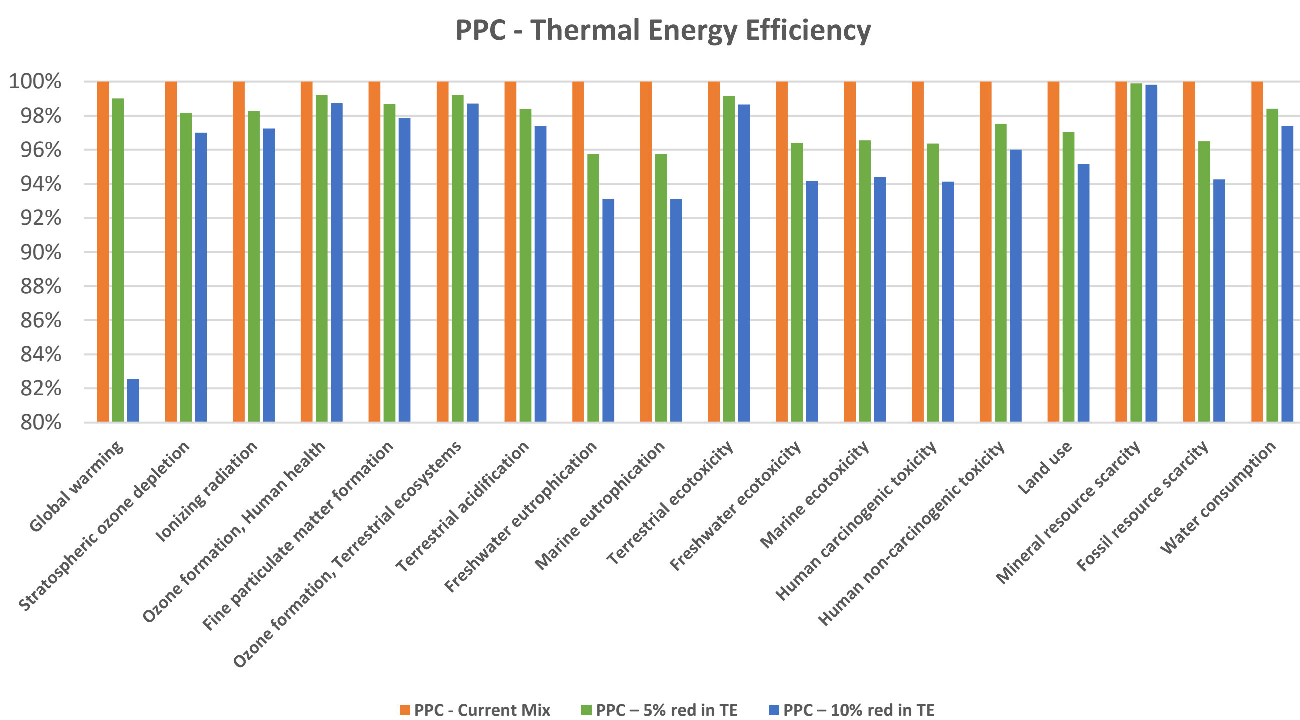

Figure 19: Impact of improving thermal energy efficiency – PPC

6.3.6 Alternative Fuels & Raw Materials

Cement production is resource-exhaustive and currently a mix of coal, pet coke, biomass and waste materials are used as a fuel source. The use of alternative fuels such as biomass or waste materials has a direct influence on the carbon footprint of the sector, and while the industry presently uses considerable amounts of such materials, this may increase in the future. Because of the cement industry's specific process and energy requirements, fuel blends that would not be viable for many other sectors can be used. The capacity to combine fossil fuels such as coal or gas with waste materials, biomass, and industrial by-products is advantageous in terms of both fossil fuel scarcity and resource efficiency.

Following tables summarizes the environmental impact of increasing AFR share by 15% for OPC & PPC production.

