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Sustainability assessment in environmental impact study of cement manufacturing process with waste absorption consideration

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Abstract

Environmental Impact Assessment (EIA) is an important tool that identifies impact parameters, qualitatively and quantitatively predicts and evaluates the anticipated adverse and beneficial impacts. Cement is the most widely used as ingredients in the construction activities and particularly in concrete manufacturing. From the earliest Portland cement having more than 95% raw material-based clinker to modern blended cement envisages 80% replacement of clinker with waste material. Sustainability issues of economic, environmental and social aspects are inherently incorporated in Terms of Reference mandated by regulatory authority for the preparation of EIA report. In this paper, we undertake impact analysis in the EIA report of cement plant in India considering the waste assimilation ability of the cement manufacturing process. While considering the impact issues in different stages of project, a Rapid Impact Assessment Matrix (RIAM) assessment is performed. Option 2 scenario with Environmental Management Plan (EMP) and waste absorption aspects is found to have substantial positive score of + 152 compared with that of option 1 with EMP but without waste absorption with a slightly negative score of -3. Appraisal of sustainability issues and partial fulfillment of some Sustainability Development Goal (SDG) is deliberated upon, in order to justify the viability of the project.

1. Introduction

In the conflicting scenario between environment and development, the sustainable development comes as emerging choice. In the early 1987, Brundtland (WCED 1987) defined the idea of sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. Since then, the lot of idea comes in support of sustainability in development process. In 1992, the first major conference in sustainable development under the aegis of United Nations was held in Rio de Janeiro (UNCED 1992). Sustainability is a key word in the development process. Sustainability having the three important segments namely economic, environment and social issues is inherently incorporated in environmental impact assessment process.

With the use of various industrial wastes as blending material in in cement production ad usage of the waste including that of municipal solid waste and some hazardous waste as secondary fuel, the cement industry may be considered as scavenger (Rejinders 2007). Quantification of environmental impacts was performed as early in 1998 in the form Rapid Impact assessment method (RIAM) and it is one of the best method adopted even now (Pastakia and Jensen 1998). Subsequent, many authors followed this method with different degree of variations. This method was attempted for selecting the different landfill option (Mondal et al 2010). While assessing the impact associated with different composting alternatives, the authors used RIAM and Iranian Leopold matrix methods together to find out the best result (Valizadeh and Hakimian 2018). With the use mathematical model incorporating sustainability, the authors applied to RIAM results to furnish effective appropriate solution to sustainable waste management mathematical model of sustainability to the RIAM results has provide a potential step forwards in meeting the goal of finding appropriate solutions for achieving sustainable waste management (Phillips and Mondol 2014). Modern cement manufacturing needs a more investigation in order to provide sustainable, economical

and durable consideration in order to support sustainable infrastructure solution (Poudyal and Adhikary 2021). The authors reviewed the usage of waste material in the manufacturing of blended cement with a view to reducing carbon emission with the use of alternative waste fuel and waste heat recovery option reduce the equivalent carbon emission (Ahmed et al., 2021). Cement production particularly more common dry process involve crushing and fine grinding of huge amount of raw and waste material. Therefore, stringent air pollution control measures are required to keep the particulate and gaseous emission at acceptable level (Tun et al., 2021). The quantitative evaluation of impact by using modified Leopold matrix, Total Impact Score (TIS) was computed separately with or without EMP and waste absorption. (Panda et al 2022). The authors made an effort to integrate SDGs with environment assessment practices (Boess and Campo 2023). The authors reviewed the various issues impacting waste management pracices. They recommended that the waste management steps include prevention, minimization, recycling and reuse in that order (Mostaghimi and Behnamian 2023). In this review paper, the authors have explored the industrial waste and mineral tailings in the formation of different important cement phases. The usage of these waste materials replacing clinker in cement grinding drastically reduces raw material based ordinary Portland cement (Mache et al 2025). A recent publication using Life Cycle Assessment (LCA) approach for pavements find the reduction of impacts is feasible and there is enough opportunity of impact reduction in making the road transport more sustainable (Aryan et al 2025).

There have been many literatures covering environmental impact and sustainability aspects. Some literatures develop sustainability score to quantify the environmental impact. Some have used life cycle analysis to emphasize the sustainability issues in environmental impact analysis. Environmental Impact Assessment (EIA) and its important accompaniment Environmental Management Plan (EMP) is the most important techno-management and legal document has to pass through rigorous review process before its suitability to get the Environmental Clearance (EC) for most of the development projects in India and elsewhere. In the scoping process, the authorities provide a set of Terms of Reference (ToR 2015), on the basis of which, the project proponents and their consultant have to prepare the report while complying with every ToR condition. The novelty of this work is the incorporation of the sustainability segment in ToR conditions and identification of most of the Sustainability Development Goals (SDG) components in different stages of impact analysis are converged towards the partial fulfilment of these goals at local/regional level. The research significance of the paper is the application of slightly modified RIAM method to an industry which has the potential of higher waste assimilation ability. With a slight modification in the original quantification proposed in RIAM method, it is proposed to include the Waste Absorption (WA) as fifth item in addition to usual four items as proposed in the method. Finally, the quantification will be better analysed by evaluating the Total Environmental Score (TES) for each of the options.

2.0 Methodology

Selection of location of the plant is an important consideration with respect to resource availability, road and rail connectivity and proximity to feasible water resources. Project size, product portfolio and flow

diagram are reflected in the detailed project report. Socio-economic and environmental impact of the project will be decided in consultation with project proponent and experts in the field while complying with the guidelines issued by regulatory authority.

2.1 Suitability of the location of the project

Present location of the cement plant is proposed in Jharsuguda industrial area, India. The area has many distinct advantages for setting up a cement industry. The proposed unit requires large quantities of important raw materials like limestone, coal, and quartz and additives and many industrial wastes in the form of mill scale, red mud blast furnace sludge etc. along with blending waste materials like blast furnace slag, fly ash, phosphogypsum and Flue gas desulphurization (FGD) gypsum. The said raw material resources and waste components are available within 50 to 100 km from the site. The waste additives and blended materials can be procured from the nearby steel, power alumina refinery units within 50 to 100 km from the site. Water can be sourced from Ib, a nearby river. Location is well connected with rail and road network. Nearest sea port is around 300 km from the site and airport is about 20 km from the location. Considering availability of all these facilities, the proposed site is one of the best for cement industry with respect to resource availably, connectivity resulting in the reduction of transportation cost of raw material and waste.

