Measuring Environmental Costs: The role of Construction Supply Chain Management, Material Flow, Environmental Practices, and Life Cycle Costing

Ahmed Ghazi Taher, College of Administration and Economics – University of Basrah
Email: ahmed.ghazi@uobasrah.edu.iq

Suhail Abdullah Nasser Al-Timeemi, College of Administration and Economics – University of Basrah
Email: Suhail.naser@uobasrah.edu.iq

Corresponding Author: Ahmed Ghazi Taher, Email: ahmed.ghazi@uobasrah.edu.iq

ABSTRACT

Dealing with the environmental cost and its reduction is the key concern among several policymakers for which the role of construction supply chain management is quite evident. Considering this notion, in the first phase, the study investigates environmental cost measurement and reduction strategies in cement production, focusing on the research and development stage, lost quarries and crushers, and the mill stage at the Badoosh Expansion Cement Plant for the years 2021–2023. More specifically, the objective of this research is to identify the use of techniques for measuring environmental costs and to examine Material Flow techniques, Product Life Cycle Costing, and Benchmarking. The Ministry of Industry and Minerals / the Iraqi General Cement Company / Northern Cement Directorate was selected as the study population, and the Badoosh Expansion Cement Plant was chosen as the study sample. The applied study was conducted at the plant through personal interviews and repeated meetings with accountants and officials at the plant and the directorate, in addition to collecting accounting data from the plant's books and records. Environmental costs were measured using Material Flow techniques, Product Life Cycle Costing, and Benchmarking for three years (2021–2023), in order to calculate the environmental costs arising from abnormal losses across all production stages. The study reached several key conclusions, most notably that the Badoosh Expansion Cement Plant generally bears higher environmental costs, whether in absolute terms or in the ratio of environmental costs to total costs in some years, although the ratios of environmental costs to total costs remain within a relatively close range (7.134%–10.316%). This indicates that resource-use efficiency at the Badoosh Expansion Cement Plant is better, despite its large production scale; however, further improvement is still required to achieve a competitive advantage in the cost per ton produced. Moreover, in the second phrase, the study by using the quantitative survey of investigation (sample of 246 respondents) reveals that among several factors, the role of construction supply chain management is significantly positive and the highest in nature in determining the environmental cost reduction, followed by the life cycle costing and material flow optimization, respectively. However, the study was unable to find any significant influence of the environmental practices towards the environmental cost reduction for which there is a need to reconsider the current practices followed by the relevant industry.

Keywords: Environmental cost measurement, material flow, product life cycle, benchmarking.

INTRODUCTION

The measurement of environmental costs is mainly related to specification and quantification of the costs related to the environmental impact of the production process of the company or industry (Jasch, 2003; Nickie Petcharat & Mula, 2012; Panagiotopoulou et al., 2021). It contains the direct costs dynamics in the form of waste management, emissions and energy utilization as well as some indirect costs that are associated with the damage to the environment and regulatory compliance, respectively (Imran et al., 2024; Shahbazi et al., 2023). The key aspect is that by using techniques such as material flow or simply the MF (Malega et al., 2024) and life cycle costing (Rodrigues & da Silva, 2024), The cost of the environment can be followed by business groups and industries at every production step. Also, there is the aspect of benchmarking where the performance of a company is compared with the industry standards, area of improvement is identified. At the same time the element of precise measurement would be favorable to the aim of observing the inefficiencies and limit waste that could lead to more sustainable operations to the industry and business units. It also allows the businesses to lower-down on their expenses towards the aim of enhancing the competitiveness in the process of promoting cleaner production methods. It eventually leads to environmental and financial sustainability of the business groups.

Among others, the construction industry is commonly referred to as having a higher degree of consumption of the sources with the high production of waste, which creates an adverse effect on the environment (Xu & Wang, 2020). Furthermore, as the economies of the globe continue to strain towards the circular economy, consequently, there has been an increased tendency to the clean production and conservation of resources by the building industry, as well (Guerra et al., 2021). Nonetheless, it is evident that the critical information in the industry is disjointed because the construction industry has many individuals with each linking up with their own information and resources (Guerra et al., 2021). Furthermore, to promote the practice of sustainable development, the construction requires a lot of industrialization and enhancement in the interaction of various resources and factors. To facilitate the sustainable development practices, the requests towards the collaboration of various practices have been submitted at the global level as interconnected with various activities in relation to construction (Liao et al., 2023). That is why the concept of construction supply chain management has been proposed, in which the main objective is to deliver the projects on time within the potential reduced cost, and consider the economic and environmental aspects. This would reflect the idea of establishing the collaboration between the companies as well as the integration of the information, therefore enabling the construction teams to streamline their work on the project-based management idea (Liao et al., 2023).

This study has been carried out in two stages. On the initial phase, it has attempted to explore concerning the measurement of the cost of environment research and development phase in the Badoosh Expansion Cement Plant, an industrial plant owned by the state in the territory of Iraq. The most important in the country is the plant industry as it satisfies the domestic demand. In the further analysis, the study has aimed to analyze the environmental Costs of Lost Quarries and Crushers for Badoush Expansion Plant for the Years 2021 / 2022 / 2023. Furthermore, the analysis for the Environmental Costs of Loss from the Mill Stage of the Badoush Expansion Plant for the Years 2021 / 2022 / 2023 has also been provided for the better understanding. For this purpose, the key objective is to conduct the environmental cost analysis and reduction strategies in cement production.

The study followed the first phase with the second stage which primarily relates to the analysis of the role of the construction supply chain management, environmental practices, optimization of material flow and life cycle costing to the environmental cost reduction through the collection of the data of the various respondents who worked in the same region and had the job title of Plant Manager, Production Supervisor, Environmental Officer, and Supply Chain Coordinator. The study is meaningful as it comes up with a survey questionnaire (see appendix-1) the outcomes of which indicate that the largest and most substantial impact of construction supply chain management on the environmental cost reduction comes first, and then the life cycle costing, and material flow, respectively.

