JAMEA

JOURNAL OF ADVANCED MECHANICAL ENGINEERING APPLICATIONS
e-ISSN: 2716-6201

Vol. 7 No. 1 (2026) 27-43
https://publisher.uthm.edu.my/ojs/index.php/jamea

A Pilot Study on Environmental Factors, Production Performance and Recycling Practices in Cement Plants in Pakistan

Temoor Abbas Larik[1]*, Yusri Yusof[1], Faheemllah Shaikh[2], Zohaib Khan[1]

[1] *Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, MALAYSIA*

[2] *Electrical Engineering Department, Mehran University of Engineering and Technology,76062 Jamshoro, Sindh, PAKISTAN*

*Corresponding Author: temoor_abas@yahoo.com
DOI: https://doi.org/10.30880/jamea.2026.07.01.003

Article Info

Received: 6 February 2026
Accepted: 4 May 2026
Available online: 30 June 2026

Keywords

Environment, production processes, recycling, cement industry, sustainability

Abstract

The cement manufacturing industry is highly environmentally intensive due to its energy consumption, clinker production, and greenhouse gas emissions. Despite increasing sustainability pressures, there is limited empirical evidence on how environmental practices and recycling initiatives influence production performance, particularly in developing contexts such as Pakistan. Recycling and the use of industrial byproducts are considered key strategies for improving resource efficiency and reducing environmental impact. However, the effectiveness of these practices in enhancing operational performance remains insufficiently understood. This study aims to assess the relationships between environmental practices, recycling adoption, and production performance in cement plants. Prior to full-scale analysis, a pilot study with 100 respondents was conducted to evaluate the measurement instrument's reliability and to conduct correlation analyses. The results demonstrate excellent internal consistency across all constructs. The Cronbach's Alpha values range from 0.897 to 0.917, exceeding recommended thresholds. Key constructs such as Regulatory Framework (α = 0.905), Waste Management Regulations (α = 0.906), Cost Efficiency (α = 0.906), and Impact on Cement Strength (α = 0.917) exhibited particularly strong reliability. Descriptive findings indicated moderate response variability, with most standard deviations ranging from 0.50 to 0.80, suggesting meaningful differentiation among respondents. However, correlation analysis suggests a strong positive relationship between environmental practices and production performance, environmental practices and recycling adoption, and recycling adoption and production efficiency within cement plants (r = 0.780, 0.617& r = 0.639, respectively; p = 0.000). Overall, these findings confirm the robustness of the research framework and highlight the interconnected role of environmental orientation, recycling initiatives, and production performance in cement plant operations.

1. Introduction

The cement manufacturing industry is a significant source of greenhouse gas emissions and other environmental problems, primarily due to its energy-intensive clinker production and heavy reliance on fossil fuels [1]. Interest in emissions reductions and the environment in the sector is rapidly emerging, and studies on technical and managerial approaches to reducing emissions and minimizing material inputs to cement production are becoming increasingly prevalent; these include energy efficiency improvements, the use of alternative fuels, alternative materials, and circular economy approaches [2].

At the same time, recycling processes and the use of alternative materials (such as fly ash or recycled concrete aggregates) are viewed as key levers for improving environmental performance and resource efficiency within the cement and concrete value chains [3]. Research on the recycling of concrete and construction materials identifies key success factors for the adoption of recycling. It indicates that recycling can reduce raw material demand and relieve waste-disposal responsibilities, though the practical adoption rates of such recycling vary widely between countries, materials, and firm capabilities [4].

Yet little research directly examines how these environmental orientations relate to outcomes such as production outcomes (process efficiency, output stability, quality) in developing country contexts [5]. In Pakistan, green cement and recycling capabilities have recently been emphasized in feasibility studies and engineering guidelines, while energy-efficiency improvements have begun to emerge in industry assessments [6] and [7]. Analyses of environmental factors remain a relative rarity in systematic survey data, particularly for predicting production or recycling outcomes. The question arises, therefore, whether the findings from these other developing and transitional economies are indeed generalizable, given that managerial capabilities, regulatory environment, and technological levels differ between developed and developing countries [8], [9].

Thus, the present study aims to examine the existence of direct relationships among environmental factors, recycling adoption, and production performance in cement plants. Rather than propose a direct or mediated/ moderated model at this early stage in the examination of these questions, the present study asks three research questions regarding direct relationships: a) between environmental factors and production performance; b) between environmental factors and the adoption of recycling; and c) between recycling and production performance.

1.1 Research Objectives and Questions

This study aimed to examine the relationships between environmental factors, recycling adoption, and production performance in the cement industry. The main emphasis is on determining which, and to what extent, these direct associations exist. The relationships between environmental factors and production performance, environmental factors and recycling adoption, and recycling adoption and production performance are the three specific relationships we began studying. Table 1 presents the research questions and their purposes in the study.

Table 1 *Research questions and objectives*

Research questions	Research objective of the study
RQ1. What is the relationship between environmental factors and production performance?	To examine the relationship between environmental factors and production performance.
RQ2. What is the relationship between recycling and production performance?	To determine the relationship between recycling and production performance.
RQ3. What is the relationship between recycling adoption and production performance?	To understand the relationship between recycling adoption and production performance.

2. Literature Review

This section presents a synthesis of studies on environmental management practices, recycling, and the production performance of the cement sector. The studies related to these topics are organized into three main streams of literature: environmental management in cement production; the relationship between environmental factors and the production performance of the cement sector; and the relationship between environmental management practices and both recycling and production performance within the cement sector. By reviewing these studies, it is possible to conduct a theoretical investigation into whether a direct relationship exists between environmental factors, recycling practices within the cement sector, and the performance of cement-producing processes in a developing economy.

J. Adv. Mech. Eng. Appl. Vol. 7 No. 1 (2026) p. 27-43

2.1 Environmental Practices in the Cement Industry

The cement industry is currently considered the most energy- and carbon-intensive manufacturing sector in the world. Such high levels of energy use and carbon emissions by the cement industry are the result of the energy and carbon emissions that are inherently created by the processes that are employed by the cement plants, the high temperatures to which those processes must be heated, and the amount of raw materials that those plants process to produce cement. Cement production is a calcination process that requires temperatures over 1400°C to produce clinker, which is then ground to make cement; these high temperatures generate enormous amounts of carbon dioxide with each batch of cement produced [10]. Furthermore, because the raw materials that are used in cement production contain carbonate elements, those elements are removed from the raw materials during calcination as carbon dioxide - an essential but undesirable byproduct of cement production [11].