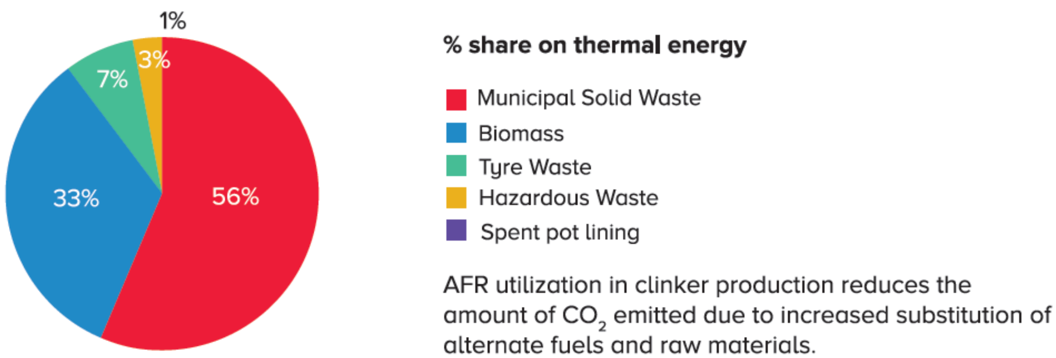

Figure 20: Alternate fuel and raw materials (AFR) usage in clinker

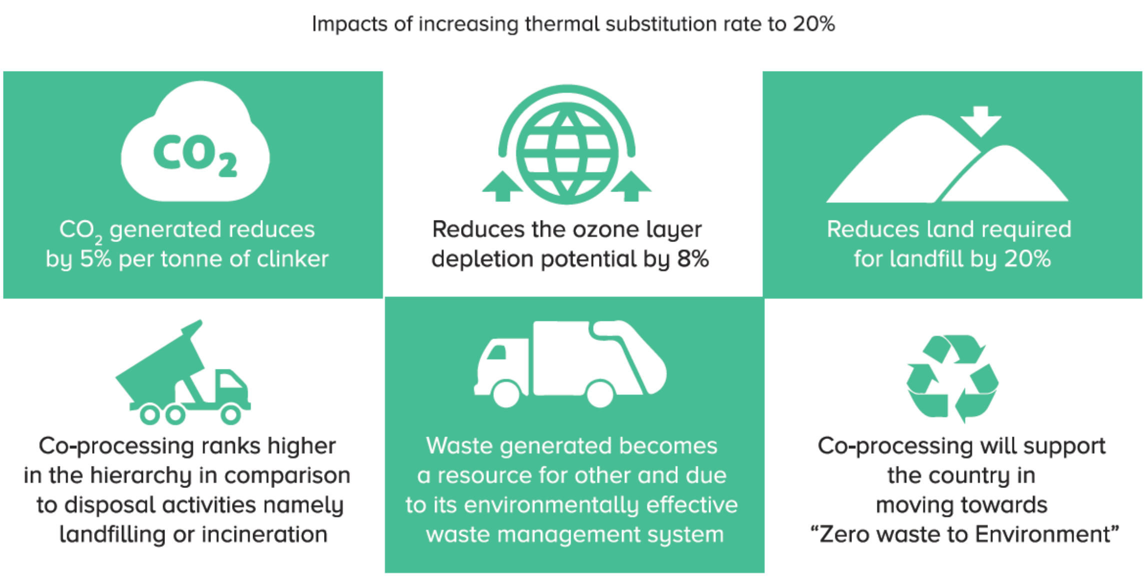

Figure 21: Benefits of using AFR

Table 28: Impact of increasing AFR - OPC

Impact category	Unit	OPC Current Mix	OPC Proposed Mix	% impact reduction
Global warming	kg CO_2 eq	873.38	821.56	-6%
Stratospheric ozone depletion	kg CFC-11 eq	0.00005	0.00005	0%

Ionizing radiation	kBq Co-60 eq	1.34	1.21	-10%
Ozone formation, Human health	kg NOx eq	1.28	1.23	-4%
Fine particulate matter formation	kg PM2.5 eq	0.05	0.05	0%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.28	1.24	-3%
Terrestrial acidification	kg SO2 eq	0.98	0.92	-7%
Freshwater eutrophication	kg P eq	0.14	0.12	-13%
Marine eutrophication	kg N eq	0.009	0.01	-17%
Terrestrial ecotoxicity	kg 1,4-DCB	131.23	121.47	-7%
Freshwater ecotoxicity	kg 1,4-DCB	4.72	4.07	-14%
Marine ecotoxicity	kg 1,4-DCB	1.63	1.41	-13%
Human carcinogenic toxicity	kg 1,4-DCB	0.05	0.04	-18%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.1	0.97	-12%
Land use	m^2a crop eq	4.26	3.69	-13%
Mineral resource scarcity	kg Cu eq	1.89	1.88	-1%
Fossil resource scarcity	kg oil eq	104.95	89.22	-15%
Water consumption	m^3	0.45	0.41	-9%

Table 29: Impact of increasing AFR - PPC

Impact category	Unit	PPC Current Mix	PPC Proposed Mix	% impact reduction
Global warming	kg CO_2 eq	598.68	564.04	-6%
Stratospheric ozone depletion	kg CFC-11 eq	0.00004	0.00003	-8%
Ionizing radiation	kBq Co-60 eq	1.04	0.95	-9%
Ozone formation, Human health	kg NOx eq	0.90	0.87	-3%
Fine particulate matter formation	kg PM2.5 eq	0.04	0.04	-6%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.91	0.88	-3%
Terrestrial acidification	kg SO2 eq	0.70	0.66	-6%
Freshwater eutrophication	kg P eq	0.10	0.08	-15%
Marine eutrophication	kg N eq	0.01	0.01	-15%
Terrestrial ecotoxicity	kg 1,4-DCB	135.42	128.89	-5%
Freshwater ecotoxicity	kg 1,4-DCB	3.39	2.96	-13%
Marine ecotoxicity	kg 1,4-DCB	1.18	1.03	-12%

Human carcinogenic toxicity	kg 1,4-DCB	0.03	0.03	-13%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.87	0.78	-10%
Land use	m^2a crop eq	3.27	2.89	-12%
Mineral resource scarcity	kg Cu eq	1.29	1.29	-1%
Fossil resource scarcity	kg oil eq	75.13	64.61	-14%
Water consumption	m^3	0.33	0.30	-8%