2.2 Cement manufacturing process

An integrated cement manufacturing unit is planned with the production of clinker, the basic ingredient in any cement production process, cement grinding units and blended cement manufacturing process. Raw materials required for the process is primarily calcareous material like limestone and additives mostly waste material that include siliceous material like sand stone, ferruginous material like mill scale and red mud and aluminum bearing materials. Voluminous industrial wastes like ground granulated blast furnace slag (GGBFS) and fly ash required for the production of blended cement can be procured from the nearby steel and power units. Waste chemical gypsum mostly phosphogypsum from phosphatic fertilizer unit and flue gas desulphurization (FGD) gypsum procured from nearby thermal power plants are suitably processed and may be used (5%) for setting purpose in any cement production process. Waste fuel from nearby industries, municipal solid waste (MSW) and plastic waste from nearby urban areas may be used as co-processing along with fuel coal. The process of clinkerisation and cement grinding with the co-processing and waste blending aspects are suitably illustrated with, the help of flow diagram in Fig. 1.

2.3 RIAM quantification of impact in EIA

Considering the subjective nature of impact assessment, the objective criteria may be formulated by visiting the cement industry, interact with expert and referring to the project report. The objectivity can be induced in the impact quantification and the same is carried out by the use of simple and yet popular RIAM (Pastakia 1998, Mondal et al 2010, Valizadeh and Hakimian 2018).

The RIAM approach (Pastakia 1998) is based on two important criteria. Semi-quantitative values are assigned to each of these criteria to provide individual score for each condition. The impacts due to each project activity are determined with respect to corresponding environmental component and accordingly a score is allotted to that component. The assessment criteria have two important divisions namely group (A) important to individual conditions that can change the obtained score and group (B) is valuable to the situations but is not capable of changing the obtained score.

The scoring system for group A requires the multiplication of each component with individual allotted score. The scoring system for group B components with corresponding score is added to get the score .for criteria group B. If A1 and A2 are the individual components of group A and B1, B2 and B3 are the individual components for group B. The scores of criteria group A and group B are obtained by using equations 1 and 2.

$$A1 \times B1 = A \quad \text{.....1}$$

$$\mathrm{B1} + \mathrm{B2} + \mathrm{B3} = \mathrm{B} \quad \text{.....2}$$

Final assessment score is obtained by multiplying the individual scores of group A and group B. The procedure for getting environmental score (ES) is obtained using simple mathematical equations as shown in Eq. 3.

$$A \times B = (A1 \times A2) \times (B1 + B2 + B3) = ES \quad \text{.....3}$$

The allotment of assessment scores are based on the guidelines (Pastakia and Jensen 1998) and the same is mentioned in Table 1.

Table 1
Criteria for assessment

Criteria	Scale	Description
A1: Importance of condition	4	Importance to national/international interest
	3	Importance to regional/national interest
	2	Important to areas outside the local condition
	1	Important to the local condition
	0	No importance
A2: Magnitude to change/effect	+ 3	Major positive benefit
	+ 2	Significant improvement
	+!	Improvement
	0	No change
	-1	Negative change
	-2	Significant negative change
	-3	Major negative change
B1: Permanence	1	No change/Not applicable
	2	Temporary
	3	Permanent
B2: Reversibility	1	No change/Not applicable
	2	Reversible
	3	Irreversible
B3: Cumulative	1	No change/Not applicable
	2	Non-cumulative-single
	3	Cumulative-synergistic

RIAM categorizes four basic components for the estimation of Environmental Score (ES) Physical and Chemical (PC) component considers entire pollution problem affecting physico-chemical aspects of environment. Biological/Ecological (BE) component covers the entire issues related to biological environment including ecological sensitivity. Sociological and Cultural (SC) component deals with all the issues related social and human aspects of environment. The Economic/Operational (EO) component takes up the economic aspects.

A score is obtained using afore mentioned equations and corresponds to different Range Bands (RB) as shown in Table 2 to each project components under different category. Then the final environmental score (ES) is estimated so as to prepare the RIAM matrix.

Table 2
Standard environmental score and range band

Environmental Score	Range Bands (RB)	Description of Range Bands
72 to108	+E	Major positive change/impacts
36 to 71	+D	Significant positive change/impacts
19 to 35	+C	Moderately positive change/impacts
10 to 18	+B	Positive change/impacts
1 to 9	+A	Slightly positive change/impacts
0	N	No change/status quo/not applicable
-1 to -9	-A	Slightly negative change/impacts
-10 to -18	-B	Negative change/impacts
-19 to -35	-C	Moderately negative change/impacts
-36 to -71	-D	Significant negative change/impacts
-72 to -108	-E	Major negative change/impacts

2.4 Sustainability components in EIA

Terms of Reference (ToR) are prescribed by appropriate authority for complying and preparing Environmental Impact Assessment (EIA) and Environmental Management Plan (EMP) report in India. EIA is integrally connected with EMP and contains different segments of sustainability as indicated in ToR specification (ToR 2015). There are three major stakeholders namely project proponents with their consultants, affected people and government the final approval authority. One very important component of EC process is the public consultation process wherein all the stakeholders are actively participated. Besides, the project proponent, affected people and their representative are allowed freely to put forth their views and submit their demands and the government is represented by district administration and authorities from the corresponding state pollution control board. This process is culminated after acceptance of most of the feasible demands from public by project proponent and is usually recorded and certified by state pollution control board authority. In fact, the project proponent is obligated to spend 2 to 3% of their project cost towards the local development as a part of their Enterprise Social Commitment (ESC). Different sustainability components are inherently incorporated in ToR conditions. The United Nations designated 17 Sustainable Development Goals (SDG) are usually considered at global/ regional scale. Here attempts have been made to satisfy some of the SDGs in local and regional level.

3.0 Results and discussion

Most of the cement manufacturing in India and elsewhere adopt dry process technology. This technology involves crushing and grinding of raw materials and fuel and then the fine ground material is heated in pyro-processing rotary kiln at a temperature about 1200 to 1500 deg C. The clinker with desired composition is cooled and stored. Clinker along with blended waste material like blast furnace slag and fly ash and setting material gypsum are ground to the required size to prepare the different types of cement. Therefore, the impacts associated with dry cement manufacturing process are primarily air pollution. The wastewater and solid waste generation impact is not that serious to be considered.