These cement plants have begun adopting various environmental management practices to mitigate the negative environmental impacts of their operations and reduce the amount of fossil fuels required to power them. Some of these practices include the use of fossil-fuel substitution to minimize the amount of fossil fuels used in cement plants while maximizing the use of alternative fuels [12]. Substituting raw materials used in cement production with alternative raw materials is another environmental management practice; these include supplementary cementitious materials. Furthermore, the heat produced during cement production is another resource managed by those plants; waste heat is recovered from the exhaust fumes of the kilns used to produce cement [8], [9]. Each of these practices has had a positive impact on the environment by reducing the amount of energy, chemicals, and raw materials consumed by cement manufacturing plants.

One important environmental management practice adopted by the cement industry is the use of blended cements in cement products. These types of blended cement are used to minimize the amount of clinkers required in cement products; reducing the clinker content reduces the energy and carbon dioxide emissions released during cement production [13]. Each of these practices helps broaden the processes performed within cement plants; they require those plants to expand beyond their traditional focus on plant profitability. These adaptations to the processes within cement plants can be achieved by incorporating environmental considerations into their operations [14]. For instance, each of the companies that are members of the Cement Sustainability Initiative has recognized that reducing the amount of clinkers in cement products is one of their major goals. The initiative has discovered and implemented methods to alter the raw materials used in cement production to both fuel cement plants and serve as raw materials for producing cement products; it has become the industry's major environmental management practice [15].

The adoption of these environmental management practices by the cement plants has enabled them to expand their operations beyond those focused solely on increasing their traditional profitability. Instead, these cement plants are expanding their operations to incorporate environmental management considerations to gain a competitive advantage in the industry [16].

2.2 Impact of Environmental Practices on Production Performance

Research effort in this area has only recently begun to focus on the role of environmental management in enhancing firm productivity. Within the cement industry, which is among the most energy and resource-intensive of all industrial processes, environmental innovations are primarily implemented to enhance production efficiency. Additionally, environmentally friendly practices implemented in cement production processes are associated with improvements in production efficiency, leading to the formation of better, more efficient plants in general [17].

For instance, improvements in energy efficiency in cement plants have been shown to lead to massive reductions in the use of both thermal and electrical energy [18]. Additionally, practices such as the use of alternative fuels and the recovery of process heat have been shown to improve the efficiency of those cement plants, as have improvements in kiln efficiency and fuel use [19]. Additionally, practices that aim to reduce the decarbonization of cement plants, such as the use of clinker substitutes and waste heat recovery systems, have also been shown to improve the performance of those cement plants [20]. Each of these improvements in environmental practices leads to improvements in the performance of cement plants due to reductions in the amount of fuel required to power those production processes, improvements in the efficiency with which energy is used within those plants, and greater ability to implement changes to those production processes.

These findings therefore indicate that the environmental orientation of this firm is a strategy that may be adopted by a cement manufacturing company and is related to each of the major elements of the production process. Such elements include the stability of the output of the production process, the efficiency with which the materials required to produce those cement products are utilized, the energy used in their production, and the quality of the cement produced by the plants. Overall, these findings suggest that environmental management of cement production plants will provide the greatest benefits to companies in terms of plant production, rather than as a means of reducing their environmental impact or compliance with environmental regulations.

2.3 Environmental Practices and Recycling Adoption

The literature also posits that environmental mechanisms influence behaviors related to recycling. For instance, the use of industrial byproducts, such as fly ash, slag, and recycled concrete aggregates in the production of cement, is recognized as a means of reducing the environmental impact of cement production and the consumption of natural resources required for cement production [21] and [22]. Thus, these recycling activities relate to the environmental factor by helping reduce the environmental impact of cement production.

Furthermore, the use of industrial byproducts in cement production reduces the need for raw materials, reduces the environmental impact of extracting those raw materials, and further increases the sustainability of the cement and concrete industry. Studies of firms that have implemented systems to improve their environmental performance indicate that these firms have tended to use more production processes related to recycling [23]. For instance, authors [23] found that using recycled fly ash to produce green cement in Pakistan was associated with both environmental and economic benefits for the company that used the cement; the environmental impact of the cement was reduced, as was the cost of producing it [24].

Yet another reason for implementing recycling activities in cement production is their relationship to the circular economy. The circular economy proposes using industrial waste products as raw materials for other industrial processes. Thus, cement industry firms can improve their sustainability in line with the circular economy by valorizing their waste within the cement industry and becoming more resource-efficient in their operations [25]. Thus, these recycling activities are related to the organization's environmental factors and its environmental orientation, supporting the second hypothesis that recycling behaviors are correlated with an environmental orientation.

2.4 Recycling and Production Performance

A final way in which recycling incorporation may relate to production performance is by directly improving it. Recycling inputs and byproducts into cement products can help firms avoid some of the issues caused by securing virgin materials [26]. Byproducts or waste products from other production processes are often more readily available, which can help stabilize the firm's supply chain. Furthermore, the cost-reducing benefits of recycling can also be extended to production performance [27].

For instance, recycling processes have the potential to reduce production costs for a number of reasons; such reasons may include reducing the costs of securing raw materials, but also increasing the energy efficiency of production, such as through the substitution of certain raw materials in clinker that reduces the energy required to produce cement in some cases [28]. A technical feasibility analysis that was conducted on the Pakistani cement sector by author [29], for instance, determined that using fly ash as a partial substitute for cement in production not only led to less energy being required to produce cement, but also that it had the potential to improve productivity of the manufacturing process itself.

Recycling, therefore, can be applied to optimize other operational factors, including energy efficiency, cost performance, and process stability, in addition to its influence on environmental factors. Finally, recycling operations may also become increasingly sustainable over time, as recycling processes inherently reduce waste [30]. This benefit helps ensure that the firm remains within the limits of sustainable practices and compliant with regulatory policies [31]. In these various ways, then, recycling practices can be seen to help connect sustainability with outcomes like production performance; sustainability and operational performance are seemingly linked regarding at least cement plant operations. Fig. 1 presents the taxonomy of the research variables examined in this study.