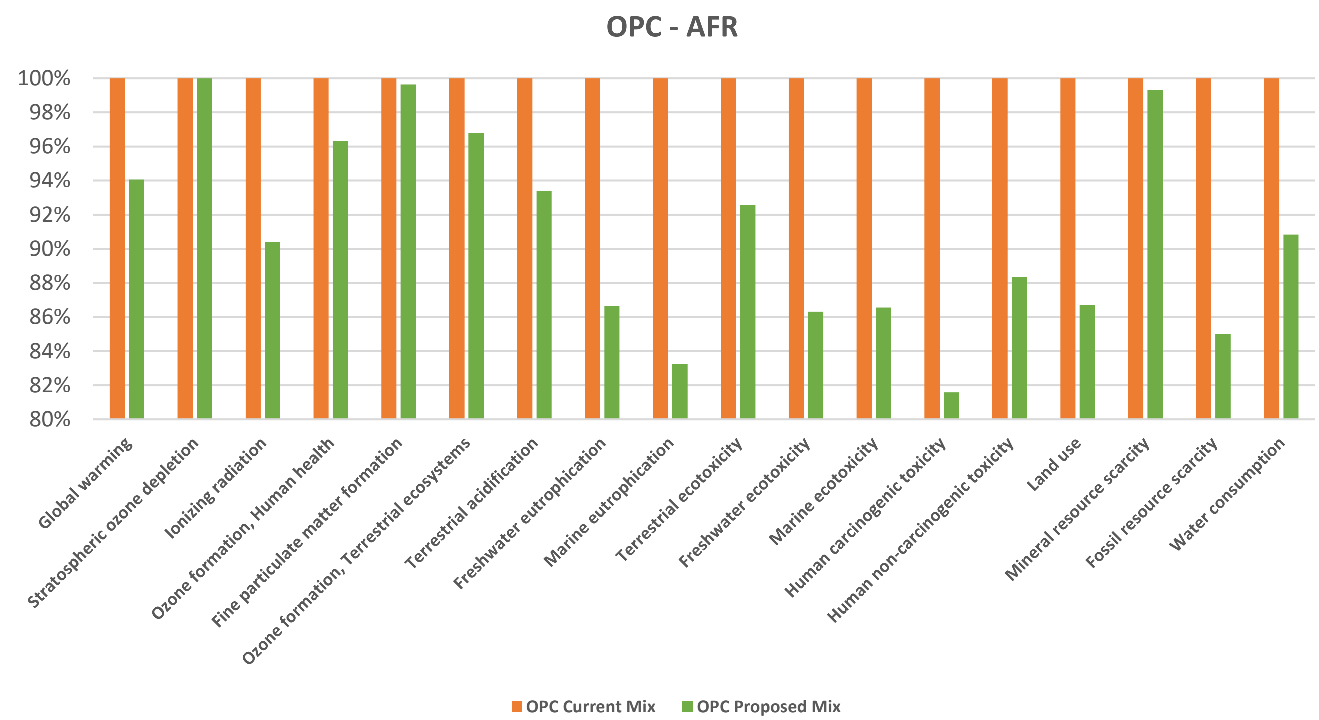

Figure 22: Impact of increasing AFR - OPC

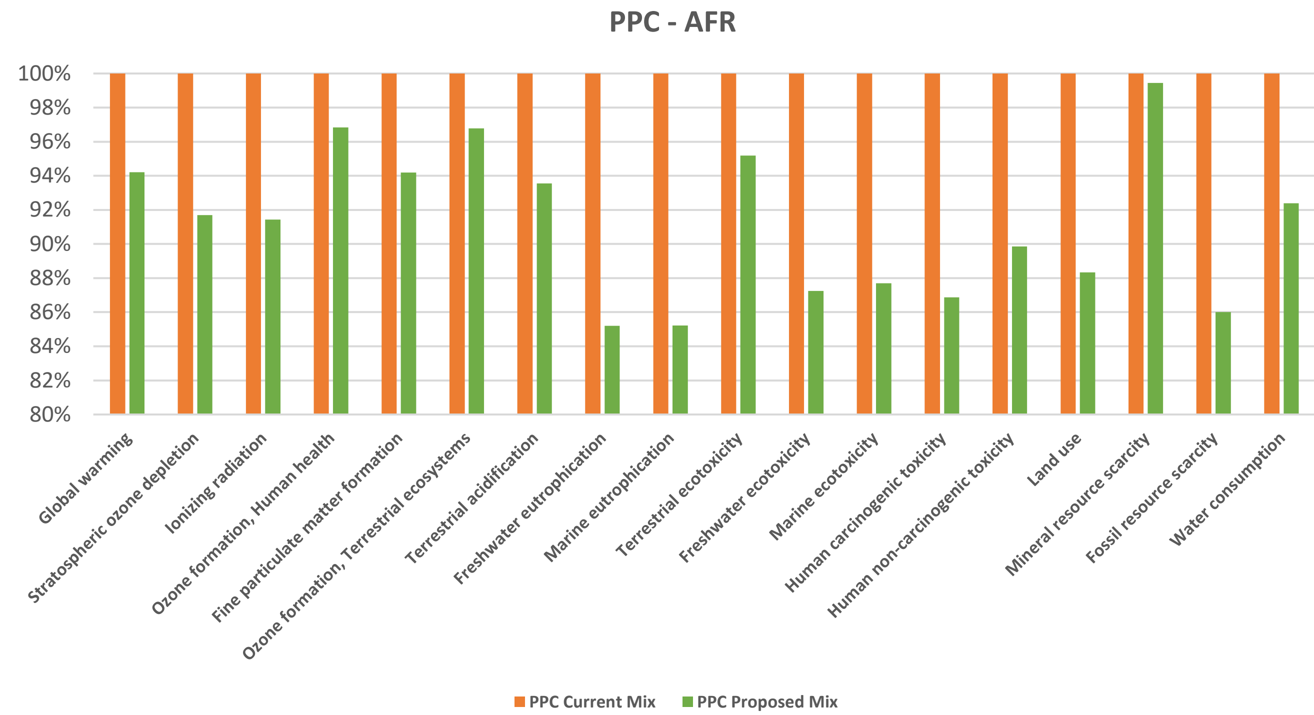

Figure 23: Impact of increasing AFR - PPC

6.3.7 Advance Technology – CCUS

Carbon capture is a critical technique for decarbonizing cement manufacturing since the chemical process of calcining calcium carbonate emits up to 70% of CO_2 emissions, which other technologies cannot achieve. Currently, CCUS is in early stages of development however, it is an advanced decarbonisation pathway that Sagar Cements Limited, Mattampally unit could consider in the long term. Following tables summarizes the environmental impact of investing in a CCUS plant for OPC & PPC production.