3.1 Air pollution and other pollution control measures

As the current trend for dry processing approach, the most important pollution problem in this process involves emission from point source industrial stacks/chimney and fugitive emission from area, volume and line sources within the core area of the industry. After identifying the pollution sources, the polluted gases from the process are routed through the stringent air pollution control devices (APCD) like bag house (BH) and electrostatic precipitators (ESP) and are finally discharged through tall stack for effective dispersion to atmosphere. Stack emission is standardised by Ministry of Environment, Forest and Climate Change (MoEFCC) through notifications the emission standards for without co-processing (G.S.R. 496(E) 2016) and with co-processing (G.S.R. 497 (E) 2016) are shown in Table 3 (a) and Table 3 (b).

Table 3
(a) Standards for stack emission without co-processing

Source	Nature of stack	Emission type	APCD	Emission norm (mg/m^3)
Limestone crushing	Volume source-point source	PM	BH	30
Additive crushing	Volume source-point source	PM	BH	30
Coal crushing	Volume source-point source	PM	BH	30
VRM grinding	Volume source-Point source	PM	BH	30
Rotary kiln	Point source	PM,SO_2, NO_2	ESP	PM-30 SO_2-100 NO_x-100
Cooler	Point source	PM,SO_2, NO_2	ESP	PM-30 SO_2-100 NO_x-100
Slag drying	Area source-point source	PM,SO_2	BH	PM-30 SO2-100
Fly ash drying	Area source-point source	PM,SO_2	BH	PM-30 SO_2-100
Cement grinding	Volume source-point source	PM	BH	PM-30
Product packing	Volume source-point source	PM	BH	PM-30

Table 3
(b) Standards for stack emissions with co-processing

Parameter	Without co-processing Emission standards (mg/Nm3)	With co-processing Emission standards (mg/Nm3)
PM	30	30
SO_2	100	
NO_x	600	
HCl	10	10
HF	1	1
TOC	10	10
Hg and its compounds	0.05	0.05
Cd and Tl and their compounds	0.05	0.05
Sb + As+Pb + Co + Cr + Cu+Mn + Ni+V and their compounds		0.5
Dioxins and Furans		0.1 ngTEQ/ Nm^3

Cement industry processes large quantities of raw materials, coal, waste materials and additives mostly by dry processing techniques. Air pollution mostly in the form of particulate pollution is very serious that requires urgent attention. Besides stack emission, there is uncontrolled fugitive emission from different areas in of cement manufacturing unit. Vehicular transportation of raw materials and wastes, loading and unloading operation, storage yard of raw and waste materials generate considerable amount of fugitive particulate matter from these sources Two kinds of control measures for fugitive emission namely emission extraction and emission suppression are adopted. Extraction steps are usually applicable to confined area and volume sources. Pressurised air is allowed to sweep the flying emission and convers to gaseous stream having fugitive emission. This fugitive particulate laden gas is taken to APCD to remove same and the dust free gas is dispersed to atmosphere through tall stack. This type of control schemes are implemented in the closed circuit crushing and grinding units. Alternatively where extraction is not possible, suppression with spraying liquid (most commonly water) is used to settle down the flying dust particulates. The necessary measures for fugitive emission control in their proposed cement unit are implemented as per the Central Pollution Control Board guidelines (PROBES 118 2007). Realising the importance of plants as a good sink for air borne pollutants, the comprehensive greenbelt in and around raw material yard, material handling section, solid waste dump yard and is developed.

In a dry process cement production unit, the make-up water consumption is usually less and mostly required for direct and indirect cooling process. Normally small amount of cooling tower blow down in case of indirect cooling and the collection of direct cooling water is collected and cooled in settling pond.

Retrieved wastewater may be recycled to direct cooling and some will be required for dust suppression and in the green-belt area.

.In plant particulates collected in air pollution control devices (APCD) attached with VRM raw meal preparation, rotary kiln and cement grinding and packing units are normally recycled to the same process units. Thus, zero in-plant solid waste emission can be conveniently achieved in cement manufacturing process.

In order to reduce the dependence in fossil fuel like coal and natural gas, waste fuel like used oil/lubricant and oily sludge can be used as fuel with coal in calcination process. The combustible components of Municipal Solid Waste (MSW) and waste plastics are segregated and are size reduced so as to utilise these waste along with coal powder as co-processing utility in rotary kiln for calcination purpose. In this context, the emission norms are to follow the regulatory standards as shown in Table 3 (b).

3.2 Terms of reference with sustainability components

Different sustainability segments identified with the ToR specifications are enlisted in Table 4.

Table 4
Terms of reference for cement projects

ToR numbers	Description of ToR	Sustainability segments
3.Project descriptions		
iii	Importance and benefit of the project	Economic
iv, v	Requirement of raw materials, their source, transportation and storage..	Economic
vi	Emission, effluents, solid and hazardous waste generation details and their management.	Environment
vii	Need of human resource, water sourcing and requirement of power supply.	Economic and social
ix	Safety, risk and disaster management. .	Environment
vii	Water balance diagram	
11	CO_2 emissions	Environment
4. Site details		
i	Suitability of the site with respect to proposed project	Economic and environment
viii	Land use break-up	Economic
xi	Drainage details in the core and buffer zone.	Environment
xiii	R&R details in respect of land in line with government policy	Economic and social
5. Forest and wildlife related issues		
i	Forest clearance	Environment
iv	Location of ecologically sensitive area within 10 km buffer zone	Environment
v, vi	Wild life conservation plan and wild life clearance	Environment
6. Existing environmental scenario		
i	Determination of site specific meteorological data and atmospheric inversion level..	Environment
ii	Monitoring of ambient air quality data (except rainy season) at 8 locations for PM10, PM2.5, SO2, NOX, and CO as per CPCB guidelines.	Environment
iv, vi	Surface water quality of nearby river and other drains and groundwater quality (8 locations) as per as per MoEFCC guidelines.	Environment
vii, viii	Noise and soil monitoring data shall be included.	Environment

ToR numbers	Description of ToR	Sustainability segments
x	Detailed description of flora and fauna	Environment
xi	Socio-economic condition of the impact zone	Social and economic
7. Impact and Environment Management Plan		
i, v, vi	Air pollution control measures to meet the stack emission standards and Measures for fugitive emission control. Air quality modelling and prediction of resultant Ground Level Concentration (GLC) at different locations to be under NAAQS standard values.	Environment
ii, iv	Water Quality modelling - in case of discharge in water body. A note on treatment of wastewater from different plant operations, extent recycled and reused for different purposes shall be included. Complete scheme of effluent treatment. Characteristics of untreated and treated effluent to meet the prescribed standards of discharge under E(P) Rules	Environment
iii	Impact of the transport of the raw materials and end products	Environment
vi	Details of hazardous waste generation and their storage, utilization and management. Solid waste management plan including recycling and reuse. Fly ash utilisation plan as per Fly ash notification 2009.	Environment
ix	Action plan for the green belt development plan in 33% area	Environment
x	Action plan for rainwater harvesting measures at plant site	Environment
8 (ii)	Details of existing and proposed occupational and safety hazards	Environment and social
11. Enterprise Social Commitment (ESC)		
8 (ii)	Details of existing and proposed occupational and safety hazards	Social and economic
i	Allocation of required funds (about 2 to 3% of the project cost) shall be done towards the ESC based on the proceedings in Public consultation process	Social and economic
B5	Environment management plan of trace elements in raw material	Environment
B6	Follow up of Corporate Responsibility towards Environmental Protection (CREP) for cement plant	Environment
B7	Energy consumption per ton of clinker and cement grinding	Economic
B8	Provision of waste heat recovery boiler	Economic and Environment
B9	Arrangement for use of hazardous waste	Environment