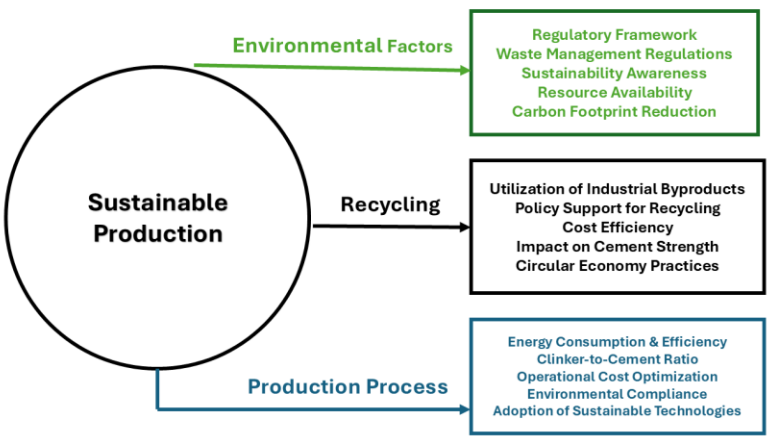

Fig. 1 *Taxonomy of research variables*

J. Adv. Mech. Eng. Appl. Vol. 7 No. 1 (2026) p. 27-43

2.5 Variables of the Study

The three main variables of the study are discussed below:

- Environmental practices are the adoption of environmental supervision, such as compliance with protocols, waste management, sustainability awareness, and carbon emission reduction [32].
- Whereas recycling is the use of industrial byproducts such as fly ash and slag. Recycling is the reuse of waste materials to produce new products [33].
- The Production process in the cement plant is a series of operations, from the design to the fabrication of final products that meet the demands of customers.

2.6 Conceptual Framework

This study translates the logic of environmental management practices as strategic resources and internal capabilities for production performance and recycling behavior into a testable hypothesis and model. Using the resource-based concepts of competitive advantage and the theory of sustainable operations, the conceptual model hypothesizes three direct relationships: that environmental factors improve production performance, that environmental factors increase the adoption of recycling, and that the adoption of recycling improves production performance. See Fig. 2. The production performance benefits of recycling materials are justifiable on theoretical grounds by the production environment, but direct effects are tested here, while mediation effects are reserved for future research.

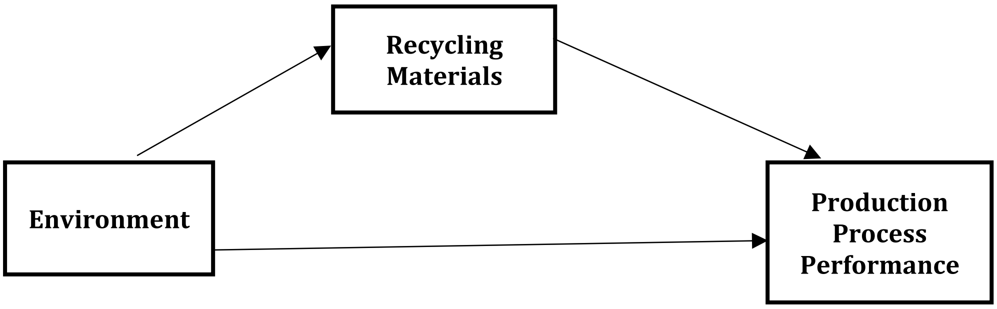

Fig. 2 *Conceptual framework of the research*

2.7 Hypotheses Development

Based on the theoretical arguments and empirical evidence presented in the preceding sections, the present study proposes the following hypotheses to investigate direct relations among the environment, recycling, and the production process in the cement industry.

- H1: The environmental factors have a positive impact on the production process.
- H2: The environmental factors have a positive influence on the recycling of materials.
- H3: The recycling materials have a positive impact on the production process performance.

3. Methodology

A cross-sectional survey was used in this study to assess variables related to the environment, recycling, and the production process of cement companies in Pakistan. Data will be collected from both workers and managers of these companies using a questionnaire. This research study will utilize measures of survey reliability and the correlation between variables, as these are common methods for exploratory research with relatively small populations of participants. In line with the research that has been performed in the cement industry, the unit of analysis for this research study will be the organization itself, the cement manufacturing plants. While data will be collected from each worker or manager, the opinions of these individuals will be considered representative of the organization and its plants. Each of these processes regarding the population, sample, instrument, data collection, and analysis will be presented in each of the following sub-section.

3.1 Research Design

In this paper, a quantitative research method using a survey was used to determine the direct relationship between the three variables: environment, recycling behavior, and production in the cement manufacturing industry. The use of a quantitative method was suitable for this research, as it aimed to quantify respondents' perceptions of the survey items and test hypotheses about the variables. A cross-sectional survey was used to collect data from individuals in the cement manufacturing plants who hold operational and managerial positions. The data were collected from a specific unit of analysis: the cement manufacturing plants themselves. Thus, the analysis of the survey will reflect the environmental practices, recycling behaviors, and production of the cement plants in question. The software that was used for data analysis was SPSS 27. This software was chosen for its use in exploratory studies with small sample sizes and in studies whose data may not be normally distributed.

3.2 Population and Sampling

The study sample comprised employees from the cement manufacturing plants in the provinces of Sindh and Punjab, Pakistan. These provinces are hubs of cement manufacturing in the country and host both large- and medium-scale cement manufacturers. The sample included 100 study respondents. The respondents were technical and operational staff, namely production engineers, supervisors, and line managers, who were employed in environmental and production processes. These individuals were selected because of their direct involvement in organizational practices related to environmental management, recycling, and production operations, enabling them to provide informed insights that reflect plant-level conditions. A random sampling process was employed to select respondents from different departments within the plant, to include a range of operational roles within the plant in the sample, and to maximize the external validity of the results during work operations. Data were collected over 2 months, and respondents completed a structured questionnaire designed to assess their perceptions of environmental practices, recycling practices, and organizational-level production performance.