Table 30: Use of advance technology – OPC

Impact category	Unit	OPC Current Mix	OPC Proposed Mix	% impact reduction
Global warming	kg CO_2 eq	873.38	857.35	-2%
Stratospheric ozone depletion	kg CFC-11 eq	0.00005	0.00005	-3%
Ionizing radiation	kBq Co-60 eq	1.34	1.26	-6%
Ozone formation, Human health	kg NOx eq	1.28	1.25	-2%
Fine particulate matter formation	kg PM2.5 eq	0.05	0.05	-1%
Ozone formation, Terrestrial ecosystems	kg NOx eq	1.28	1.25	-2%
Terrestrial acidification	kg SO2 eq	0.98	0.93	-5%
Freshwater eutrophication	kg P eq	0.14	0.14	-3%
Marine eutrophication	kg N eq	0.009	0.01	-7%
Terrestrial ecotoxicity	kg 1,4-DCB	131.23	129.12	-2%

Freshwater ecotoxicity	kg 1,4-DCB	4.72	4.53	-4%
Marine ecotoxicity	kg 1,4-DCB	1.63	1.55	-5%
Human carcinogenic toxicity	kg 1,4-DCB	0.05	0.05	-9%
Human non-carcinogenic toxicity	kg 1,4-DCB	1.1	1.06	-4%
Land use	m^2a crop eq	4.26	4.08	-4%
Mineral resource scarcity	kg Cu eq	1.89	1.89	0%
Fossil resource scarcity	kg oil eq	104.95	99.92	-5%
Water consumption	m^3	0.45	0.42	-6%

Table 31: Use of advance technology – PPC

Impact category	Unit	PPC Current Mix	PPC Proposed Mix	% impact reduction
Global warming	kg CO_2 eq	598.68	587.96	-2%
Stratospheric ozone depletion	kg CFC-11 eq	0.00004	0.00004	-12%
Ionizing radiation	kBq Co-60 eq	1.04	0.98	-6%
Ozone formation, Human health	kg NOx eq	0.9	0.88	-2%
Fine particulate matter formation	kg PM2.5 eq	0.04	0.04	-4%
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.91	0.89	-2%
Terrestrial acidification	kg SO2 eq	0.7	0.67	-4%
Freshwater eutrophication	kg P eq	0.1	0.09	-5%
Marine eutrophication	kg N eq	0.01	0.01	-41%
Terrestrial ecotoxicity	kg 1,4-DCB	135.42	134.01	-1%
Freshwater ecotoxicity	kg 1,4-DCB	3.39	3.26	-4%
Marine ecotoxicity	kg 1,4-DCB	1.18	1.13	-4%
Human carcinogenic toxicity	kg 1,4-DCB	0.030	0.033	10%
Human non-carcinogenic toxicity	kg 1,4-DCB	0.87	0.84	-4%
Land use	m^2a crop eq	3.27	3.15	-4%
Mineral resource scarcity	kg Cu eq	1.29	1.29	0%
Fossil resource scarcity	kg oil eq	75.13	71.76	-4%
Water consumption	m^3	0.33	0.31	-5%