3.3 Impact actions in cement manufacturing with SDG

In course of land acquisition to post-operation phase, the different intermediate phases have various impacting action. Various anticipated impacts in different and the corresponding management plan along with sustainability segments and Sustainable Development Goal (SDG) numbers are presented in Table 5.

Table 5
Impact action in cement plant

Impacting action	Anticipated impact	Management plan	Sustainability component	SDG Number
Land Use and locational Environmental sensitivity				
Forest cover	Flora and fauna	Forest clearance	Environment	13,15
Eco-sensitive area	Ecological impact	Wild life management plan/ Alternative location	Environment	13,15
Critically polluted area	Pollution impact	Pollution management /Alternative location	Environment	03
Coastal Regulatory zone	Marine impact	Alternative location	Environmental	14
Displacement of people	Human impact	As per government R & R Plan	Social	11
Acquisition of land	Loss of livelihood	Adequate compensation	Social	11
Opposition at public hearing	Human impact	Alternative location	Social	1,3,4,6
Construction				
Civil construction	Particulate pollution Noise pollution	Adequate pollution control measure	Environmental	3
Mechanical construction	Particulate pollution Noise pollution	Adequate pollution control measure	Environmental	3
Movement of workmen	Water pollution and solid waste	Adequate pollution control measure	Environmental	6
Transportation	Air, water and noise pollution	Adequate pollution control measure	Environmental	3
Transportation and storage of raw material and product				
Vehicular Transportation	Air and noise pollution	Adequate pollution control measure	Environmental	3
Traffic	Public movement	Alternative measure	Social	9
Storage of raw material & product	Fugitive dust Water pollution	Adequate pollution control measure	Environmental	9,12
Plant operation				

Impacting action	Anticipated impact	Management plan	Sustainability component	SDG Number
Land Use and locational Environmental sensitivity				
Emission	Air pollution	Adequate pollution control measure	Environmental	3
Wastewater generation	Water pollution	Water management with zero discharge norm	Environmental	6
Solid waste disposal	Land & water pollution		Environmental	3,12
Energy consumption	Air pollution & GHG emission	Energy conservation, replacement of fossil fuel Waste heat recovery	Environmental	3,12,13
Risk & Hazard	Health impact	Risk & disaster management	Environmental	3
Profit	Sustainable production	Generate more profit	Economic	8,9,12
Employment generation	Employment	Economic development	Economic	1,2
Business opportunities	Income	Economic development	Economic	1,2
Infrastructure development	Improvement of transportation & communication network, water supply etc.	Wellbeing of people	Economic, Social	6,9, 11.12
EMP	Pollution control Water conservation Green belt development	Considerable reduction of pollution Improvement of local ecology	Environmental	6,8,9,12
Waste utilization	Utilization of fly ash, BF Slag and Phosphogypsum	A good sink for industrial waste. Eliminates waste disposal cost and land	Environmental and Economic	6,9,11,12,13
Use of hazardous combustible waste(HCW) fuel	Air pollution	Eliminates waste disposal cost and land	Environmental	3,6,9,12
Enterprise Social Commitment (ESC) as per public hearing proceeding				

Impacting action	Anticipated impact	Management plan	Sustainability component	SDG Number
Land Use and locational Environmental sensitivity				
Local employment	Local economy	Economic development	Economic and Social	1,2,3
Help to local entrepreneurs	Local economy	Economic development	Economic	1,2
Pollution control	EMP	Reduction of pollution problem	Environmental	3,8,12
Drinking water supply	Sufficient funds (around 2 to 3% of the project cost) shall be allocated for ESC as per the outcome of the Public Hearing deliberations. Action and commitment of the project proponent is required towards the issue raised by affected public, time bound action plan and any other related issues.		Economical Social	6
Medical facility				3
Road connectivity				8,9,11
Fund to school and cultural organization				4,11

3.4 Sustainability assessment and SDG

Sustainability components are the most important aspects likely to be addressed by EIA specialist while preparing the EIA report (Weaver 2008). In fact the three major segments of sustainabity are well represented in ToR conditions required for EIA study. The sustainability assessment is comprehensively documented with the compliance to these conditions. Some researchers used sustainability indices and tools to validate the sustainability assessment (Shadiya and High 2012, Singh et al 2012) and others make use of an environmental sustainable indices to watershed projects (Silva et al 2023).

3.4.1 Economic appraisal

The economic segment is the most important one and so the prime motive of setting up of the project for making profit. Therefore, the organization emphasizes most on productivity and marketability factors. As the cement is one of the most important and sought after material for infrastructure development, so that it is readily marketable locally as well as outside. But this profit making is obviously reduced because of mandatory expenditure towards EMP and ESC. But focussing on various underlined cost reduction measures, this mandatory cost overrun can be nullified and in the long run, there will be more profit to the organization.

- Use of abundantly available industrial waste fly ash and GGBFS in the vicinity for the manufacture of more acceptable blended cement like PPC, PSC and PCC
- Complete replacement of mineral gypsum by processed waste chemical gypsum like FGD and phosphogypsum

- Partial replacement of resource based raw material by nearby industrial and urban waste
- Drastic reduction of transportation cost of raw material and waste material because of their availability in close proximity
- Complete recycling of in-plant waste
- Usage of in-plant hot flue gas from kiln for preheating incoming raw meal and drying of blended waste fly ash and GGBFS
- Use of nearby available co-processing waste in part replacing the fossil fuel coal in calcination process

3.4.2 Environmental appraisal

EMP is an integral component of EIA process. It envisages the total management solution of air, water, noise pollution along with solid and hazardous waste emission. Ecological restoration work is supplemented with planned green-belt development. Since, it is a dry process operation, the pollution problem mainly confined to air pollution in the form of stack emission and fugitive emission. Presently highly efficient APCD equipments are available so as to comply with stringent emission standards. Zero liquid discharge norms will be easily implemented. Complete recycle of in-plant solid waste is usually practised. With highly efficient grinding equipment with in-built noise control features will be adequate to keep the noise quality with compliance standard. In this way, the organization will be able to comply with all the environmental norms.