3.3 Instrument Development

The survey instrument was developed based on empirical studies on environmental management, recycling behavior and cement industry production. The questionnaire comprised two sections. Sections I and II were used to measure respondents' demographics and their professional affiliations and the study constructs, respectively. Three reflective measurement scales were used to assess the three latent constructs: Environmental Factors, Recycling Materials, and Production Process. Each construct was measured across five dimensions and five indicators, yielding 25 items. Every item was measured on a five-point Likert scale from 1 = Strongly Disagree to 5 = Strongly Agree. Environmental Factors included regulatory, managerial, and technological dimensions of environmental orientation, such as compliance with environmental regulations, managerial waste management activities, sustainability awareness, resource availability, and carbon reduction. Recycling Materials measured the adoption of recycling practices, policy encouragement, cost-effectiveness, material performance, and circular-economy activities. The Production Process construct measured firms' operational performance in terms of energy efficiency, clinker-to-cement ratio, cost reduction, regulatory compliance, and the use of sustainable technologies. The measurement items were adapted from validated scales cited in the literature and tailored to the cement industry context in Pakistan. Academic experts and industry professionals were consulted to check the clarity, relevance and suitability of the questionnaire.

3.4 Data Collection Procedure

Data were gathered through a structured questionnaire from employees in the cement production industry in the Punjab and Sindh provinces of Pakistan, which are Pakistan's cement production hubs. The questionnaires were self-administered on paper and via Google Forms, depending on the availability and restrictions of the various departments. All subjects in the study were informed of the study's purpose and assured of the confidentiality of their responses, to minimize social desirability effects. The respondents were production engineers, supervisors, line managers, and technical workers who were directly involved in environmental management, recycling, and production activities. Approximately 100 usable responses were collected over a time period of two months. The response dataset was considered suitable for SPSS, a sophisticated analytical approach that is limited to exploratory models and datasets of relatively small size.

3.5 Data Screening and Preparation

Prior to the analysis, the data was screened and prepared in accordance with procedures established by the statistical package, i.e., the Statistical Package for the Social Sciences (SPSS), for use as a dataset for analysis. First, the dataset was checked for any missing values. One of the steps ensured that there were no missing values with a significant impact and that all records were included in the analysis. Second, outlier analysis was conducted (i.e., both score-based outlier evaluation and boxplots for outlier detection). No significant outliers were found that would have negatively impacted on the results. Third, response statistics (e.g., means and standard deviations) were computed for each item. Fourth, the dataset's normality assumption was evaluated. While there were some indicators of non-normality, this did not pose a problem. Finally, the cleaned dataset was exported to SPSS for reliability testing and hypothesis testing.

J. Adv. Mech. Eng. Appl. Vol. 7 No. 1 (2026) p. 27-43

3.6 Data Analysis Technique

The data analyzed using SPSS was used to test the direct relationships between Environment, Recycling Materials, and Production Process. This analysis was performed in two steps. The first step involved the measurement model, which was used to assess the reliability and validity of the constructs. Internal consistency reliability was assessed using Cronbach's alpha, standard deviation, and correlation analysis.

4. Results

4.1 Demographic Characteristics of Respondents

The demographic variables of the respondents are shown in Table 2. The sample included 100 respondents who occupy operational, technical, and managerial roles within the firms in the cement manufacturing industry. The demographics indicate that the respondents have relevant education and sufficient industry tenure, making their perspectives suitable for the analysis.

Table 2 *Demographic analysis*

Parameter	Position	Quantity
	Production manager	18
	Deputy / Assistant manager (Production)	12
	Mechanical / Maintenance engineer	09
	Process / Shift engineer	08
Job title / Designation	HSE manager	11
	Quality control manager	08
	Electrical / Instrumentation engineer	10
	Production engineer	16
	Senior technician/Lab supervisor/Foreman	08
	Production	32
	Mechanical engineering	20
Department	Environment / Safety	16
	Quality control	18
	Electrical & Instrumentation	14
	25–35 years	43
Age Group	36–45 years	31
	46–55 years	19
	55 years and above	07
	Diploma	24
Education Level	Bachelor's degree	41
	Master's degree	29
	PhD	06
Work Experience	6–10 years	39
	11–15 years	33
	More than 15 years	28

4.2 Reliability Analysis (Cronbach's Alpha)

Cronbach's Alpha (α) is the most widely used statistic that tests the reliability and internal consistency of the scales of questions that are used in survey-based research [34]. More specifically, it measures the correlation of the items of a construct. The calculation of this statistic interprets its values in a manner typical of the research literature [35].

A reliability value between 0.60 and 0.70 is acceptable only for exploratory research, indicating that the measurement scale is still in its early stages [36].

Extremely reliable values, however, may mean that the scale has redundant questions. These interpretations of the reliability values, though, will assist in determining whether the constructed questionnaire is reliable enough to be used in the main study.

Table 3 *Rule of thumb*

Alpha Value	Interpretation
< 0.60	Poor reliability
0.60 – 0.70	Acceptable (pilot only)
0.70 – 0.80	Good
0.80 – 0.90	Very good
> 0.90	Excellent

Table 4 *Reliability analysis (Cronbach's alpha)*

Factors	Item code	N	Cronbach's alpha
Regulatory framework	A1	100	.905
Waste management regulations	A2	100	.906
Sustainability awareness	A3	100	.900
Resource availability and material efficiency	A4	100	.900
Carbon footprint reduction	A5	100	.897
Utilization of industrial byproducts	B1	100	.900
Policy support for recycling	B2	100	.901
Cost efficiency	B3	100	.906
Impact on cement strength	B4	100	.917
Circular economy practices	B5	100	.901
Energy consumption efficiency	C1	100	.906
Clinker to cement ratio	C2	100	.903
Operational cost optimization	C3	100	.901
Environmental compliance	C4	100	.908
Adoption of sustainable technologies	C5	100	.911

A pilot study was conducted with 100 respondents to assess the reliability and internal consistency of the survey instrument before initiating full-scale data collection. The findings of the reliability analysis indicate that all constructs achieved excellent Cronbach's Alpha coefficients, as shown in Table 4. The Regulatory Framework construct alone yielded a reliability value of 0.905, as its companion construct, Waste Management Regulations Constructs related to sustainability dimensions also achieved strong reliability, including Sustainability Awareness (α = 0.900), Resource Availability and Material Efficiency (α = 0.900), and Carbon Footprint Reduction (α = 0.897). Constructs related to circular (and industrial) sustainability, including the application of industrial byproducts (α = 0.900), Policy Support for Recycling (α = 0.901), and Circular Economy Practices (α = 0.901), also confirmed the reliability of the measurement scale.