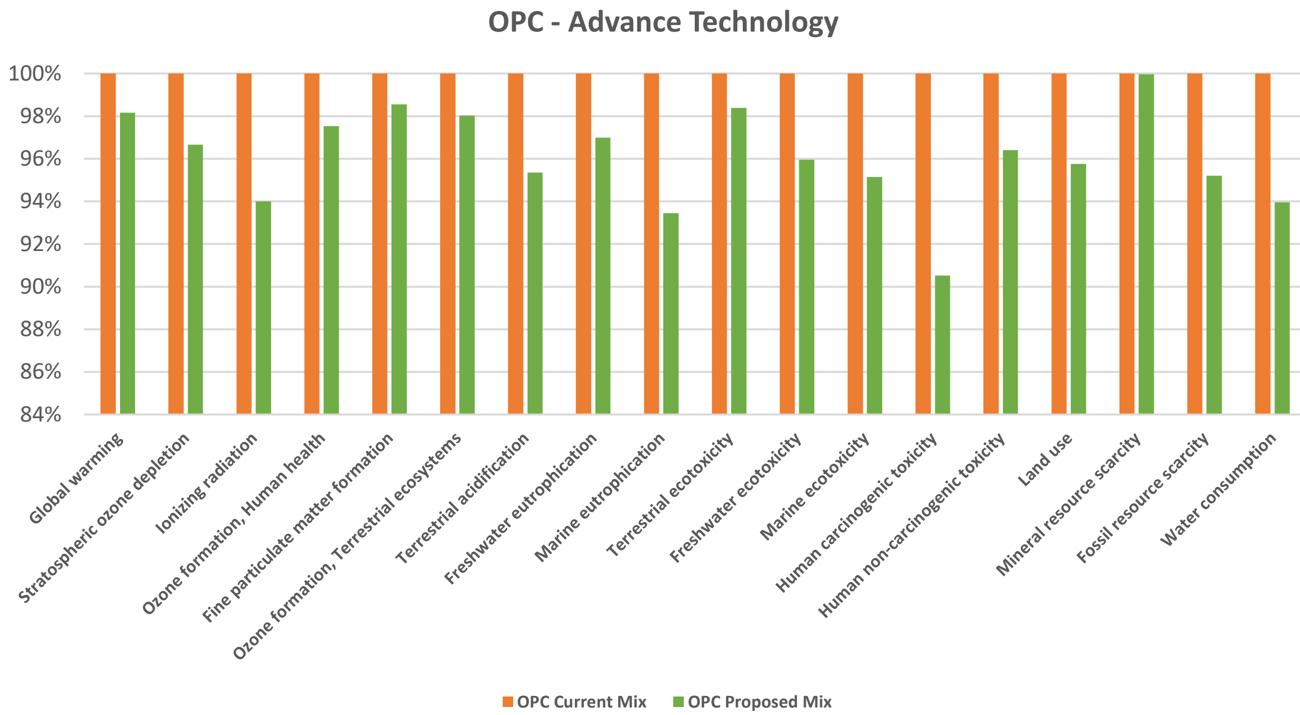

Figure 24: Use of advance technology – OPC

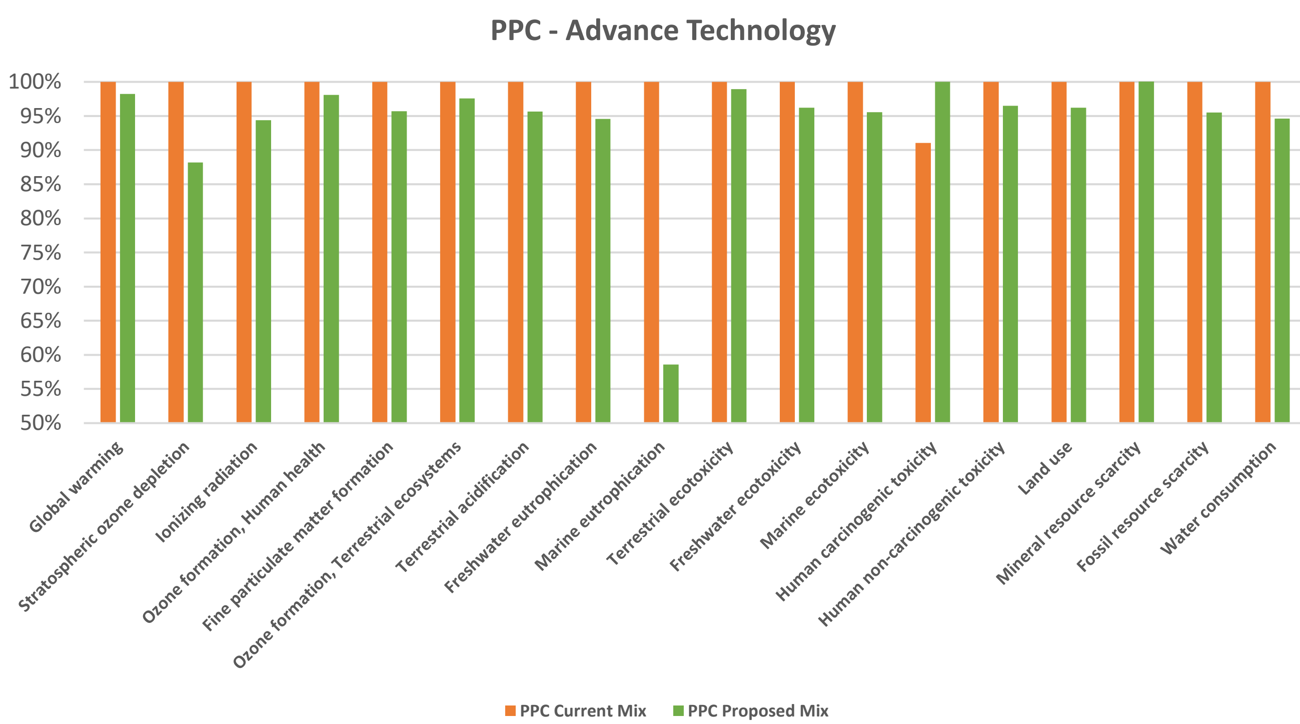

Figure 25: Use of advance technology – PPC

Annexures

Annexure – A – About LCA

Introduction to Lifecycle Assessment

The search for innovation and cost-effective ways of resource optimization has led to the development of a wide array of concepts and tools for effective decision making. Today, a range of performance tools focusing on environment in tandem with efficiency improvements are largely espoused by industries. Studies like Life Cycle Impact Assessment (ISO 14044), Greenhouse Gas Accounting (ISO 14064) and Environmental Product Declaration, EPD (ISO 14025) are taken up by the industries for objective analysis in the areas of product design development, process improvement, economies of scale and policy strategy formulation etc. Life Cycle Impact Assessment (LCA) tool has emerged as a powerful tool for product improvement and raw material substitution to attain the twin objectives of sustainability and profit maximization.

"LCA is a technique for assessing the environmental aspects and potential impacts (damages) associated with a product, by

- Compiling an inventory of relevant inputs and outputs of a system;
- Evaluating the potential environmental impacts (damages) associated with those inputs and outputs;
- Interpreting the results of the inventory and impact (damage) phases in relation to the objectives of the study.

LCA studies the environmental aspects and potential impacts (damages) along the continuum of a product's life (i.e., cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences" (ISO, 1998).

- Goal and scope definition (ISO 14041, 1998);
- Inventory analysis (ISO 14041, 1998);
- Impact assessment (ISO 14042, 2000);
- Interpretation (ISO 14043, 2000).

The relation between the different phases is illustrated in figure 2.1. The figure shows that the 4 phases are not independent of each other. It also shows that the scope, the boundaries and the level of detail of an LCA depend on the intended use of the study.