PREVIOUS STUDIES

Benchmarking has also been determined as basic measure of comparing the cost of energy in a company with that of other companies and to establish the origins of the cost difference and the ultimate goal is to establish the strengths and performance improvement opportunities (Al-Sabaawe et al., 2024). It is possible to define benchmarking as multi-faceted process of gradual enhancement designed to create higher value on the money, or systematic approach of comparing the performance of an organization with other organizations in the same sphere, drawing on the knowledge of the most pertinent information to make specific improvements.

According to the above-presented definitions, benchmarking may be referred to as a contemporary managerial accounting method, which assumes the comparison of the activities and practices of the organisation with the best practices of other similar companies to enhance the performance and remove the gaps, thus resulting in competitive advantage and leadership. The abovementioned can be enumerated to be the reasons that support the advantages of benchmarking in an organizational setting as follows (Krishnamoorthy et al., 2014).

- Benchmarking ensures alignment between organizational objectives and the overarching vision, thereby enhancing the effective achievement of planned goals.
- It provides a clear picture of the organization's performance relative to competitors, helping to identify gaps and support continuous improvement and innovation.
- It contributes to improving operational processes and increasing financial efficiency by reducing costs and achieving financial savings.
- It enables performance monitoring by comparing the organization with players within and beyond the same industry, enhancing sensitivity to environmental changes and promoting rapid responses.
- It helps reveal gaps in performance and execution while offering an external perspective that supports setting clear objectives to close these gaps and improve output.
- Strong top management commitment enhances the success of benchmarking. It also supports employee involvement and motivation, increasing recognition of individual and team efforts.
- It encourages the adoption of new creative practices and the diffusion of a culture of innovation and practical thinking, thereby supporting competitiveness and market leadership.

For the rest of the variables and their interlinkages the study covers a literature summary as provided in the Table 1 below:

Table 1: summary of Some Past studies

Variables of consideration	Main results	Source of the study
Green Supply Chain Management (GSCM) in construction	Market/supplier pressures (76.67%/91.03%), internal factors (74.44%), regulations (60%) push GSCM. Green practices (e.g., green purchasing, eco-design) improve environmental and economic performance. Barriers: financial/technical/human.	(Alam et al., 2024)
Precast construction and environmental impact	Precast components help sustainability, but value losses (waste, time, scrap) affect cost-efficiency. High costs correlate with negative environmental impact.	(Dräger & Letmathe, 2022)
Time-cost-quality-environmental impacts on construction projects	Discrete time-cost-quality-environmental impacts trade-off model minimizes time, cost, and environmental impacts while maximizing quality. Results show efficiency in rural water supply project optimization.	(Banihashemi et al., 2020)
Process control in construction supply chain risks	Process control reduces supply chain risks; information security mediates the relationship between process control and risk. Positive but modest impact of process control.	(Alzoubi et al., 2025)
Construction supply chain (CSC) management	CSC resilience ensures stability in uncertain environments. Focus on interaction, information integration, resilience measurement, and digitization.	(Liao et al., 2023)
Prefabricated construction cost factors	Prefabricated construction cost influenced by government promotion, working pressure, prefab quality, and mold quality. GPD has the highest influence.	(Zhang et al., 2021)
Li-ion batteries (LIBs) environmental impact	LIBs' environmental sustainability questioned; production and electricity generation still rely on fossil fuels. Life cycle assessment of EVs shows LIBs impact.	(Yang et al., 2022)
Additive Manufacturing (AM) and sustainability	AM reduces material waste, energy use, and emissions. It supports sustainability, with numerous applications in manufacturing for eco-friendly production systems.	(Javaid et al., 2021)

ANALYSIS AND DISCUSSION

Phase I

The Applied Aspect of the Study

In this section, environmental costs are measured using Material Flow and Product Life Cycle techniques by identifying the inputs to and outputs from each stage of the life cycle. The difference between them represents **loss**, which is classified into **normal loss** and **abnormal loss**. Abnormal loss is the most environmentally impactful; therefore, its cost is calculated by multiplying the abnormal loss quantity by the cost of that loss at the relevant stage of the product life cycle.

The Badoosh Expansion Cement Plant was selected as the study sample by integrating material flow into the product life cycle and applying benchmarking for the same plant based on financial data for three years, in order to reach the study's results.

First: Research, Development, and Design Stage

In Table 2 below, the measurement of environmental costs for the research and development stage at the Badoosh Expansion Cement Plant is presented. The highest environmental costs were recorded in 2022, amounting to IQD 25,916,082, while the lowest environmental costs were recorded in 2021, amounting to IQD 21,998,592.

Table 2: Environmental Costs of the First Phase R&D and Design of the Badoosh Expansion Plant for the years 2021 / 2022 / 2023

Details / R&D & Design Waste	Raw Material/Tons			Observations
	2021	2022	2023	
Input	34,870	35,613	47,609	
Output	23,350	23,730	31,931	
Losses	11,520	11,883	15,678	
80 % abnormal loss	9,216	9,507	12,542	
Total Laboratory Costs	51,004,594,171	58,288,161,003	54,850,296,061	
Production Quantity	641,080	641,460	882,474	
3 % of the cost per ton	2,387	2,726	1,865	
Environmental Costs of Lost Materials/JD	21,998,592	25,916,082	23,390,830	

The table is prepared by the researcher based on the financial statements of the laboratory

Second: Quarrying and Crushing Stage

In this second stage of the product life cycle, Table (3) below presents the environmental costs of the quarrying and crushing stage. The highest environmental costs were recorded in 2022, amounting to IQD 211,417,591, while the lowest environmental costs were recorded in 2021, amounting to IQD 181,018,890.