Constructs related to economic and operational performance were also reliable: Cost Efficiency (α = 0.906), Operational Cost Optimization (α = 0.901), and Energy Consumption Efficiency (α = 0.906). Finally, the construct of Impact on Cement Strength was shown to be the most reliable, achieving a strong coherence value of (α = 0.917), thereby confirming the reliability of its measurement items. Overall, all alpha values exceeded the recommended threshold of 0.70, indicating that the survey instrument was a reliable tool for testing the study's main research hypotheses.

Additional tests performed on the survey instrument, though not associated with reliability per se, also evaluated the items descriptively: responses to the questionnaire items had a moderate standard deviation, ranging from 0.50 to 0.80, as shown in Table 5. These values generally indicate that the respondents were not hindered in their ability to make relative judgments between the responses provided in the questionnaire. A relative handful of items returned higher standard deviation values (SD $\approx$ 0.97–0.98), indicating that those statements may have elicited differing perceptions among respondents and that these items may need to be better refined before being presented to the final respondents in the actual survey study. Together, these analyses indicate that the developed survey instrument is reliable for examining the sustainability-driving regulatory, environmental, and operational conditions in this study.

Table 5 *Standard deviation*

Questions/Item Code	N	Std. Deviation
A1Q1	100	.69786
A1Q2	100	.76947
A1Q3	100	.72311
A1Q4	100	.72467
A1Q5	100	.72486
A2Q1	100	.78762
A2Q2	100	.78312
A2Q3	100	.72467
A2Q4	100	.72017
A2Q5	100	.73569
A3Q1	100	.67313
A3Q2	100	.74618
A3Q3	100	.66617
A3Q4	100	.79173
A3Q5	100	.65073
A4Q1	100	.72174
A4Q2	100	.66617
A4Q3	100	.87962
A4Q4	100	.69927
A4Q5	100	.70089
A5Q1	100	.69115
A5Q2	100	.70089
A5Q3	100	.70410
A5Q4	100	.72174
A5Q5	100	.70028
B1Q1	100	.67565
B1Q2	100	.65094
B1Q3	100	.66892
B1Q4	100	.67627
B1Q5	100	.97584
B2Q1	100	.67627
B2Q2	100	.66892
B2Q3	100	.71781
B2Q4	100	.71525
B2Q5	100	.70511
B3Q1	100	.71781
B3Q2	100	.71228
B3Q3	100	.58125
B3Q4	100	.67313
B3Q5	100	.64550
B4Q1	100	.70089
B4Q2	100	.97931
B4Q3	100	.89868
B4Q4	100	.74769
B4Q5	100	.53441
B5Q1	100	.68458
B5Q2	100	.47538

Questions/Item Code	N	Std. Deviation
B5Q3	100	.70089
B5Q4	100	.67565
B5Q5	100	.78905
C1Q1	100	.50422
C1Q2	100	.59447
C1Q3	100	.64309
C1Q4	100	.81286
C1Q5	100	.69115
C2Q1	100	.74314
C2Q2	100	.70109
C2Q3	100	.71997
C2Q4	100	.69115
C2Q5	100	.67627
C3Q1	100	.69380
C3Q2	100	.78905
C3Q3	100	.71997
C3Q4	100	.67460
C3Q5	100	.69927
C4Q1	100	.97772
C4Q2	100	.72467
C4Q3	100	.66298
C4Q4	100	.70089
C4Q5	100	.72408
C5Q1	100	.70028
C5Q2	100	.67565
C5Q3	100	.53652
C5Q4	100	.58488
C5Q5	100	.62887
Valid N (listwise)	100	

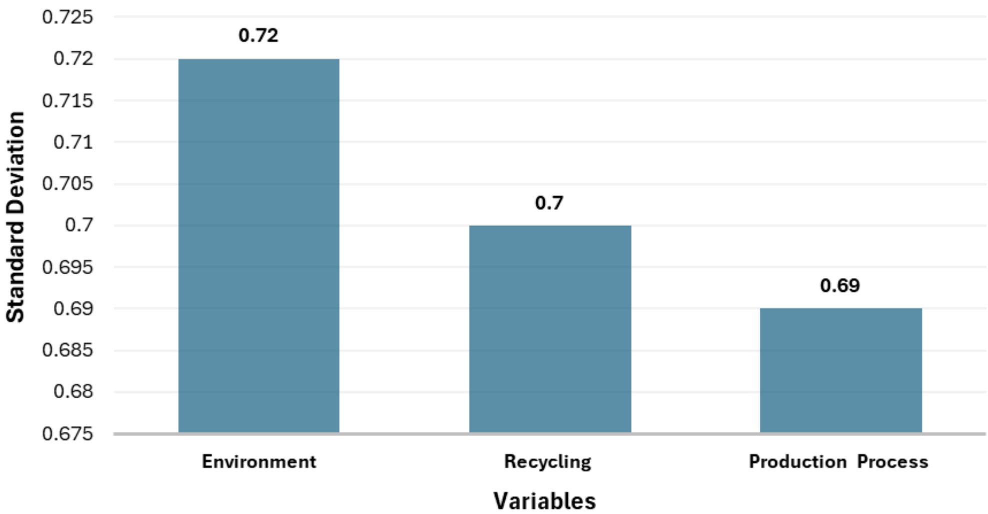

Fig. 3 *Variability of research variables*

Fig. 3 shows the graphical description of variability across variables. It indicates a consistent distribution between the environment, recycling, and the production process.

J. Adv. Mech. Eng. Appl. Vol. 7 No. 1 (2026) p. 27-43

4.3 Correlation Analysis

Correlation analysis is a statistical method that identifies significant relationships between two or more quantitative variables [37]. Correlation assesses the level of association and dependence between variables. The range of correlation values is usually between -1 and +1. Correlation is expressed as a correlation coefficient [38]. Table 6, showing correlation analysis between 3 variables: Environmental Factors, Recycling Materials, and Production Performance. Based on N = 100 respondents.

The study assesses the direct relationship between variables, so the Pearson correlation analysis is the most suitable option for the analysis of direct relationships. The pilot nature of the study and small sample size are not appropriate for the more complex methods, such as regression or structural equation modeling.

4.3.1 Environmental Factors and Recycling Materials

The correlation between Environmental Factors and Recycling Materials is $r = 0.617$. There is a moderately strong positive relationship between the two variables: higher environmental factors are associated with greater recycling of materials. The significance value ($p = 0.000$, 2 tailed) is less than 0.01; at least 1% significance level.