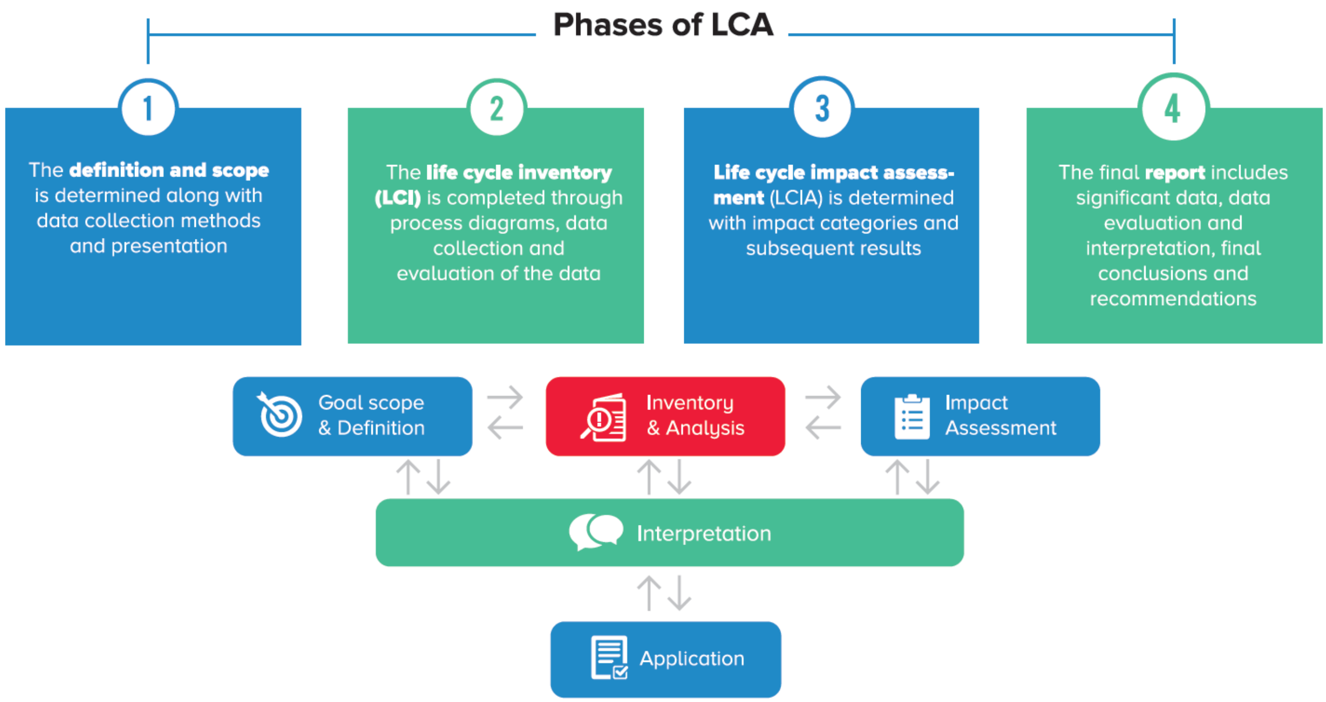

Figure 26: Lifecycle Assessment Framework

Goal and scope definition

In the first phase of an LCA, the intended use of the LCA (the goal) and the breadth and depth of the study (the scope) have to be clearly defined. The scope definition has to be consistent with the goal of the study. In the following paragraphs, aspects that should be clearly agreed upon at the start of the study are discussed briefly (ISO 14040, 1997 and ISO 14041, 1998).

The goal definition of an LCA includes a clear description of:

- The reasons for carrying out the LCA;
- The intended use of its results;
- The audience(s) to which the results are intended to be communicated.

In general, the reasons for carrying out an LCA depend on following 2 different choices:

Specific LCA:

- Determining the environmental profile of a product / process, and
- Finding out the environmental improvement opportunities of the product / process to be studied

Comparative LCA:

- Determining the environmental profile of different existing product systems, and

- Comparing the different environmental profiles.

In general, an LCA-study can be aimed at:

- Internal use: the results will be used internally (remark: the impact profile can be normalized and weighted in order to obtain one final environmental index for the system studied)

- External use: commercial use of positive results for application and marketing (remark: ISO 14040 says "in the case of comparative assertions disclosed to the public, the evaluation shall be conducted in accordance with the critical review process and presented category indicator by category indicator").

Scope of the LCA

The scoping process links the goal of the assessment with the extent of the study: what will or will not be included in the assessment? While defining the scope the following parameters are decided:

- Functional unit is defined

- The system boundaries are fixed

- Types of data required are chosen.

According to ISO 14040 and 14041 standards in defining the scope of the LCA study the following items shall be considered and clearly described:

- The functions of the product system(s);
- The functional unit;
- The product system(s) to be studied;
- The product system(s) boundaries;
- Allocation procedures;
- Types of impact and methodology of impact assessment, and subsequent interpretation to be used;
- Data requirements;
- Data quality requirements;
- Assumptions;
- Limitations;
- Type of critical review, if any;
- Type and format of the report required for the study.

The scope should be sufficiently well defined to ensure that the breadth, the depth and the detail of the study are compatible and sufficient to address the stated goal.

Function and functional unit

The function(s) that are fulfilled by the system(s) under study should be clearly defined. Derived from that, the functional unit has to be defined. The functional unit measures the performance of the system, and provides a reference to which the input and output data will be normalized. In comparative LCAs, comparisons can only be made on the basis of equivalent functions, i.e. LCA data can only be compared if they are normalized to the same functional unit.

Description of the system(s) studied

The system that will be studied in the LCA should be clearly described. Flow diagrams can be used to show the different subsystems, processes and material flows that are part of the system model.

System boundaries

The system boundaries of the LCA should be clearly defined. This includes a statement of:

- Which processes will be included in the study;
- To which level of detail these processes will be studied;
- Which releases to the environment will be evaluated;
- To which level of detail this evaluation will be made.

Ideally, all life cycle stages, from the extraction of raw materials to the final waste treatment, should be taken into consideration. In practice however, there is often not sufficient time, data or resources to conduct such a comprehensive study. Decisions have to be made regarding which life cycle stages, processes or releases to the environment can be omitted without compromising the results of the study. Any omissions should be clearly stated and justified in the light of the defined goal of the study.

LCA study is categorized into different types based on the system boundary as follows:

- **Cradle to Grave** system analyses and identifies environmental impacts associated from raw material extraction for the product development to end of life phase of the same product
- **Gate to Gate** system studies the environmental impacts associated with the product occurring within the plant boundary excluding the impacts associated with upstream and downstream process
- **Cradle to Gate** system explores the environmental impacts associated with the product from upstream phase to manufacturing phase, but does not include impacts arising from downstream system

Allocation procedures

Allocation procedures are needed when dealing with systems involving multiple products. The materials and energy flows as well as associated environmental releases shall be allocated to the different products according to clearly stated procedures, which shall be documented and justified.

Methodology

The impact assessment phase of the LCA is aimed at evaluating the significance of potential environmental impacts using the results of the life cycle inventory analysis. In general, this process involves associating inventory data with specific environmental impacts and attempting to understand those impacts. The level of detail, choice of impacts evaluated and methodologies depends on the goal and scope of the study. The LCA ends with the environmental profile of the alternatives, in which the contribution of each alternative is shown for each individual environmental impact or damage category.

Data and data quality requirements

It should be identified which data are needed in order to meet the goal of the study, and which level of detail is required for different data categories. The different data sources that will be used should be stated. This may include measured data, data obtained from published sources, calculated or estimated data. The data requirements are dependent on the questions that are raised in the study. Efforts do not need to be put in the quantification of minor or negligible inputs and outputs that will not significantly change the overall results of the study.