Table 3: Environmental Costs of Lost Quarries and Crushers for Badoush Expansion Plant for the Years 2021 / 2022 / 2023

Details / Waste quarries and crushers	Raw Material/Tons			Observations
	2021	2022	2023	
The amount of stone in production	1,138,126	1,164,230	1,541,806	
Outcomes of the process	1,081,245	1,106,059	1,464,763	
Losses	56,881	58,171	77,043	
80 % abnormal loss	45,505	46,537	61,634	
Total Laboratory Costs	51,004,594,171	58,288,161,003	54,850,296,061	
Production Quantity	641,080	641,460	882,474	
5 % of the cost of the tonne	3,978	4,543	3,108	
Environmental Costs of Lost Materials/JD	181,018,890	211,417,591	191,558,472	

The table is prepared by the researcher based on the financial statements of the laboratory

Third: Raw Material Milling Stage

This is the third stage of the cement production life cycle. Table (4) below presents the environmental costs of the raw material milling stage. The highest environmental costs were recorded in 2022, amounting to IQD 2,618,282,745, while the lowest environmental costs were recorded in 2021, amounting to IQD 2,164,111,560.

Table 4: Environmental Costs of Loss from the Mill Stage of the Badoush Expansion Plant for the Years 2021 / 2022 / 2023

Details / Mill Stage Waste	Raw Material/Tons		
	2021	**2022**	**2023**
Amount of Material Input	1,065,994	1,105,658	1,468,342
Outcomes of the process	612,644	625,433	845,860
Losses	453,350	480,225	622,482
60 % abnormal loss	272,010	288,135	373,489
Total Laboratory Costs	51,004,594,171	58,288,161,003	54,850,296,061
Production Quantity	641,080	641,460	882,474
10% of the cost per tonne	7,956	9,087	6,216
Environmental Costs of Lost Materials/JD	2,164,111,560	2,618,282,745	2,321,607,624

Note: The table is prepared by the researcher based on the financial statements of the laboratory

Environmental Cost Analysis and Reduction Strategies in Cement Production

First: The Level of Environmental Costs and Their Share of Total Costs

1- The financial data indicate that the Badoosh Expansion Cement Plant bears relatively higher environmental burdens. Total environmental costs amounted to approximately IQD 4,221,432,893 in 2021, increased to IQD 5,257,988,007 in 2022, and then declined to about IQD 3,916,072,015 in 2023. This reflects fluctuations in the plant's efficiency in resource utilization and loss control, while environmental costs have remained at relatively high levels.

2- The percentages of total environmental costs to total costs show that environmental costs constitute a non-negligible share of production cost. At the Badoosh Expansion Cement Plant, these ratios ranged between 8.275% in 2021, 9.004% in 2022, and 7.134% in 2023. This confirms that environmental costs are a fundamental factor affecting the competitiveness of the cost per ton produced, rather than marginal costs that can be overlooked.

Second: Distribution of Environmental Costs Across the Product Life Cycle Stages at the Badoosh Expansion Cement Plant

3- At the Badoosh Expansion Cement Plant, the data show that the raw material milling stage is the largest contributor to total environmental costs, accounting for approximately 51.26%, 49.79%, and 59.29% in 2021, 2022, and 2023, respectively. This makes it the most critical stage for targeting efficiency-improvement programs and reducing material losses to lower costs and protect the environment.

4- The cement production stage also represents a major center of environmental costs at the Badoosh Expansion Cement Plant. Its share ranged from 37.2% in 2021 to 39.09% in 2022, then declined to 28.74% in 2023. This suggests that most abnormal loss and pollution associated with energy consumption and equipment wear are generated collectively in the milling and cement production stages.

5- In comparison, the quarrying and crushing stage represents lower proportions at the Badoosh Expansion Cement Plant (approximately 4.02%–4.89%). The contributions of the R&D and design stage, packaging, labeling, and marketing, and pollution arising from precipitator downtime remain low but not negligible. This underscores the comprehensiveness of the approach used to measure environmental costs across the entire product life cycle.

6- The data on additional environmental costs at the Badoosh Expansion Cement Plant (including cleaning labor costs, medical supplies, afforestation, and workers' equipment) show increases in some years, particularly 2022 and 2023. This reflects the plant's response to environmental safety and preventive requirements, despite the absence of environmental fines or compensation for environmental damages during the three years under study. This is well covered below in Table 5.

Table 5: Total Environmental Costs from Abnormal Loss of Cement Production Life Cycle for Badoush Expansion Cement Plants for the Years 2021 / 2022 / 2023

Details	Badoush Cement Expansion Plant 2021	Percentage to Total Environmental Costs 2021	Badoush Cement Expansion Plant 2022	Percentage to Total Environmental Costs 2022	Badoush Cement Expansion Plant 2023	Percentage to Total Environmental Costs 2023
R&D and Design Phase	21,998,592	0.52%	25,916,082	0.49%	23,390,830	0.60%
Quarry & Crusher Stage	181,018,890	4.29%	211,417,591	4.02%	191,558,472	4.89%
Stage Mills Material	2,164,111,560	51.26%	2,618,282,745	49.79%	2,321,607,624	59.29%
Environmental costs due to the shutdown of material mills	1,768,619	0.04%	1,365,776	0.03%	1,348,250	0.04%
Clinker Production Stage	135,945,212	3.22%	177,295,686	3.37%	32,601,456	0.83%
Furnace contaminants (for clinker production)	59,490,820	1.41%	59,910,161	1.14%	81,573,870	2.08%
Cement Production Stage	1,570,140,468	37.2%	2,055,225,600	39.09%	1,125,494,867	28.74%
Packaging and Marketing Stage	1,225,224	0.03%	1,399,367	0.03%	1,317,686	0.03%
Other environmental costs including cleaning and medical workers	85,733,508	2.03%	107,174,999	2.04%	137,178,960	3.50%
Total environmental costs	4,221,432,893	100%	5,257,988,007	100%	3,916,072,015	100%

Third: Abnormal Loss, Black Oil Consumption, and Operational Downtime

7- The tables on black oil losses used in clinker production kilns indicate that the quantities of loss in liters, and thus the associated environmental costs, are substantial in both plants. The environmental pollution cost calculated at 3% of the loss value adds an avoidable financial burden that could be reduced by controlling actual consumption rates to approach the standard rate of (120 liters/ton) instead of continuing at (140 liters/ton).