4.3.2 Environmental Factors and Production Performance

The correlation between Environmental Factors and Production Performance is $r = 0.780$. There is a moderately strong positive relationship between the two variables; better environmental factors lead to better production performance. The p-value (0.000) is less than 0.01, which is the 1% significance level.

4.3.3 Recycling Materials and Production Performance

The correlation between Recycling Materials and Production Performance is $r = 0.639$. There is a moderately strong positive relationship between the two variables; more recycling materials leads to better production performance. The relationship is statistically significant; the p-value (0.000) is less than 0.01, the 1% significance level.

4.4 Overall Interpretation of Correlation Analysis

- All three variables are positively related at the 0.01 significance level.
- Environmental Factors and Production Performance have the strongest positive relationship ($r = 0.780$).
- Recycling Materials has a moderately strong positive relationship with both other variables.

The findings suggest that better environmental conditions and greater use of recycled materials are associated with improvements in production performance in the organizations analyzed. Fig. 3 and 4 present a graphic representation of associations between variables.

Table 6 *Correlations analysis of variables*

Correlations analysis		Environmental factors	Recycling materials	Production performance
Environmental factors	Pearson Correlation	1	.617	.780
	Sig. (2-tailed)		.000	.000
	N	100	100	100
Recycling materials	Pearson Correlation	.617	1	.639
	Sig. (2-tailed)	.000		.000
	N	100	100	100
Production performance	Pearson Correlation	.780	.639	1
	Sig. (2-tailed)	.000	.000	
	N	100	100	100

Correlation is significant at the 0.01 level (2-tailed).

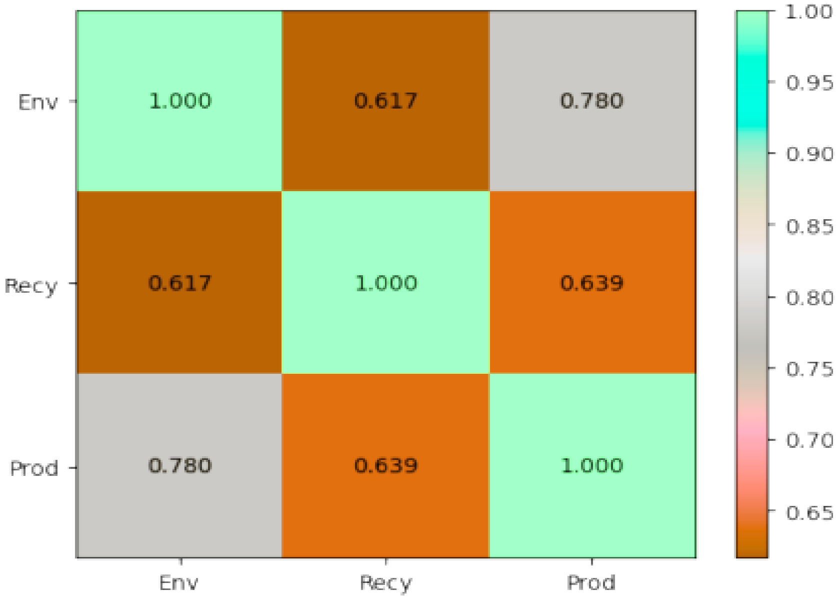

Fig. 4 *Heatmap correlation analysis of variables*

Fig. 4 and 5 indicate the graphical representation of correlation. Fig. 3 shows the heatmap of correlation, while Fig. 4 compares the correlation values. It indicates positive relationships between all variables, with environmental factors having the strongest relationship with production performance.

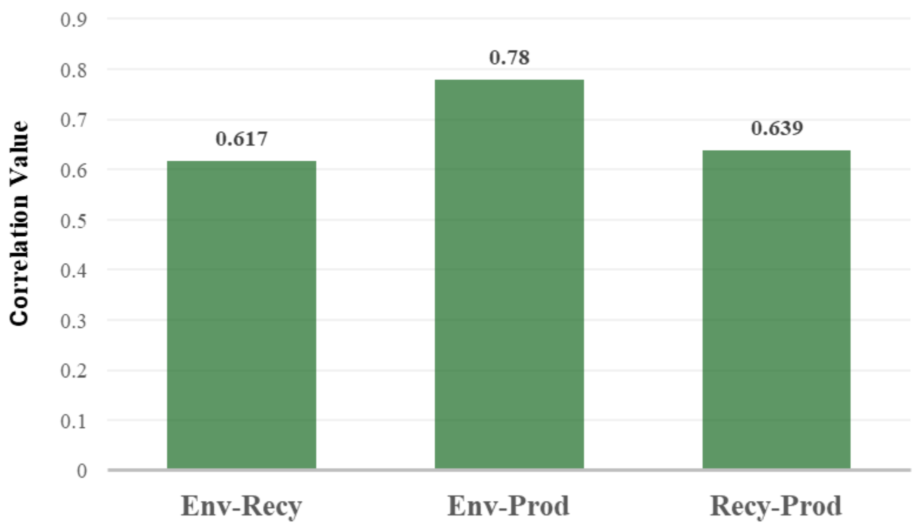

Fig. 5 *Key correlation analysis between variables*

A Pearson correlation analysis was conducted to test the hypotheses (H1-H3). The test results demonstrated that each variable exhibited a positive relationship with the others, and each was statistically significant at the 1% level, as shown in Table 7. For instance, environmental factors were found to have a moderately strong relationship with the recycling of materials within the cement plants ($r = 0.617$) and exhibited a strong positive relationship with the production performance of the cement plants ($r = 0.780$). Furthermore, the variable related to material recycling within cement plants also showed a positive relationship with those plants' production performance ($r = 0.639$). These results support all three hypotheses (H1, H2, and H3). Thus, the study indicates that the improvement of environmental factors within the cement manufacturing and processing plants will lead to both a direct and indirect improvement in the production performance of those plants

Table 7 *Summary of hypothesis testing results*

Hypothesis	Relationship Tested	Correlation (r)	p-value	Result
H1	Environmental Factors → Recycling Materials	0.617	0.000	Supported
H2	Environmental Factors → Production Performance	0.780	0.000	Supported
H3	Recycling Materials → Production Performance	0.639	0.000	Supported

5. Discussions

5.1 Summary of Key Findings

The study explored direct relationships among the environment, recycling, and production performance in cement manufacturing in Pakistan, a developing nation. The findings support the hypothesized model, indicating that environment is a strong predictor of both recycling and production performance in the cement industry [39]. More specifically, the factors that create the environment are positively related to production performance, meaning that production can be made more consistent and efficient by firms that improve their focus on regulatory compliance, enhance their knowledge of the environment through education and dissemination, and minimize resource consumption [15].