A complete description of the required data quality includes the following parameters:

- Geographical coverage;
- Time period covered;
- Technology coverage;
- Precision, completeness and representativeness;
- Consistency and reproducibility;
- Sources of the data and their representativeness;
- Variability and uncertainty of the information and methods.

Assumptions and limitations

All assumptions made during the course of the project and the limitations of the study will be commented on in the report. The results of the LCA will be interpreted in agreement with the goal and scope and therefore with the ISO 14041 and 14043 guidelines.

Critical review

A critical review is a process to verify whether an LCA has met the requirements of international (ISO) standards for methodology, data collection and reporting. Whether and how a critical review will be conducted should be specified in the scope of the study.

Three types of critical review are defined by ISO 14040:

- Internal review, performed by an internal expert independent of the LCA study;
- Expert review, performed by an external expert independent of the LCA study;
- Review by interested parties, performed by a review panel chaired by an external independent expert - the panel includes interested parties that will be affected by conclusions drawn from the LCA study, such as government agencies, non-governmental groups.

When an LCA study will be used to make a comparative assertion that is disclosed to the public, ISO standards require a critical review by interested parties to be conducted. In all other cases, critical reviews in LCA are optional and may utilize any of the three review options mentioned above.

Type and format of the report

The results of the LCA will be fairly, completely and accurately reported to the intended audience, in keeping with ISO 14040.

Inventory analysis

The inventory analysis involves data collection and calculation procedures to quantify the inputs and outputs that are associated with the product system(s) under study. This includes use of resources, releases to air, water and land. Procedures of data collection and calculation should be consistent with the goal and the scope of the study. The results of the inventory analysis may constitute the input for the life cycle assessment as well as an input for the interpretation phase.

Input and output data have to be collected for each process that is included in the system boundaries. After collection, the data for the different processes have to be normalized to the functional unit and aggregated. This corresponds to a calculation of all inputs and outputs referenced to the functional unit, which is the final result of the inventory analysis.

Inventory analysis is an iterative process. As data are collected and the system is better known, new data requirements or limitations may become apparent. This may require better or additional data to be collected or system boundaries to be refined.

Allocation

A special issue related to the inventory analysis is the so-called allocation problem. This refers to the allocation of environmental inputs and outputs of a process to different products. Examples of processes were allocation is needed are:

- **Co-production:** processes in which two or more products are produced simultaneously; the environmental inputs and outputs of these processes need to be allocated to the different products;

- **Processing of mixed waste streams:** processes in which two or more waste streams are processed simultaneously; the environmental inputs and outputs of these processes need to be allocated to the different waste streams;

- **Open-loop recycling:** processes in which a discarded product from one product system is used as a raw material for another product system; the environmental inputs and outputs of these processes need to be allocated to the different product systems.

Different approaches can be used for carrying out allocation. The following stepwise allocation procedure is recommended by ISO and by Society of Environmental Toxicology and Chemistry (SETAC) - Wherever possible, allocation should be avoided or minimized. This can be done by detailing multiple processes into two or more sub processes, some of which can be located outside the system boundaries. It can also be done by expanding the system boundaries so that inputs/outputs remain inside the system.

- Where allocation cannot be avoided, it should preferentially be based on causal relationships between the system inputs and outputs. These causal relationships between the flows into and out of the system may be based on physical or economic parameters.

- Where causal relationships cannot be established, allocation to different products may be based on their economic value.

Impact assessment

In the impact assessment, the results of the inventory analysis are linked to specific environmental damage categories (e.g. CO_2 emissions are related to global warming and climate change, SO_2 emissions are related to damages to the ecosystem caused by acidification, etc.). It is important to note that the inventory results generally do not include spatial, temporal, dose-response or threshold information. Therefore, impact assessment can not and is not intended to identify or predict actual environmental impacts. Instead, the impact assessment predicts potential environmental damages (impacts) related to the system under study.

Methodology

Various methods are in use to assess the environmental effects of products and systems. Almost all methods operate on the assumption that a product's entire life cycle should be analyzed. One of the methods is the Eco-indicator 99 method (Goedkoop et al., 2000). This method is used for impact assessment in the study.

For a more detailed description of the Eco-indicator 99 method, we refer to annex 1 of this report.

The framework proposed by ISO 14042 and followed by the Eco-indicator method consists of the following elements:

- Selection of impact categories, category indicators and characterization models;
- Classification: assignment of inventory data to impact categories;
- Characterization: calculation of category indicator results;
- Normalization: calculating the magnitude of category indicator results relative to reference information
- Grouping: sorting and possibly ranking of the impact categories;
- Weighting (valuation): converting and possibly aggregating indicator results across impact categories using numerical values based on value-choices.

The first three elements are mandatory, the last three are optional. ISO 14040 says "in case of comparative assertions disclosed to the public, the evaluation shall be conducted in accordance with the critical review process and presented category indicator by category indicator".

Interpretation

According to ISO 14043, in the interpretation phase of an LCA, the results of the inventory analysis and the impact assessment are critically analyzed and interpreted in line with the defined goal and scope of the study. The findings of this interpretation may take the form of conclusions and recommendations to decision makers.

It may also take the form of an improvement assessment, i.e. an identification of opportunities to improve the environmental performance of products or processes.

Annexure – B – Cement Life Cycle

Product Manufacturing Process

The environmental impacts are calculated on the basis of the functional unit wherein each flow related to material consumption, energy consumption, emissions, effluent and waste is scaled to the reference flow. The processes listed below for the production of the final product including primary packaging is included.

The processes which are mandatory to be included in plant operation (i.e. clinker production and cement production), in particular are (For LCA):

- Raw material production (mining and crushing)
- Raw meal preparation
- Clinker production
- Grinding of cement
- Packaging

The manufacturing of buildings, other capital goods and plant dismantling are not included. Inbound transportation of raw materials and fuel are included, and outbound transportation of cement product is not included as per PCR. Following is the summary for cement manufacturing process.