8- The data on downtime of cement mill electrostatic precipitators show that environmental pollution and additional environmental costs arise from the annual downtime hours. Although their percentage of total environmental costs is limited (less than 0.8% in all years), they reflect an operational gap that can be improved through preventive maintenance programs for precipitators and supporting equipment.

9- The results also confirm that applying environmental cost measurement based on Material Flow (MF) across Product Life Cycle (PLC) stages clearly revealed the key waste points (milling, cement production, and fuel consumption in clinker kilns). This strengthens the role of environmental cost accounting in identifying opportunities for cost reduction and improvement, while simultaneously supporting the Product Life Cycle Costing approach in allocating environmental costs across the cement life-cycle stages and highlighting their impact on price competitiveness and the environmental quality of the product. This is well covered in table 6.

Table 6: Shows the ratio of environmental costs for each stage of the life cycle to the total costs of the Badoush Cement Plant expansion for the years 2021 / 2022 / 2023

Details	Badoush Expansion 2021	2022	2023
R&D and Design Phase	0.04%	0.04%	0.04%
Quarry & Crusher Stage	0.35%	0.36%	0.35%
Stage Mills Material	4.24%	4.49%	4.23%
Environmental costs due to the shutdown of material mills	0.003%	0.002%	0.002%
Clinker Production Stage	0.27%	0.30%	0.06%
Furnace contaminants (for clinker production)	0.12%	0.10%	0.15%
Cement Production Stage	3.08%	3.53%	2.05%
Packaging and Marketing Stage	0.002%	0.002%	0.002%
Other environmental costs including cleaning and medical workers	0.17%	0.18%	0.25%
Total environmental costs	8.275%	9.004%	7.134%

Phase II

Environmental Cost's Reduction Assessment and SEM Analysis in Cement Production

In the second phase, the study determines the key independent and dependent variables as provided in Table 7, showing that there are three explanatory variables linked to the environmental cost reduction. The study has the main independent variable named as construction supply chain management, followed by environmental practices, material flow optimization and life cycle costing. A questionnaire was developed (details in appendix-1), using different demographic factors and variables being taken into consideration. The questionnaire is well updated by getting the experts during the pre-testing procedure and final version is adopted for the data collection. Overall, an initial distribution of 300 copies among different respondents as covered in the demographic section (appendix-1). In the total efforts, researchers were able to collect a total of 271 copies from the respondents, out of which 25 copies were filled wrongly. Therefore, we were forced to dropped them from our sample. A final version consisted of 246 questionnaires as explained in the analysis part.

Table 7: Variables and Description

Independent Variables (IVs)	Dependent Variable (DV)	Data Collection Method	Items for each variable	Analysis Method
1. Construction Supply Chain Management (CSCM)	Environmental Cost Reduction (3 items ECR)	Questionnaire on cement plant's integration with the construction supply chain.	5 items	Demographics analysis and two step using Smart PLS
2. Environmental Practices ENP			4 items	
3. Material Flow Optimization MF			4 items	
4. Life Cycle Costing (LCC)			4 items	

Demographic Analysis

The study covers a total of 246 respondents, representing different demographic factors. As in Table 8, the position/role distribution shows that maximum participation is coming from the supply chain coordinators, followed by environmental officers, production supervisors and those linked with the other category. Moreover, for the experience category, it is found that a total of 127 respondents, covering the highest number are linked with the experience of between 11-20 years. However, there are 37 respondents having an experience of 21+ years. Regarding the size of the plant, the study found that 69 were small, 125 were medium, and 52 were those who belong to larger firms. In the end, the location factor shows that 124 units were situated in the urban areas, followed by 67 in rural areas, whereas only 55 were those which were situated in the suburban areas, respectively. The individual and overall distribution of the demographic factors are also covered through bars in Figure 1.

Table 8: Details of Demographic Factors

1. Position/Role:	No.
¨ Plant Manager	29
¨ Production Supervisor	33
¨ Environmental Officer	65
¨ Supply Chain Coordinator	77
¨ Other:	42
total	246
2. Years of Experience in Cement Production/Construction:	
¨ 0–5 years	16
¨ 6–10 years	66
¨ 11–20 years	127
¨ 21+ years	37
total	246

Table 8(continued): Details of Demographic Factors

3. Size of Cement Plant/Construction Firm:	
¨ Small (1–50 employees)	69
¨ Medium (51–200 employees)	125
¨ Large (201+ employees)	52
total	246
4. Location of Plant/Project:	
¨ Urban Area	124
¨ Suburban Area	55
¨ Rural Area	67
total	246