Environmental factors also significantly influence recycling, meaning that firms with more “mature” environmental management systems are more likely to incorporate by-products from other industries and implement circular economy practices in their operations [8]. Furthermore, recycling is positively related to production performance, meaning that such operations enable firms to improve production efficiency, reduce reliance on raw materials, increase resource use efficiency, and make production runs more consistent [40]. The supported relationships therefore indicate that environment, recycling, and production performance are related dimensions of a sustainable cement production operation, as well as the implications of failing to properly incorporate an environmental focus in a firm’s production operations [41], [42].

5.2 Practical Implications

These implications are therefore clearly practical for policymakers and industry managers who wish to improve the sustainability outcomes of cement production. From the perspective of policymakers, the implication is that improvements in environmental policy and enforcement mechanisms can serve as critical drivers of both increased recycling use and improved recycling practice in production efforts. Policymakers can therefore work to improve the environmental sustainability of cement production by establishing clearer requirements for recycling, improving the incentive structures for the industry’s use of industrial byproducts such as fly ash, and enabling the cement production sector through investment in cleaner production methods. Similarly, plant managers can recognize that environmental practices should not be viewed solely as burdensome requirements for regulatory compliance, but also as essential practices to improve plant performance. The integration of recycling practices into cement production can increase the availability of concrete production materials, decrease costs and make it easier to implement processes such as clinker substitution. In these various ways, improvements in the field’s environmental regulations and the implementation of environmental recycling practices can ecologically benefit circular cement production methods by enabling a shift towards more circular methods.

5.3 Theoretical implication

From a theoretical perspective, this paper makes an academic contribution to existing literature by establishing a link between environmental factors, recycling practices, and the production performance of cement manufacturing plants. While previous studies have considered each of these variables separately, this research has demonstrated the impact of environmental factors on production performance, both directly and indirectly through their effects on recycling practices in the cement manufacturing process. The results of this research indicate that environmental management practices are not limited to the consideration of sustainable practices for the cement manufacturing process. Instead, focusing on such practices can increase the efficiency of manufacturing plants’ production processes and their overall performance. The positive and significant relationships among the variables considered contribute to the resource-based view of the firm and the circular economy theory. Both theories suggest that a company's resource utilization efficiency will have a positive impact on its overall performance.

Finally, this research also extends the existing literature on the topic by considering an underrepresented developing economy. The findings of this research contribute to the existing literature by establishing that the principles of environmental management and recycling can also be applied within developing economies, and that their application will lead to similar generalizability in the effect of sustainability on the performance of manufacturing plants.

6. Conclusion

The study assesses the significance of environmental factors and recycling for increasing the performance of the production process in the cement industry. It indicates that environmental management and recycling can increase the sustainability and efficiency of production systems. This paper contributes to the emerging research on sustainability-based performance in the cement sector by demonstrating a relationship between environment, recycling, and production performance. These insights reveal how environmental management actions can be directly linked to improvements in production performance while also strengthening the incentive to adopt recycling initiatives at the cement manufacturing plants. The influence of recycling on production performance also underscores the operational advantages of implementing circular-economy activities. Thus, the research demonstrates the benefits of sustainability-based environmental management in the cement sector, as it can make these factories more operationally efficient and consistent in their production. Overall, the findings provide valuable insights into industrialists and policy makers to increase sustainability in cement production.

7. Future Studies

Despite this study's contributions to the current literature on the direct associations among environment, recycling, and production outcomes, it also identifies several opportunities for future research. First, the environment-recycling-production performance model can be further tested in future research to identify whether there are factors that mediate or moderate the strength of these direct associations to the production performance outcomes, such as factors like technological capability, organizational culture, or government incentives. Second, future research can use longitudinal studies to examine how environmental and recycling practices affect production outcomes over time, especially as government regulations shift. Third, future research can expand the types of sustainability performance outcomes assessed within the scope of green cement manufacturing, including carbon-reduction manufacturing performance, life-cycle assessment outcomes, and financial performance outcomes, enabling more comprehensive assessments of this industry's sustainability performance. Finally, future research can also test different countries or industries to enhance the external validity of this study's findings and establish more widespread evidence on the impacts of environmental management practices on circular economy implementation and operational performance.

Acknowledgement

I am thankful to my Professor Dr. Yusri Yusof for their support and thankful to UTHM Malaysia for providing the resources.

Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Temoor Abbas Larik;* ***data collection, analysis and software:*** *Temoor Abbas Larik;* ***overall supervision, review and editing:*** *Yusri Yusof;* ***draft preparation:*** *Faheemullah Shaikh;* ***final formatting and editing:*** *Zohaib Khan. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Busola Dorcas Akintayo, Damilola Calec Akintayo & Oludolapo Olanrewaju (2023) Material substitution strategies for energy reduction and greenhouse gas emission in cement manufacturing, *Atmosphere*, *14(8),* 1200, https://doi.org/10.3390/atmos14081200

[2] Francis Boluwaji Elehinafe, Somina N. Ezekiel, Oyetunji B. Okedere & Olayemi O. Odunlami (2022) Cement industry–Associated emissions, environmental issues and measures for the control of the emissions, *Mechanical Engineering for Society and Industry*, *2(1),* 17–25, https://doi.org/10.31603/mesi.5622

[3] Rawaz Kurda, Jose Dinis Silvestre & Jorge de Brito (2018) Toxicity and environmental and economic performance of fly ash and recycled concrete aggregates use in concrete: A review, *Heliyon*, *4(4),* https://doi.org/10.1016/j.heliyon.2018.e00611

[4] Salman Shooshtarian, Savindi Caldera, Tayyab Maqsood & Tim Ryley (2020) Using recycled construction and demolition waste products: A review of stakeholders' perceptions, decisions, and motivations, *Recycling*, *5(4),* 31, https://doi.org/10.3390/recycling5040031

[5] Huong Giang Luong, Thi Lan Anh Nguyen & Vu Ngoc Xuan (2026) Assessing sustainability indicators of carbon emissions in the Netherlands: The roles of innovation, renewable energy, and economic openness, *Environmental and Sustainability Indicators*, 101167, https://doi.org/10.1016/j.indic.2026.101167

[6] Atiq, A. (2023). Utilization of reclaimed bricks to facilitate circular economy (CE) in the construction industry: A study of Pakistan's construction industry. [Master's degree thesis, Södertörn University]. DiVa Portal.

