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Life Cycle Sustainability Analysis of Cement Industry through Evaluation Framework

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ABSTRACT

Cement industry is under development from initial extraction phase to final process of concrete due to lack of advance techniques used in the process. The life cycle of concrete involves waste, atmospheric dust, carbon dioxide and excess fuel consumption resulting in poor economic, environment and societal impacts. Unless some restricted conventions are imposed by resident establishments to make sure compliance with national and international standards upon this industry, the rise of cement plants and their connected quarries in the area may weaken the quality of air, quality of life, workers' health and safety, and thus can destroy the fragile ecosystems in the area. Therefore, cement industry requires an augmented model and improved methods at process, product and service levels. This research focuses on the total life cycle of cement product under the environmental, societal, and economic indicators of sustainability. Different sets of questionnaires are distributed among different cement industries. On the basis of significant parameters under economic, societal and environmental indicators marked by executives, experts and workers, a framework is developed to find the sustainability of cement industries. Its result shows that the cement industry has a total product sustainability index value of 46% and is evaluated at the average level of sustainable development after comparison with the international standards.
Keywords: Sustainability, Sustainability indicators, Product index value, Sustainability framework, Cement industry.

1. INTRODUCTION

Cement is the elementary material of construction and the utmost commonly used construction material [1]. Only cement has the potential of increasing viscosity of concrete which in returns delivers improved locking of sand and gravels together in a concrete mix [2]. Cement industry is booming in the Middle East and North African countries due to fast population growth, revolution in living style and availability of raw material in the area. Restricted conventions are necessary to protect the quality of environment and life [3]. There is a growing need to make cement industry sustainable based on economic, societal and environmental indicators. Cement manufacturing is based on energy and resources and it has both good and bad effects. The effects are both local and worldwide. Certain criteria in terms of sustainability business, addressable basic problems, focus of the industry are analyzed. Jawahir defines sustainability development as a policy deal to fulfill the need of current generation by considering the capability of coming generations to meet their requirements [4]. It is an idea that systems comprising natural and human ones need to be re-formed [5]. Design and manufacture of goods having high value product with improved functionality include energy efficient safe technologies and manufacturing procedures. Such systems use optimal assets and energy by generating less wastes and discharges, and provide supreme recovery, reusability, recyclability and re-manufacturability with redesign features.

Social sustainability deals with the social structure, such as a domestic, society and country to work at a definite level of public harmony and welfare. Problems like battle, injustice, scarceness, and low literacy rates are the indications if a system is socially not sustainable [6-9]. Environmental sustainability can be defined as the capability of the environment to support high quality and extractions of natural assets at a definite level. [10]. Economic sustainability deals with the economy to maintain a definite level of economic production. Since the

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Great Recession of 2008, this is the world's biggest seeming problem, which threatens the development on the environmental sustainability issues [11]. The 2005 World Summit on societal development has identified economic and societal development and environmental protection as a sustainable progress goals [12]. Figure 1 shows three indicators of sustainability that are not totally unrelated and can be commonly strengthening. These indicators are common basis for sustainable process. Standards of triple bottom line consist of Rainforest Alliance, Fair trade and UTZ Certified [13].

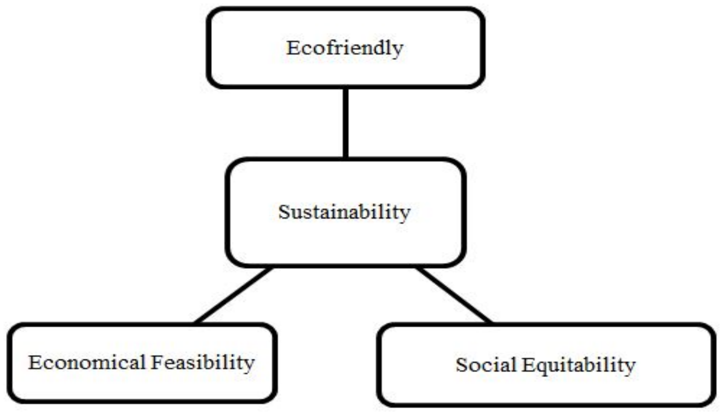
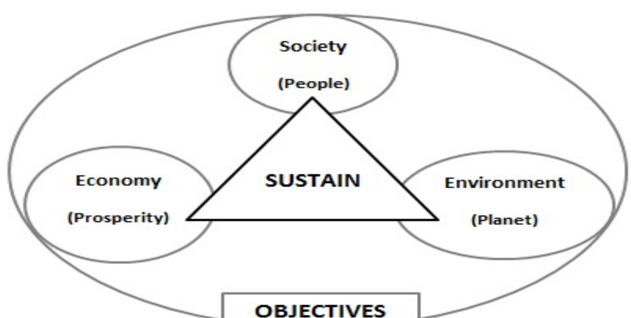