3.3 Social appraisal

ESC is the result of public hearing outcome. The organisation is to comply with issues raised during the public hearing proceeding. Main issues will be the local employment and business opportunities along with peripheral development that includes supply of drinking water, road connectivity, renovation of school building and cultural/sports activities Involving more and more local deserving people with the production activities and meeting with their justifiable demands will instil confidence and goodwill among them for the organisation

However, these additional costs towards EMP and ESC can be nullified with the use of waste assimilation capability of cement making with the use of waste material in clinker making and as blending material in cement making. In this way, the manufacturer will earn profit despite fulfilling the environmental and social needs. RIAM analysis of impact study directly makes use of the three basic segments of sustainability as its basic components.

3.4.4 Fulfilment of SDG

The 17 numbers of SDG as defined under United Nation’ directive (Luchsinger 2024) considering from local perspective is deliberated. Local region considers the entire affected area due to implementation of the project. Besides the core zone having all the industrial activity, ten kilometre radius around the core zone is considered as impact zone or buffer zone from environmental stand-point as mentioned in ToR

specification. Accordingly, extent of fulfilment of different SDGs in the impact zone is considered here. With the consideration of local employment and business opportunities will definitely improve the well-being of the people. There is likely the alleviation of poverty and hunger (SDG1) and (SDG2). Provision of medical facilities and arrangements of medical camp will certainly improve the healthcare and well-being of the people in affected area (SDG3). As part of ESC, there will be opening of school or renovation of the existing school, provision of drinking water supply to affected villages and improving road connectivity that will likely to improve education, water supply, infrastructure and other welfare activities in the area (SDG4,SDG6, SDG11) (Fig. 2). Adequate pollution control measures to keep the ambient air quality (AAQ) under the National Ambient Air Quality Standard (NAAQS 2009) norm, zero liquid discharge (ZLD), various waste utilization programme and green belt development in local as well as impact zone are mandated by the regulatory authority as indicated in ToR document. With the sincere and professional implementation of these programmes will obviously improve the economic gain and productivity sustainably and elevate the stature of the organisation as responsible and innovative (SDG8, SDG9, SDG11, SDG12 and SDG13) (Fig. 2). So the implementation of EMP, thrust on waste utilisation schemes and allocation of funds with sincere implementation of ESC programmes will obviously improve the various sustainable development goals. The manufacturer will earn profit despite fulfilling the environmental and social needs. The organization will be identified as one who contributes towards fulfilment of SDGs like decent work and economic growth (SDG8), Industry Innovation and infrastructure (SDG9) and Responsible production and consumption (SDG12). The sustainable segments with partially satisfied SDG components are illustrated in Fig. 2.

3.5 Impact quantification using RIAM

Quantification of impact was carried out RIAM method. The different impacting actions associated with four different components are identified. Each action is allotted different values as per the criteria (Pastakia 1998, Mondal 2010). Accordingly range bands (RB) and corresponding ES values are computed with respect to each impacting action. The quantified RIAM matrix for EIA integrated with EMP and ESM (Option 1) is presented in Table 6.

Table 6
RIAM Matrix for cement manufacturing process with EMP (Option 1)

Code	Component	Criteria						
		A1	A2	B1	B2	B3	ES	RB
Physical/chemical aspects (PC)								
PC1	Land use	1	-1	2	2	2	-06	-A
PC2	Water abstraction	1	-1	2	2	2	-06	-A
PC3	SW Quality	1	-1	2	2	2	-06	-A
PC4	GW Quality	1	0	2	2	2	00	N
PC5	Air quality	1	-1	2	2	2	-06	-A
PC6	Fugitive emission	1	-1	2	2	2	-06	-A
PC7	Noise	1	-1	2	2	2	-06	-A
PC8	Solid waste disposal	1	-1	2	2	2	-06	-A
PC9	Energy use	2	-2	3	3	2	-32	-C
PC10	Climate change	3	-1	3	3	3	-27	-C
PC11	Occupational Health	1	-1	2	2	2	-06	-A
PC12	Risk & Hazard	1	-1	1	2	2	-04	-A
PC13	Safety and fire	1	-1	1	2	2	-04	-A
Biological /Ecological aspects (BE)								
BE1	Ecological Sensitivity	1	-1	3	3	2	-08	-A
BE2	Endangered/Endemic species	1	-1	3	3	2	-08	-A
BE3	Biodiversity	2	-1	3	3	2	-16	-B
BE4	Loss of vegetation	1	-1	2	2	2	-06	-A
BE5	Green-belt development	1	+ 1	2	2	2	+ 06	+B
Social /Cultural aspects (SC)								
SC1	ESC-Employment to locals	2	2	3	3	2	+ 32	+C
SC 2	ESC-Business opportunities	2	2	3	3	3	+ 36	+C
SC 3	ESC-Local Infrastructure	1	2	3	3	2	+ 16	+B
SC4	ESC-Education and culture	1	1	3	3	2	+ 08	+A

Code	Component	Criteria						
		A1	A2	B1	B2	B3	ES	RB
SC5	Migration of people	2	-1	2	2	2	-12	-B
SC6	Loss of land (livelihood)	1	-1	3	3	2	-08	-A
SC7	Displacement of people	2	-1	3	3	2	-16	-B
Economical/Operational aspects (EO)								
EO1	Profit	2	3	3	3	3	+ 54	+D
EO2	Employment generation	2	2	3	3	3	+ 36	+D
EO3	Ancillary development	2	2	3	3	3	+ 36	+C
EO4	Importance of product	2	1	2	2	2	+ 12	+B
EO5	Tax payment to government	2	1	3	3	2	+ 16	+B
EO6	Cost of Regulatory compliance	2	-1	2	2	2	-12	-B
EO7	EMP cost-air pollution control	2	-1	2	2	2	-12	-B
EO8	EMP-cost-water management	2	+ 1	2	2	2	+ 12	+B
EO9	EMP-Noise pollution control	1	-1	2	2	2	-06	-A
EO10	EMP-Greenbelt development	1	-1	2	2	2	-06	-A
EO11	Compensation- rehabilitation	2	-1	2	3	2	-14	-B
EO12	ESC Cost- Drinking water	1	-1	3	3	2	-08	-A
EO13	ESC Cost- Infrastructure	1	-1	3	3	2	-08	-A
EO14	ESC-Education and culture	1	-1	2	2	2	-06	-A

3.6 Waste absorption in cement manufacturing process

Substitution of raw material by waste components

Many industrial wastes have been identified for use in cement production process. In the raw meal preparation many waste material like iron bearing waste namely mill scale, red mud, blast furnace dust etc. can be used in place of naturally sourced material. These wastes are normally available in the various integrated steel, thermal power, alumina refinery etc. in the nearby industries located within 100 to 150 km around the project site.