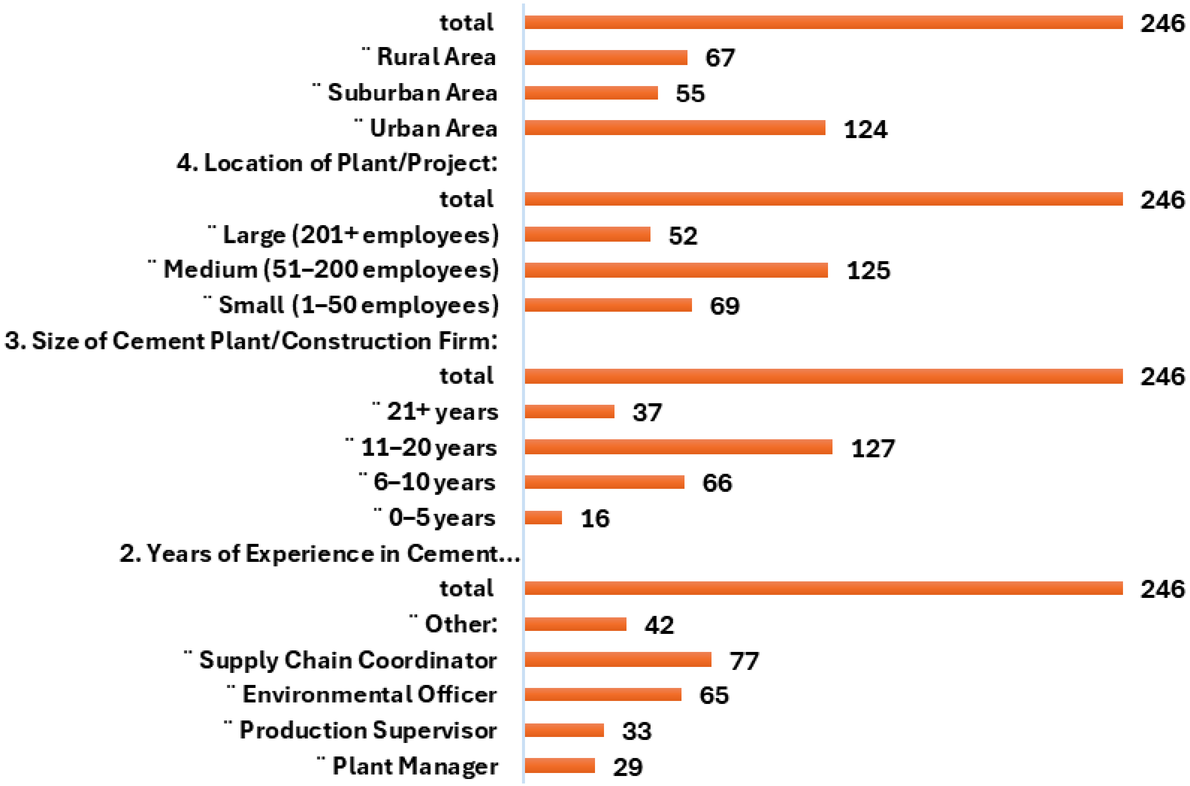

Figure 1: Respondents Profile

Analysis of the Measurement Model

Investigating the measurement model is the key step before applying the structural equation modelling for the hypothetical relationships between the variables. This technique is widely recommended in the modern literature (Gorai et al., 2024; Kock, 2014). The output results are presented by considering all the relevant statistical techniques. As in Table 9, the alpha values for the variables are 0.816, 0.859, 0.749, 0.764, and 0.793. moreover, both the measures of composite reliability are confirming the values as above 0.70, therefore, they are in acceptable range. However, it is important to note that the composite reliability values are highest as 0.875 and 0.914 for the CSCM and FCR. Moreover, the results are also reflecting the average amount of the variance being captured by these variables. The literature determines that the AVE values must be above than the 0.50. Considering this level, we found that the AVE values are 0.570, 0.780, 0.537, 0.668, and 0.545. Therefore, it is claimed that the constructs are covering the average amount of variance as required for their convergent validity. We also presented in the measurement model output diagram (Figure 2) for which the loadings of the selected items are presented. For example, for the CSCM, the loadings are as lower as 0.563 and as highest as 0.874. Overall, based on these loadings, the findings in Table 3 confirming the reliability and convergent validity. Similarly, for the ENP. The loadings are as lowest as 0.650 and as highest as 0.759. These loadings are truly capturing the amount of reliability and validity being presented in Table 3. However, for the MFO, the loadings for the items like MFP4 and MFP5 were lower than 0.50, therefore, these items were removed from the given model. Additionally, the first item of the LLC was also deleted due to lower value of the loadings. Besides, for the main outcome variable, ECR, the loadings for the three items named as ECR1, ECR2, and ECR3 were 0.895, 0.866, and 0.889, respectively. The overall R-square value is above 0.70, indicating a good amount of variation in the main outcome variable.

Table 9: alpha, reliability and average variance extracted

	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
CSCM	0.816	0.875	0.865	0.570
ECR	0.859	0.859	0.914	0.780
ENP	0.749	0.715	0.822	0.537
LLC	0.764	0.788	0.858	0.668
MF	0.793	0.835	0.778	0.545

Independent Variables (IVs): Construction Supply Chain Management (CSCM), Environmental Practices (ENP), Material Flow Optimization (MF), Life Cycle Costing (LCC) Dependent Variable (DV): Environmental Cost Reduction (ECR)