Figure 1.Three major indicators of sustainability

Such a sustainable manufacturing requires efforts on product, process and system levels with the entire supply chain with objectives that are given in figure 2 [5].



SOCIETY	ENVIRONMENT	ECONOMY
• Improved Health • Safety • Enhanced Quality of Life • Ethics	• Cleaner Air, Water, Soil • Eco-balance & Efficiency • Greater Implementation of Regulations & Codes	• New Employment • Product & Process Innovation • Large Scale New Business Opportunities

Figure 2.Objectives of sustainable manufacturing

There are different issues at different levels. It covers the public impacts, concentrating on community welfare including public health and safety, living surroundings, and landscape aesthetics [14, 15]. This research focuses on the total life cycle of cement products under the environmental, societal, and economic indicators of sustainability. Different sets of questionnaires are distributed among different cement industries. On the basis of significant parameters under economic, societal and environmental indicators marked by executives, experts and workers, a framework is developed to find sustainability of cement industries. This research includes explanation of the data based on economic, environmental and social indicator, that would help business to pinpoint those factors which can cause unsustainable environment in cement industry and try to work on those factors to improve the overall sustainability of the industries.

2. LITERATURE REVIEW

Cement is a binder which hardens the elements to produce joint [16]. The volcanic ash as well as pulverized components added to the actual burnt lime scale, to acquire a hydraulic binder, is later called cementum, cimentum or cement. Cements utilized in development might be characterized as hydraulic or non-hydraulic, depending on the capability of the cement used with water [17, 18]. Hydraulic cement is made by using stimulated lightweight alloy silicates and pozzolanas. The chemical reaction ends in hydrates which are soluble in water and so are quite resilient within drinking water and protected from chemical substances [19-22].

Limestone is utilized to produce Portland cement. Portland cement is the most often applied material throughout the production of concrete [23]. The long-term result connected with buildings can be reduced, where the design connected with resilient buildings is actually paramount [24]. For the products degree, it must transfer from 3R concept (Reduce, Recycle, Reuse) to 6R concept (Reduce, Recycle, Recover, Redesign, Remanufacture, Reuse). For process degree, strengthened technology with good practice set up must be available along with minimized waste products and risks [25]. All significant life time stages like pre manufacturing and production are considered in search engine optimization involving Green Creation [26]. Replacement of toxic material by non-toxic material, reduction in unsustainable output and recycling of waste materials are recommended [27].

3. METHODOLOGY

The process flows are significant to represent the problem statement and methodology of the research in the field of manufacturing sector [28]. Figure 3 shows the flow chart for this research methodology which starts with the literature review regarding sustainable development.