Co-processing with coal and waste fuel

In order to reduce the dependence in fossil fuel like coal and natural gas, waste fuel like used oil/lubricant and oily sludge can be used as fuel with coal in calcination process. The combustible components of Municipal Solid Waste (MSW) and waste plastics are segregated and are size reduced so as to utilise these waste along with coal powder as co-processing utility in rotary kiln for calcination purpose. Hazardous industrial waste like used oil, used lubricant, waste plastic and oily sludge can be used along with main fuel coal (Lamas et al 2013, Tsiliyannis 2018). Cement production units using co-processing with coal are to comply with the regulatory emission standards as shown in Table 3 (b).

Waste blended cement

Originally envisaged raw material based Ordinary Portland Cement (OPC) is now replaced by waste assimilated blended cement. Currently, Portland Slag Cement (PSC), Portland Pozollana Cement (PPC) utilise 50–60% of waste blast furnace slag and around 30% of fly ash respectively and these are now commercially well accepted. Now, Portland Composite Cement (PCC) consumes waste slag, fly ash and phosphogypsum up to 80–85% and is gaining public acceptance. Chemical phosphogypsum is a hazardous waste in phosphate fertiliser industry and flue gas desulphurisation (FGD) residue in coal based thermal power plants can be suitably processed and the processed chemical gypsum may be used replacing resource based mineral gypsum for cement setting process.

Carbon reduction potential of blended cement

There is mass scale usage of ground granulated blast furnace slag (GGBFS-50-60%) and fly ash (FA-30%) in commercial cement codified in India. These blended cements have been vastly popular and widely used. In addition to resource saving, there is appreciable reduction of carbon emission (40%) in PSC and (23%) in PPC (Gettu et al 2019).

Recycling of in-plant waste

In plant particulates collected in air pollution control devices (APCD) attached with VRM raw meal preparation, rotary kiln and cement grinding and packing units are normally recycled to the same process units. Thus, zero solid waste emission can be conveniently achieved in cement manufacturing process.

Zero liquid discharge

In a dry process cement production unit, the make-up water consumption is usually less and mostly required for direct and indirect cooling process. Normally small amount of cooling tower blow down in case of indirct cooling and the collection of direct cooling water is collected and cooled in settling pond. Retrieved wastewater may be recycled to direct cooling and some will be required for dust suppression and in the green-belt area. Thus, a complete zero liquid discharge (ZLD) norms can be achieved complying with one of the ToR condition.

Waste heat recovery

Flue gas released from the rotary kiln have the temperature around 900–100^0 centigrade. This hot kiln flue gas is recirculating through the pre-heater section of the rotary kiln for transfer of heat to incoming raw meal. The flue gas after giving away the heat content comes below 150^0 centigrade and can be safely routed through the APC device and tall stack. The waste heat may be utilised in drying the blast furnace slag and fly ash used up in production of blended cement. RIAM matrix with EMP and waste utilisation is presented in Table 7.

Table 7
RIAM Matrix with EMP and Waste absorption (Option 2)

Code	Component	Criteria						
		A1	**A2**	**B1**	**B2**	**B3**	**ES**	**RB**
Physical/Chemical aspects (PC)								
PC1	Land use	1	-1	2	2	2	-06	-A
PC2	Water abstraction	1	-1	2	2	2	-06	-A
PC3	SW Quality	1	-1	2	2	2	-06	-A
PC4	GW Quality	1	0	2	2	2	00	N
PC5	Air quality	1	-1	2	2	2	-06	-A
PC6	Fugitive emission	1	-1	2	2	2	-06	-A
PC7	Noise	1	-1	2	2	2	-06	-A
PC8	Solid waste disposal	1	-1	2	2	2	-06	-A
PC9	Energy use	2	-2	3	3	2	-32	-C
PC10	Climate change	3	-1	3	3	3	-27	-C
PC11	Occupational Health	1	-1	2	2	2	-06	-A
PC12	Risk & Hazard	1	-1	1	2	2	-04	-A
PC13	Safety and fire	1	-1	1	2	2	-04	-A
Biological /Ecological aspects (BE)								
BE1	Ecological Sensitivity	1	-1	2	2	2	-06	-A
BE2	Endangered/Endemic species	1	-1	3	3	2	-08	-A
BE3	Biodiversity	2	-1	3	3	2	-16	-B
BE4	Loss of vegetation	1	-1	2	2	2	-06	-A
BE5	Green-belt development	1	+1	2	2	2	+06	+B
Social /Cultural aspects (SC)								
SC1	ESC-Employment to locals	2	2	3	3	2	+32	+C
SC 2	ESC-Business opportunities	2	2	3	3	3	+36	+C

Code	Component	Criteria						
		A1	A2	B1	B2	B3	ES	RB
SC 3	ESC-Local Infrastructure	1	2	3	3	2	+16	+B
SC4	ESC-Education and culture	1	1	3	3	2	+08	+A
SC5	Migration of people	2	-1	2	2	2	-12	-B
SC6	Loss of land (livelihood)	1	-1	3	3	2	-08	-A
SC7	Displacement of people	2	-1	3	3	2	-16	-B
Economical/Operational aspects (EO)								
EO1	Profit	2	3	3	3	3	+54	+D
EO2	Employment generation	2	2	3	3	3	+36	+D
EO3	Ancillary development	2	2	3	3	3	+36	+C
EO4	Tax payment to government	2	1	3	3	2	+16	+B
EO5	Importance of the product	2	1	2	2	2	+12	+B
EO6	Cost of Regulatory compliance	2	-1	2	2	2	-12	-B
EO7	EMP cost-air pollution control	2	-1	2	2	2	-12	-C
EO8	EMP-cost-water management	2	+1	2	2	2	+12	+B
EO9	EMP-Noise pollution control	1	-1	2	2	2	-06	-B
EO10	EMP-Greenbelt development	1	-1	2	2	2	-06	-A
EO11	Compensation- rehabilitation	2	-1	2	3	2	-14	-B
EO12	ESC Cost- Drinking water	1	-1	3	3	2	-08	-A
EO13	ESC Cost- Infrastructure	1	-1	3	3	2	-08	-A
EO14	ESC-Education and culture	1	-1	2	2	2	-06	-A
Waste Absorption (WA)								
WA1	In plant waste utilisation	1	1	2	2	2	+06	+A