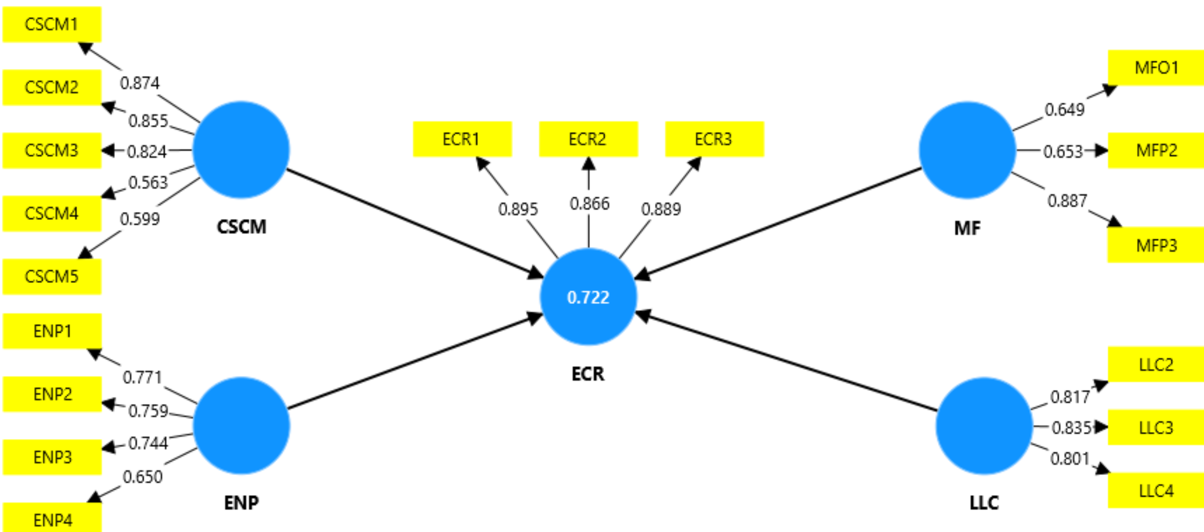

Figure 2: Study Model with the output (loadings and R-square). Independent Variables (IVs): Construction Supply Chain Management (CSCM), Environmental Practices (ENP), Material Flow Optimization (MF), Life Cycle Costing (LCC), Dependent Variable (DV): Environmental Cost Reduction (ECR)

The discriminant validity has also provided the VIF values for the items. As it shows, all the values are less than the threshold level of 5, indicating that the level of correlation between the items is in acceptable range, hence the model is free from the biasness of multicollinearity. This is presented in Table 10.

Table 10: items with VIF

Items	VIF
CSCM1	2.268
CSCM2	2.279
CSCM3	2.038
CSCM4	2.266
CSCM5	2.331
ECR1	2.410
ECR2	1.914
ECR3	2.359
ENP1	1.982
ENP2	3.709
ENP3	3.768
ENP4	1.027
LLC2	2.621
LLC3	2.687
LLC4	1.204
MFO1	1.374
MFP2	1.388
MFP3	1.152

Independent Variables (IVs): Construction Supply Chain Management (CSCM), Environmental Practices (ENP), Material Flow Optimization (MF), Life Cycle Costing (LCC) Dependent Variable (DV): Environmental Cost Reduction (ECR)

This research also investigated whether there is a presence of well discrimination between the variables. Among several, the key methods are HTMT ratio and Fornell-Larcker findings. The results are in table 11 and are dealing with the HTMT ratio. The threshold level in the literature is 0.90 and considering the same, the output is confirming that for our variables, the highest values of the HTMT ratio between the two constructs (ECR-MF) is 0.828, indicating that the variables are totally discriminated against to each other. Moreover, the ratio of HTMT for the other variables is also less than the given level of 0.90. As per such results, there is concerned related to the discriminant validity in this model.

Table 11: HTMT Ratios Output

HTMT	CSCM	ECR	ENP	LLC	MF
CSCM					
ECR	0.828				
ENP	0.197	0.273			
LLC	0.726	0.816	0.420		
MF	0.736	0.828	0.471	0.681	

Independent Variables (IVs): Construction Supply Chain Management (CSCM), Environmental Practices (ENP), Material Flow Optimization (MF), Life Cycle Costing (LCC) Dependent Variable (DV): Environmental Cost Reduction (ECR)

This is the second method to check for the discrimination levels between the variables. The value of Fornell-Larcker is based on the square root of the AVE. The values are given in the Table 12 where the ratio given at the top of each list is the highest, followed by the rest of the values. Therefore, a clear discrimination can be claimed through the second measure named Fornell-Larcker.

Table 12: Fornell Larcker Output

Fornell Larcker	CSCM	ECR	ENP	LLC	MF
CSCM	0.755				
ECR	0.744	0.883			
ENP	0.186	0.264	0.733		
LLC	0.628	0.750	0.354	0.818	
MF	0.616	0.734	0.375	0.703	0.738

Independent Variables (IVs): Construction Supply Chain Management (CSCM), Environmental Practices (ENP), Material Flow Optimization (MF), Life Cycle Costing (LCC) Dependent Variable (DV): Environmental Cost Reduction (ECR)

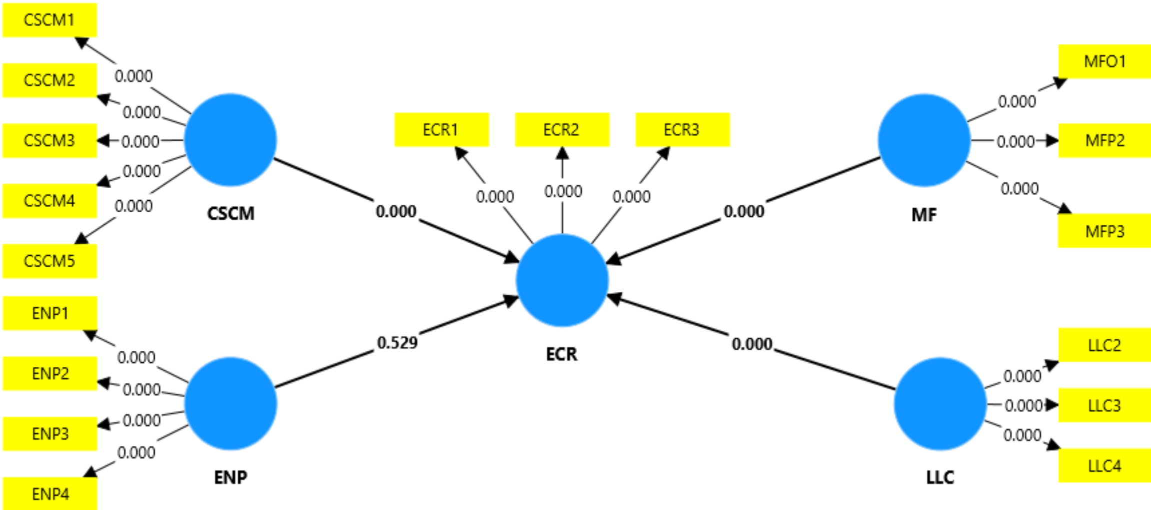

Figure 3: Independent Variables (IVs): Construction Supply Chain Management (CSCM), Environmental Practices (ENP), Material Flow Optimization (MF), Life Cycle Costing (LCC) Dependent Variable (DV): Environmental Cost Reduction (ECR)