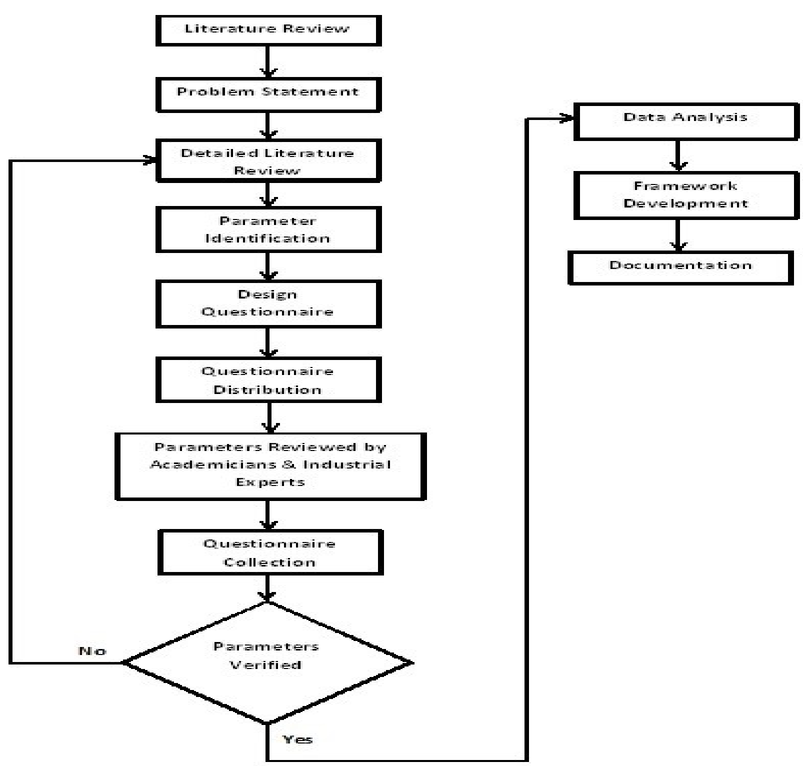


Figure 3.Flow chart of research methodology

Every product during its entire life cycle passes through four different phases i.e. pre-manufacturing, manufacturing, use and post-use. For life cycle of product, Gupta and Jawahir's forty indicators are selected as preliminary indicators [29]. During visits, the whole process from pre-manufacturing phase to final product packaging is analyzed and different parameters of significant indicators that have environmental, societal, and economic impact are observed, and the preliminary indicators are divided into sub-parameters as shown in table 1. On the basis of significant parameters for the first two phases, a questionnaire is developed. A total of 300 questionnaires are distributed among well-known engineers, executives, experts and workers of cement industries and 240 responses are received. For the next two phases i.e., Use and post-use phase, customers from different localities, contrac-

Table 1.Parameters for pre-manufacturing and manufacturing phases

<table>
<tr><th></th><th>Pre manufacturing phase indicators</th><th>Parameters</th><th>manufacturing phase indicators</th><th>Parameters</th></tr>
<tr><td rowspan="3">Environment</td><td>Material Extraction</td><td>1. Equipment's used
2. Process/ Blasting</td><td>Production Energy used</td><td>1. Tyres
2. Coal
3. Electricity
4. Other materials used/ Fuel</td></tr>
<tr><td>Material processing</td><td>1. Methods used
2. Equipment's used
3. Energy used/Fuel</td><td>Hazardous waste produced</td><td>1. Ash
2. Dust
3. Nitrogen oxide/Sulphur dioxide</td></tr>
<tr><td>Design for environment</td><td>1. Environment friendly Processes</td><td>Renewable energy used</td><td>1. Waste heat recovery
2. Energy recycling</td></tr>
<tr><td rowspan="5">Society</td><td>Work health</td><td>1. Soil
2. Air
3. Water
4. Noise
5. Dust</td><td rowspan="2">Work ethics</td><td rowspan="2">1. Relationship B/W workers &employees
2. Direct/ Indirect distinctions
3. Motivation
4. Sense of teamwork
5. Sense of responsibility
6. Integrity
7. Discipline</td></tr>
<tr><td>Work safety</td><td>1. Equipment's used
2. Tools used
3. Materials used
4. Sensors used for safety and equipment</td></tr>
<tr><td rowspan="3">Ergonomics</td><td rowspan="3">1. Work time
2. Material handling
3. Tools
4. Equipment's used for handling</td><td>Ergonomics</td><td>1. Continuous monitoring
2. Material handling
3. Tools/ Equipment's used for handling
4. Job hours</td></tr>
<tr><td>Work safety</td><td>1. Equipment's used
2. Tools's used
3. Material used</td></tr>
<tr><td>Work health</td><td>1. Ash
2. Dust
3. Smell
4. Noise</td></tr>
<tr><td rowspan="4">Economy</td><td>Raw material cost</td><td>1. Quality cost
2. Transportation cost
3. Waste produced</td><td>Production cost</td><td>1. Setup cost
2. Inventory cost
3. Equipment/Tools cost</td></tr>
<tr><td rowspan="3">Labour cost</td><td rowspan="3">1. Number of workers
2. Skilled workers
3. Unskilled workers
4. Incentives
5. Training</td><td>Packaging cost</td><td>1. Bags quality
2. Packaging cost</td></tr>
<tr><td>Energy cost</td><td>1. Fuelss
2. Tyres
3. Other resources</td></tr>
<tr><td>Transportation cost</td><td>1. Material handling
2. Supply</td></tr>
</table>