Code	Component	Criteria						
		A1	A2	B1	B2	B3	ES	RB
WA2	Use of other industry waste in raw meal preparation	2	2	2	2	2	+ 24	+C
WA3	Blending of other industry waste in cement production	2	2	3	3	3	+ 36	+D
WA4	Usage of waste fuel blended with coal-co-processing	2	2	3	3	3	+ 36	+D
WA5	Waste heat recovery/reuse	1	1	3	3	2	+ 08	+A
WA6	Saving of resources	2	2	3	3	3	+ 36	+D
WA7	Energy saving	2	1	3	3	3	+ 18	+C
WA8	Carbon dioxide reduction	3	1	3	3	3	+ 27	+C

3.7 Estimation of Total Environmental Score (TES)

Considering waste scavenging aspect in cement industry, Waste Absorption (WA) is included along with the other criteria to the original RIAM assessment. Instead of solely focussing on Range Band, it is proposed to estimate Total Environmental Score (TES) in RIAM analysis for both the options. The results are displayed in Table 8.

Table 8
Summary of scores (RB) & ES with EMP and EMP with Waste Absorption

Class	-108 to -72	-71 to -36	-19 to -35	-10 to -18	-1 to -9	Total –ve score	0	1 to 9	10 to 18	19 to 35	36 to 71	72 to 108	Total + ve score	TES
	-E	-D	-C	-B	-A	-RB	N	A	B	C	D	E	+RB	TES
Summary of scores and Total Environmental Score (TES) with EMP														
PC			2	-	10		1	-	-	-	-	-		-115
BE				1	3			1						-32
SC				2	1			1	1	2				+ 56
EO				3	5				3	1	2			+ 94
Total			2	6	19	-27	1	1	4	3	2		+ 10	-03
Summary of scores and TES with EMP and waste absorption														
PC			2	-	10		1							-115
BE				1	3			1						-32
SC				2	1			1	1	2				+ 56
EO				3	5				3	1	2			+ 94
WA								2		3	3			+ 155
Total			2	6	19	-27	1	4	4	6	5		+ 19	+ 152

3.8 Justification for the implementation of project

The EIA study with EMP was conducted for the cement project as per the ToR conditions prescribed in scoping stage. The public consultation programme duly conducted at the project site noted the comments aired at proceeding. In fact the project proponent is duty bound to spend 2 to 3% over all capital expenditure as a part of Enterprise Social Commitment (ESC). Equipped with stringent air and noise pollution control measures with rationalisation of EMP and strengthened by the ESC measures, the sustainability issues are well represented in EIA and EMP report for environmental clearance of the project. RIAM matrix for EIA and EMP with ESC measures as Option 1 take care all the segments of sustainability and expectedly get the good RB and better ES (-3) highlighting the slight negative impact.

Implicitly evident in ToR specifications, encouraged by the research and innovation that cement industry has emerged as a waste agglomeration unit, Herewith, slight departure from the original idea proposed by Pastakia et al 1998, we propose the RIAM method with EIA and EMP and Waste Utilisation (WU) as

Option 2 to compute the total RB and ES. As expected, the ES undergoes the appreciable improvement with high positive score (+ 152) Hence the RIAM computation with EIA, EMP, ESC and waste utilisation aspects need to be considered while granting EC for the cement projects.

4.0 Conclusion

Cement industry is considered for sustainability assessment in its EIA and EMP study. The following conclusions may be inferred.

- Terms of Reference (ToR) as prescribed by scoping committee to prepare the EIA and EMP report have inherent sustainability segments.
- Some of the seventeen United Nations Sustainability Development Goals (SDG) applying at the local level is partially satisfied considering at local/regional level.
- In co-processing, many waste fuels from segregated MSW and hazardous waste fuel from industry and urban area can be used with fuel coal in calcination process.
- Cement industry can be rightly called a waste agglomeration unit with the usage of many wastes as raw material, co-processing with fuel and blending agent in cement grinding process. Significant carbon reduction results with the blending of waste in cement manufacturing as compared to the originally envisaged raw material based Portland cement.

Slightly modified RIAM matrix analysis considers Total Environmental Score (TES) for EIA study with EMP along with Waste Absorption potential of the cement manufacturing industry comes out to be appreciably positive justifying the acceptance of the project at the proposed site.

Declarations

Declaration of competing interest

Ethics, Consent to Participate, and Consent to Publish declarations: not applicable.

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Author Contribution

Author Contributions: Amiya Kumar Das and Manmatha Kumar Mohanty collected the empirical data and conducted the statistical analysis. Trilochan Jena and Chittaranjan Panda designed the research framework and supervised the project and drafted the manuscript. Sudhansu Sekhar Biswal and Bibhu

Prasad Panda provided critical reviews and substantively revised the text for intellectual content. All authors have read and agreed to the published version of the manuscript, and accept personal accountability for the integrity of the work.

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Data availability

Data is provided within the manuscript or supplementary information files.