The figure represents a conceptual/structural model that sees into the impacts of the independent variables Construction Supply Chain Management (CSCM), Environmental Practices (ENP), Material Flow Optimization (MF), and Life Cycle Costing (LCC) on the dependent variable, Environmental Cost Reduction (ECR). The indicators of each latent construct (e.g., CSCM1-CSCM5, ENP1-ENP4, ECR1-ECR3, MFP1-MFP3, LLC2-LLC4) are used to measure these constructs. The arrows are some of the hypothetically suggested causal directions, with the coefficients and the significance levels of the relationship directions toward ECR showing the relationship strengths and directions.

Structural Model analysis

This data presents the results of a SEM analysis, which examines the relationships between several independent variables and a dependent variable (DV) of the study. The goal of this analysis is to understand how factors like construction supply chain management (CSCM), environmental practices (ENP), life cycle costing (LCC), and material flow optimization (MF) influence environmental cost reduction (ECR). The relationship between CSCM and environmental cost reduction is positive. The coefficient is 0.365, indicating a moderate positive effect on the main dependent variable for the cement industry. The sample mean is similar to the original sample. This means that there is a well consistency in the path coefficients. Moreover, with a high t-statistic of 7.295 and a p-value of 0.000, this result is statistically significant. The significant output is reflecting that CSCM has a significant impact on ECR. Overall, this shows that construction supply chain management is a good determinant in causing a reduction in the environmental cost.

The relationship between environmental practices and environmental cost reduction shows a very weak, negative coefficient of -0.028. This means that the environmental practices, in this case, do not appear to significantly reduce environmental costs, or the effect is almost negligible. The t-statistic of 0.629 and the p-value of 0.529 indicate that this relationship is not statistically significant. Therefore, we can conclude that ENP does not have a meaningful influence on reducing environmental costs in this analysis. The relationship between life cycle costing and environmental cost reduction is positive, with a coefficient of 0.327. This suggests that life cycle costing has a positive effect on reducing environmental costs. The t-statistic of 6.715 and the p-value of 0.000 confirm that this result is statistically significant, meaning that life cycle costing plays an important role in achieving cost reduction.

Material flow optimization has a positive influence on environmental cost reduction. This is confirmed through a coefficient of 0.290. The t-statistic of 5.787 and the p-value of 0.000 suggest that this relationship is also statistically significant. This indicates that optimizing the flow of materials can have a meaningful impact on reducing environmental costs. All of these results are in Table 13.

Table 13: SEM Model Results

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
CSCM -> ECR	0.365	0.366	0.050	7.295	0.000
ENP -> ECR	-0.028	-0.026	0.045	0.629	0.529
LLC -> ECR	0.327	0.325	0.049	6.715	0.000
MF -> ECR	0.290	0.293	0.050	5.787	0.000

Independent Variables (IVs): Construction Supply Chain Management (CSCM), Environmental Practices (ENP), Material Flow Optimization (MF), Life Cycle Costing (LCC)
Dependent Variable (DV): Environmental Cost Reduction (ECR)

The F-square results indicate that construction supply chain management, life cycle costing, and material flow optimization have statistically significant positive effects on environmental cost reduction. A detailed investigation shows that the construction supply chain management having the strongest impact on the main output variable which is environmental cost reduction. However, environmental practices show no significant effect on environmental cost reduction, as indicated by a very low F-square value and high p-value as shown in table 14.

Table 14: F-square Results

	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values
CSCM -> ECR	0.257	0.269	0.079	3.248	0.001

ENP -> ECR	0.002	0.008	0.011	0.221	0.825
LLC -> ECR	0.166	0.170	0.054	3.067	0.002
MF -> ECR	0.132	0.139	0.050	2.627	0.009

Independent Variables (IVs): Construction Supply Chain Management (CSCM), Environmental Practices (ENP), Material Flow Optimization (MF), Life Cycle Costing (LCC) Dependent Variable (DV): Environmental Cost Reduction (ECR)

CONCLUSION

It is evident that environmental costs at the Badoosh Expansion Cement Plant are mainly reflected by the raw material milling and cement production stages. To address this, targeted efficiency improvements should focus on these stages, including optimizing milling processes, reducing material losses, and enhancing kiln fuel consumption. Additionally, strengthening preventive maintenance for electrostatic precipitators and integrating real-time fuel monitoring systems would help reduce environmental pollution and related costs. Separating environmental cost accounts and adopting a more comprehensive cost measurement approach across the product life cycle will further support better decision-making and improve environmental and financial performance.

Subsequently, the findings from the structural equation modeling analysis highlight the significant relationships between construction supply chain management, life cycle costing, and material flow optimization with environmental cost reduction. Specifically, construction supply chain management and life cycle costing have a strong positive impact on reducing environmental costs. On the other side, the factor of material flow optimization also contributes meaningfully. Environmental practices, however, are aiming to reflect a negligible impact. These updated results emphasize the importance of focusing on improving supply chain management, optimizing material flow, and implementing life cycle costing strategies to achieve substantial environmental cost reductions, further supporting the plant's overall competitiveness and sustainability efforts.