tors, masons and cement industry experts are consulted and different significant parameters and their impact are discussed as shown in table 2. On the basis of the significant parameters for the use and post-use phases, second questionnaire is developed and a total of 200 questionnaires are distributed, and out of which, 160 are received.

Table 2.Parameters for use and post-use phases

	Usage phase parameters	Post-usage phase parameters
Environment	1. Emissions 2. Functionality 3. Hazardous waste generated	1. Recyclability 2. Re-manufacturability 3. Redesign 4. Landfill contribution
Society	1. Product pricing 2. Human safety 3. upgradeability 4. Complaints	1. Take back option 2. Re-use 3. Recovery
Economy	1. Maintenance cost 2. Repair cost 3. Consumer injury cost 4. Consumer warranty cost	1. Recycling cost 2. Disassembly cost 3. Disposal cost 4. Remanufacturing cost

4. DATA ANALYSIS

Average values extracted from questionnaire represent the value of indicator given by Gupta. The feedback of the questionnaires is analyzed. As a result of analysis, some parameters that were marked as invalid are excluded and some parameters are suggested by experts. To find the Product Sustainability Index (PSI), a generalized

A Framework for Total Life Cycle Evaluation Matrix for Cement Industry Sustainability

Sustainability Components	Pre-Manufacturing Phase	Score Out of 5	Manufacturing Phase	Score Out of 5	Usage Phase	Score Out of 5	Post Usage Phase	Score Out of 5		
Environment	Material Extraction	1	Productin Energy Used	2.5	Emission	3	Recyclability	0		
	Design for Environment	1.2	Hazardous Waste	3	Functionality	3	Remanufacturability	0		
	Material Processing	1	Renewable Energy Used	1.3	Hazardous waste generated	4	Redesign	0	PSI_{en} =	34.6
							Landfill contribution	1		
	$PSI_{(en\_min)}$ =	21.33333333	$PSI_{(en\_pro)}$ =	45.33333333	$PSI_{(en\_use)}$ =	66.6667	$PSI_{(en\_pu)}$ =	5		
		◔		◑		◕		◔		◔
Society	Worker Health	1.75	Work Ethics	3.28	Product pricing	3	Take Back option	2		
	Worker Safety	2	Ergonomics	2.75	Human safety	2	Reuse	0		
	Ergonomics	3	Work Safety	2	Upgradeability	1	Recovery	0	PSI_{so} =	36.3
			Worker Health	2.33	Complaints	1				
	$PSI_{(so\_min)}$ =	45	$PSI_{(so\_pro)}$ =	51.8	$PSI_{(so\_use)}$ =	35	$PSI_{(so\_pu)}$ =	13.33333		
		◑		◑		◔		◔		◔
Economy	Raw Material Cost	2.67	Production Cost	2.67	Maintenance cost	5	Recycling Cost	4		
	Labor Cost	2.4	Packing Cost	2.5	Repair Cost	3	Disassembly Cost	5		
			Energy Cost	3	Consumer injury cost	5	Disposal Cost	2	PSI_{ec} =	67.3
			Transportation Cost	2.5	Consumer warranty cost	4	Remanufacturing Cost	5		
	$PSI_{(ec\_min)}$ =	50.7	$PSI_{(ec\_pro)}$ =	53.35	$PSI_{(ec\_use)}$ =	85	$PSI_{(ec\_pu)}$ =	80		
		◑		◑		●		●		◕
	PSI_{pm} =	39.01111111	PSI_{m} =	50.16111111	PSI_{u} =	62.2222	PSI_{pu} =	32.77778	PSI_{TLC} =	46
										◑