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Figures

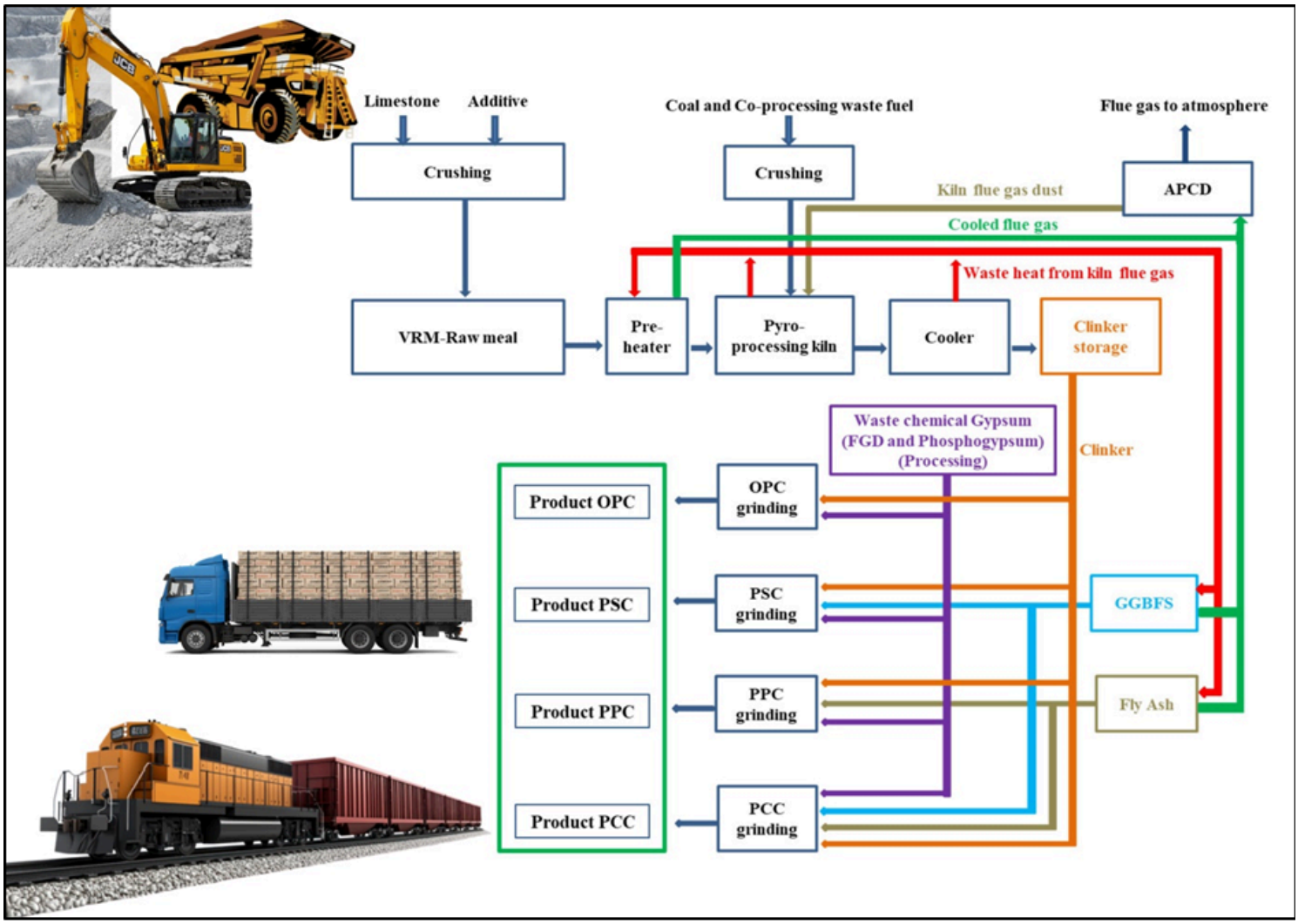


Figure 1

Cement manufacturing process flow diagram

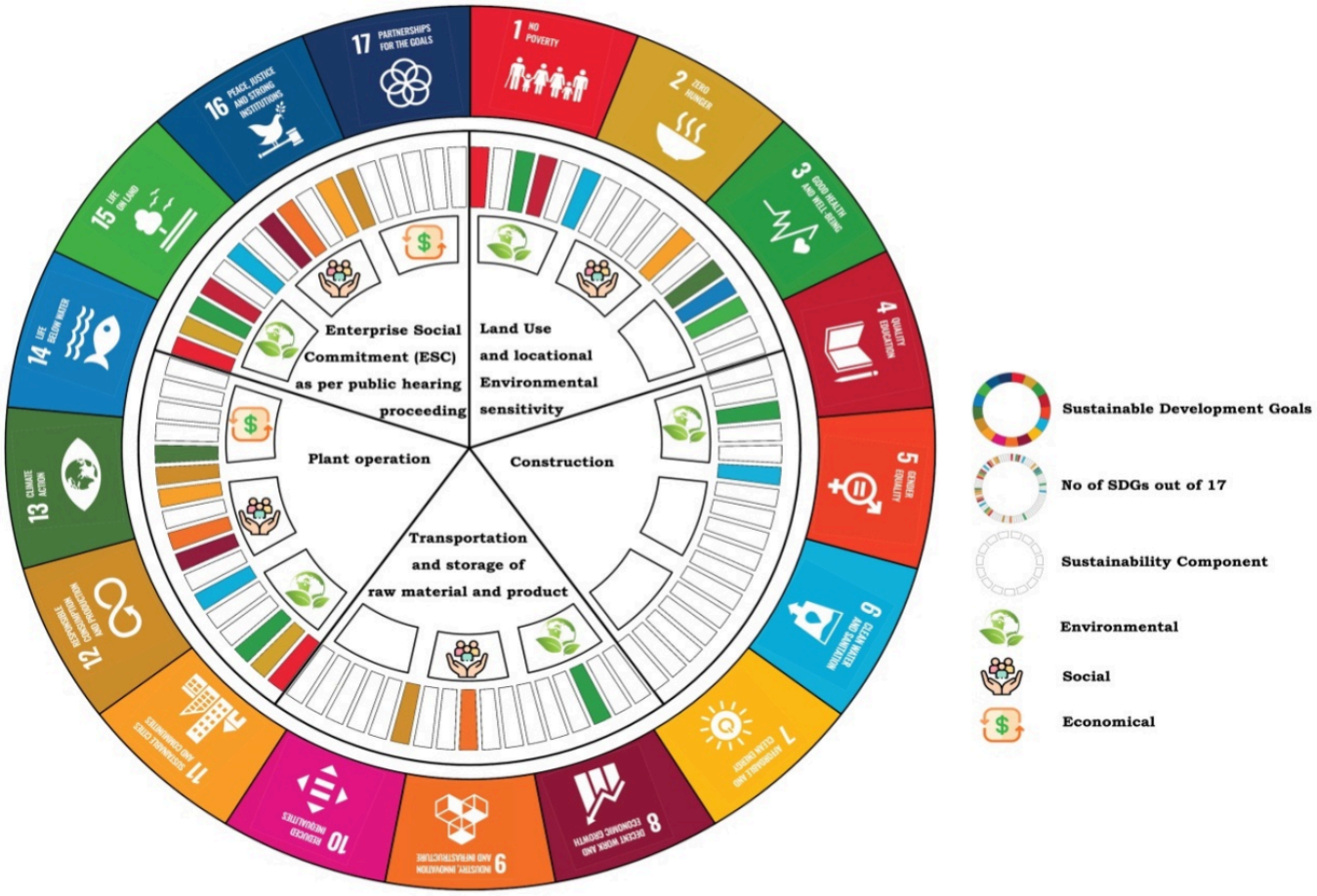


Figure 2

Sustainability component with the SDGs depicting the impacting actions