REFERENCES

Alam, O., Li, G., Zheng, X., Sultana, N., & Du, D. (2024). The Effect of Green Supply Chain Management Practices in Reduction of Construction Wastes and Carbon Emission in Bangladesh. *Journal of Material Cycles and Waste Management*, *26*(4), 2491-2508. https://doi.org/10.1007/s10163-024-01987-7

Al-Sabaawe, Y. M. K., Mansoor, H. O., Mohsin, A. N., & Abdullah, R. (2024). Value Network Development Model Through Cooperation Strategy Approach: Theoretical Review & Proposed Model for Universities. International Journal of Operations and Quantitative Management, 30(2), 63-89 . https://DOI10.46970/2024.30.2.04

Alzoubi, H. M., Shwedeh, F., Shamout, M. D., Alquqa, E. K., & Bawaneh, B. (2025). Process Control Influence on Mitigating Supply Chain Risk: Exploring the Mediating Effect of Information Security Evidence from the Uae Construction Industry. In H. M. Alzoubi,

T. Cheng Ling, & M. El Khatib, *Innovative Dynamics in Management and Engineering (IDME)* Cham.https://doi.org/10.1007/978-3-031-90131-7_30

Arocena, P., Gómez-Plana, A. G., & Peña, S. (2024). A Model for the Competitive Benchmarking of Energy Costs. *Energy Economics*, *131*, 107385. https://doi.org/10.1016/j.eneco.2024.107385

Banihashemi, S. A., Khalilzadeh, M., Shahraki, A., Malkhalifeh, M. R., & Ahmadizadeh, S. S. R. (2020). Optimization of Environmental Impacts of Construction Projects: A Time–Cost–Quality Trade-Off Approach. *International Journal of Environmental Science and Technology*, *18*(3), 631-646. https://doi.org/10.1007/s13762-020-02838-2

Dräger, P., & Letmathe, P. (2022). Value Losses and Environmental Impacts in the Construction Industry – Tradeoffs or Correlates? *Journal of Cleaner Production*, *336*, 130435. https://doi.org/10.1016/j.jclepro.2022.130435

Gorai, J., Kumar, A., & Angadi, G. R. (2024). Smart Pls-Sem Modeling: Developing an Administrators' Perception and Attitude Scale for Apprenticeship Programme. *Multidisciplinary Science Journal*, *6*(12), 2024260. https://doi.org/10.31893/multiscience.2024260

Imran, M., Jijian, Z., Sharif, A., & Magazzino, C. (2024). Evolving Waste Management: The Impact of Environmental Technology, Taxes, and Carbon Emissions on Incineration in Eu Countries. *Journal of Environmental Management*, *364*, 121440. https://doi.org/10.1016/j.jenvman.2024.121440

Javaid, M., Haleem, A., Singh, R. P., Suman, R., & Rab, S. (2021). Role of Additive Manufacturing Applications Towards Environmental Sustainability. *Advanced Industrial and Engineering Polymer Research*, *4*(4), 312-322. https://doi.org/10.1016/j.aiepr.2021.07.005

Kock, N. (2014). Advanced Mediating Effects Tests, Multi-Group Analyses, and Measurement Model Assessments in Pls-Based Sem. *International Journal of e-Collaboration*, *10*(1), 1-13. https://doi.org/10.4018/ijec.2014010101

Krishnamoorthy, B., D, C., & Lima, N. A. (2014). Benchmarking as a Measure of Competitiveness. *International Journal of Process Management and Benchmarking*, *4*(3), 342. https://doi.org/10.1504/ijpmb.2014.063240

Liao, L., Yang, C., & Quan, L. (2023). Construction Supply Chain Management: A Systematic Literature Review and Future Development. *Journal of Cleaner Production*, *382*, 135230. https://doi.org/10.1016/j.jclepro.2022.135230

Malega, P., Chovancová, J., & Majerník, M. (2024). Environmental Cost Accounting of Material Flows during Their Technological Transformation. *Ecological Engineering & Environmental Technology*, *25*(5), 14-24. https://doi.org/10.12912/27197050/184077

Nickie Petcharat, N., & Mula, J. M. (2012). Towards a Conceptual Design for Environmental and Social Cost Identification and Measurement System. *Journal of Financial Reporting and Accounting*, *10*(1), 34-54. https://doi.org/10.1108/19852511211237435

Panagiotopoulou, V. C., Stavropoulos, P., & Chryssolouris, G. (2021). A Critical Review on the Environmental Impact of Manufacturing: A Holistic Perspective. *The International Journal of Advanced Manufacturing Technology*, *118*(1-2), 603-625. https://doi.org/10.1007/s00170-021-07980-w

Rodrigues, S. L., & da Silva, E. A. (2024). Implementation of Environmental Life Cycle Costing: Procedures, Challenges, and Opportunities. *The International Journal of Life Cycle Assessment*, *29*(5), 803-837. https://doi.org/10.1007/s11367-023-02268-5

Shahbazi, A., Moeinaddini, M., Abdoli, M. A., Hosseinzadeh, M., Jaafarzadeh, N., & Sinha, R. (2023). Environmental Damage of Different Waste Treatment Scenarios by Considering Avoided Emissions Based on System Dynamics Modeling. *Sustainability*, *15*(23), 16158. https://doi.org/10.3390/su152316158

Xu, G., & Wang, W. (2020). China's Energy Consumption in Construction and Building Sectors: An Outlook to 2100. *Energy*, *195*, 117045. https://doi.org/10.1016/j.energy.2020.117045

Yang, Z., Huang, H., & Lin, F. (2022). Sustainable Electric Vehicle Batteries for a Sustainable World: Perspectives on Battery Cathodes, Environment, Supply Chain, Manufacturing, Life Cycle, and Policy. *Advanced Energy Materials*, *12*(26). https://doi.org/10.1002/aenm.202200383

Zhang, W., Kang, K., & Zhong, R. Y. (2021). A Cost Evaluation Model for Iot-Enabled Prefabricated Construction Supply Chain Management. *Industrial Management & Data Systems*, *121*(12), 2738-2759. https://doi.org/10.1108/imds-12-2020-0735