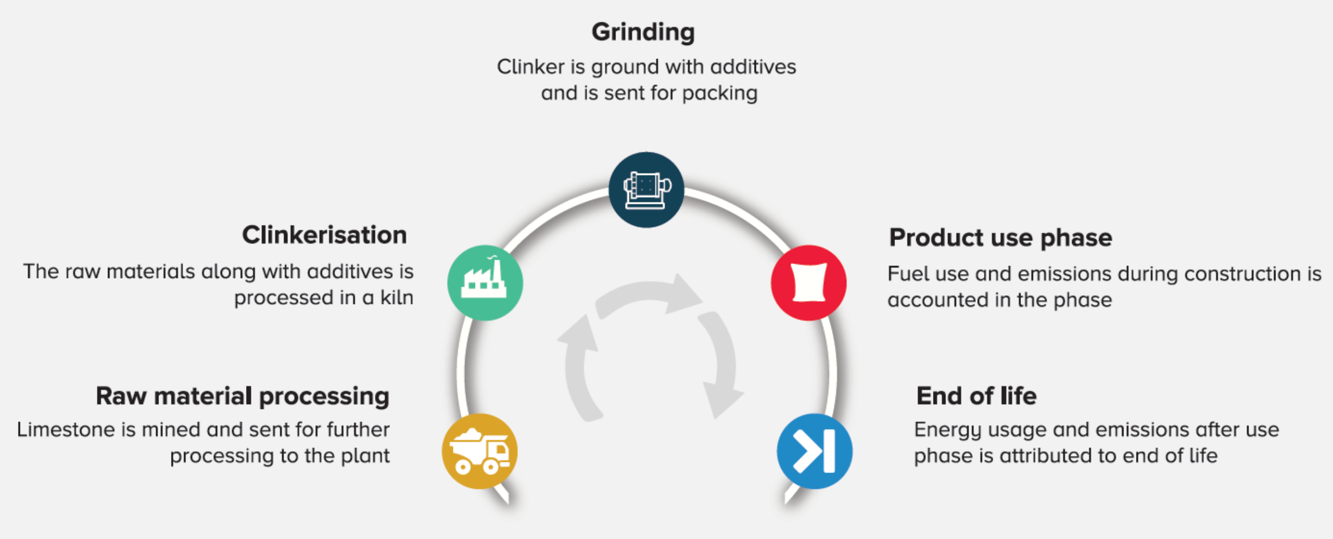

Figure 27: Cement Life Cycle

The main steps in cement manufacturing process are:

Raw material production (mining and crushing)

Cement uses raw materials that cover calcium, silica, iron and aluminum. Such raw materials are limestone, clay and sand. Limestone is for calcium. It is combined with much smaller proportions of sand and clay. Sand and clay fulfill the need of silicon, iron and aluminum. Limestone is excavated from open cast mines after drilling and blasting and loaded onto dumpers which transport the material and unload into hoppers of the limestone crushers.

Raw meal preparation (grinding, proportioning and blending)

Following extraction of the raw materials, they are crushed and milled into fine powders. These powders are tested and blended to produce a final blend, known as 'raw meal' with a precise chemical composition. After final grinding, the material is ready to face the pre-heating chamber. Pre-heater chamber consists of series of vertical cyclone from where the raw material passes before facing the kiln. Pre-heating chamber utilizes the emitting hot gases from kiln. Pre-heating of the material saves the energy and make plant environmentally friendly. The raw meal is pre-heated to temperature in excess of 900°C using the hot gases from the kiln.

Clinker production

Clinker is produced in a rotary kiln, which is a cylindrical steel shell, lined with refractory bricks. The kiln is inclined at 3% and set rotating at a speed of 4-6 RPM. The raw mix is injected into the kiln from its upper end. Burning fuel like powdered coal or pet coke or oil or hot gases are forced through the lower end of the kiln and hot flame is produced. Due to inclined position and slow rotation of the kiln, the material charged from upper end is moving towards lower end (hottest zone) at a speed of 15meter/hour. As it gradually descends, the temperature rises. In the upper part, water or moisture in the material is evaporated at 400°C temperature, therefore it is known as drying zone.

In the central part (calcination zone), temperature is around 1000°C, where decomposition of limestone takes place. After the escape of CO_2, the remaining material form small lumps called nodules.

$$CaCO_3 \rightarrow CaO + CO_2$$

The lower part (clinkering zone) have temperature in between 1500-1700°C, where lime and clay react to yield calcium aluminates and calcium silicates. This aluminates and silicates of calcium fuse together to form small and hard stones, known as clinker. The size of the clinker varies from 5-10 mm.

$2CaO + SiO_2 \rightarrow Ca_2SiO_4$ (dicalcium silicate (C2S))

$3CaO + SiO_2 \rightarrow Ca_3SiO5$ (tricalcium silicate (C3S))

$3CaO + Al_2O_3 \rightarrow Ca_3Al_2O_6$ (dicalcium aluminate (C2A))

$4CaO + Al_2O_3 + Fe_2O_3 \rightarrow Ca_4Al_2Fe_2O_{10}$ (tetracalcium aluminoferrite (C4AF))

As clinker is coming from kiln burning zone, it is very hot. It is then immediately quenched in the clinker cooler to stabilize its properties and stored in the clinker silo.

Grinding of Cement

The cement mill grinds the clinker to a fine powder. A small amount of gypsum - a form of calcium sulfate is normally ground up with the clinker. The gypsum controls the setting properties of the cement when water is added. Grinding clinker and gypsum produces Ordinary Portland cement (OPC). Fly ash and slag at required proportion is ground along with clinker and gypsum to produce Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC), respectively.

Packaging

The cement is then stored in silos and packed in bags using packing machines.