Symbol	●	◕	◑	◔
Score	Excellent >=74%	60%=<Good<74%	40%=<Average<60%	Poor <40%

Figure 4.Framework for total life cycle evaluation matrix for cement product sustainability

method proposed by Jaafar as given in (1) is used which is the weighted sum of different sub-indicators of three main sustainability indicators [30]. For example, at manufacturing phase, the PSI value of societal indicator is calculated using (1).

$$PSI_{so\_mn} = \left[\frac{\sum_{i=1}^{n} IF_{so\_mn}}{n \times 5}\right] \times 100\% \tag{1}$$

where IF_{so_mn} is the influencing factor ranging from 0-5 for the societal indicator at manufacturing stage and n is the number of factors considered. All other indicator's PSI values can be calculated in the same way. For any phase in the life cycle, the PSI value can be found out by taking average of the PSI values across the three sustainability components column wise. Similarly, the PSI value for any sustainability indicator i.e. environment, society and economy, across the four phase-life cycle of product can be determined by averaging the PSI values row wise. The Total PSI (PSI_{TLC}) can be calculated using (2).

$$PSI_{TLC} = \frac{PSI_{en} + PSI_{so} + PSI_{ec}}{3} \tag{2}$$

The impact of these indicators during the four phases of product life cycle is calculated as shown in figure 4. The framework shows that cement industry is sustainable. The framework also shows the product sustainability index value during the four phases of cement life cycle based on the three sustainability indicators.

5. RESULTS AND DISCUSSIONS

The significant economic, environmental and social indicators are found out and selected for the evaluation of cement industry in terms of sustainability. An organized and detailed framework is utilized to find the sustainability index of the cement industry. The framework is essential to provide the sustainability index values among three major factors on the basis of life cycle phases of cement industry. After the analysis of the data and application of framework, it is resulted that the cement industry has a PSI_{TLC} value of 46% known as normal value. When comparing with international standard, this value is at an average level of sustainable development. At column wise, the value of PSI with respect to environment PMI i.e., PSI_{en} 3.46 (34.6%) is below average level showing that the product is environmentally underdeveloped. While looking at the economic indicator column wise, the PSI value is 6.73 (67.3%) which is in the good region indicating that the cement product is economically developed. Furthermore, the product's post usage phase is very weak for sustainability in the form of recycling, redesign, remanufacturing and other disposal methods i.e., PSI_{pu} = 3.27 (32.7%) less than normal value. An evaluation criterion is developed specifically for the cement industry. The framework is very effective to calculate the PSI value at any phase based on PMIs.

6. CONCLUSIONS

The cement industry highly depends upon the production and management. It is under developed due to lack of advance management techniques in the form of clean, green and sustainable manufacturing. A framework is utilized to obtain the evaluation criteria of cement industry and for the assessments of the firms. Cement industry is environmentally and socially under developed with PSI values of 34.6% and 36.3% respectively. It needs sustainable development at environmental and societal level. For calculating sustainability index, a generic framework is developed. The results are meaningful to the cement managers to understand the week and strong areas on the basis of sustainability. The results are also beneficial to find the sustainability of each phase of the product. Overall the cement industry is moderately sustainable, which needs further development. The significant parameters among the three sustainability components are assessed and verified by cement industry experts, which can be considered in future research. The future extensions of this research can be the development of complex and generic framework for the implication of sustainability life cycle in other manufacturing and service industries. The significant factors used as performance measurement criteria can be selected by using analytical hierarchical process, analytical network process and data envelopment analysis. Altogether, this research provides a significant base for the experts and industrialists to understand the life cycle sustainability process and its importance.

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