[7] M. Adil Khan, Uzair Ali, Baitullah Khan Kibzai, Salma Khalid, Aamir Nazeer, Naveed Sardar & Mehraj Hameed (2025) Reforming Pakistan's Cement Industry: A Critical Pathway to Combating Climate Change, *Spectrum of Engineering Sciences*, 1057–1067, https://doi.org/10.5281/zenodo.17440506

[8] Chanaka Manoj Balasuriya, Alahakoon Amarb, Kasun Ethawuda, Bandara, G. A. I. M., Senerath Pgrlp & Arachchige, U. S. (2023) Minimizing environmental pollution in the cement industry through optimizations, *Journal of Research in Technology and Engineering, 4(3).*

[9] Sax, S. & Lautrup, J. (2024, July 10). How the cement industry is creating carbon-negative building materials. Time. https://time.com/7023365/cement-concrete-climate/

[10] Yu-Ming Huang, Chao-Shi Chen, Chen-Chung Chen & Jian-Wen LaiHuang (2024) Utilizing Industrial Sludge Ash in Brick Manufacturing and Quality Improvement, *Materials*, *17(11),* 2568, https://doi.org/10.3390/ma17112568

[11] Haimann, R. (2024, October 11). Immobilien: Schneller, günstiger, nachhaltiger – Traum vom grünen Beton rückt näher. Die Welt. https://www.welt.de/finanzen/immobilien/plus253817564/Immobilien-Schneller-guenstiger-nachhaltiger-Traum-vom-gruenen-Beton-rueckt-naeher.html

[12] Makkonen, J. (2020). Conceptualization of the production process [Bachelor's thesis, Metropolia University of Applied Sciences]. Theseus. https://www.theseus.fi/bitstream/handle/10024/334706/Makkonen_Joel.pdf?sequence=

[13] Fei Tao, Jiangfeng Cheng, Qinglin Qi, Meng Zhang, He Zhang & Fangyuan Sui (2018) Digital twin-driven product design, manufacturing and service with big data, *International Journal of Advanced Manufacturing Technology, 94(9–12),* 3563–357, https://doi.org/10.1007/s00170-017-0233-1

[14] Papp, J. (2018). *Quality management in the imaging sciences* (6th ed.) *e-book*. Elsevier. ISBN: 9780323635844

[15] Cheav Por (Paul) Chea, Ket Pinnara, Taing L., Sela Kong, Um D., Taing, Chanmoly Or, C., Aun, S. & Hang, L. (2022) Life-cycle impact assessment of air emissions from a cement production plant in Cambodia, *Open Journal of Air Pollution*, *11(04),* 85–99, https://doi.org/10.4236/ojap.2022.114007

[16] Yu-Ming Huang, Chao-Shi Chen, Chen-Chung Chen & Jian-Wen Lain (2024). Utilizing industrial sludge ash in brick manufacturing and Quality Improvement, *Materials*, *17*(*11*), 2568, https://doi.org/10.3390/ma17112568

[17] Dali Bondar, Bruno Campos & Elizabeth Gilligan (2024) Enhancement of early age strength of activated steel by-products. *Interdisciplinary Symposium on Smart & Sustainable Infrastructures*, 328–337, https://doi.org/10.1007/978-3-031-53389-1_31

[18] Yasir Basheer, Asad Waqar, Saeed Mian Qaisar, Toqeer Ahmed, Nasim Ullah & Sattam Alotaibi (2022) Analyzing the prospect of hybrid energy in the cement industry of Pakistan, using homer pro, *Sustainability, 14(19*), 12440, https://doi.org/10.3390/su141912440

[19] Guillaume Habert, Sabbie Miller, Canderley M. John, John L. Provis, Favier, A., Horvath, A., & Scrivener, K. L. (2020) Environmental impacts and decarbonization strategies in the cement and concrete industries, *Nature Reviews Earth & Environment, 1(11)*, 559–573, https://doi.org/10.1038/s43017-020-0093-3

[20] Shoaib Sarfraz, Ziyad Sherif, Mark Jolly & Konstantinos Salonitis (2024) Benchmarking of energy consumption and CO2 emissions in cement production: A case study, *The Minerals, Metals & Materials Series*, 53–65, https://doi.org/10.1007/978 3-031-50244-6_5

[21] Hidemichi Fujii, Kazuyuki Iwata, Shinji Kaneko & Shunsuke Managi (2012) Corporate environmental and economic performance of Japanese manufacturing firms: Empirical study for sustainable development, *Business Strategy and the Environment,* 22(*3*), 187-201, https://mpra.ub.uni-muenchen.de/39564/

[22] Andrew King & Michael Lenox (2001) Lean and green? An empirical examination of the relationship between lean production and environmental performance, *Production and operations management*, *10*(*3*), 244-256, https://doi.org/10.1111/j.1937-5956.2001.tb00373.x

[23] Muhammad Ikram, Peng Zhou, Syed Ahsan Ali Shah & Guoquan Liu (2019) Do environmental management systems help improve corporate sustainable development? Evidence from manufacturing companies in Pakistan, *Journal of Cleaner Production*, *226*, 628–641, https://doi.org/10.1016/j.jclepro.2019.03.265

[24] Jose-Julian Escario, Carla Rodriguez-Sanchez & Luis V. Casaló (2020) The influence of environmental attitudes and perceived effectiveness on recycling, reducing, and reusing packaging materials in Spain, *Waste Management*, *113*, 251–260, https://doi.org/10.1016/j.wasman.2020.05.043

[25] Busola Dorcas Akintayo, Olubayo Moses Babatunde, Damilola Caleb Akintayo & Oludolapo Akanni Olanrewaju (2025) Transforming Industrial Waste into Low-Carbon Cement: A Multi-Criteria Assessment of Supplementary Cementitious Materials for Sustainable Concrete Design, *Recycling, 10(6)*, 211, https://doi.org/10.3390/recycling10060211

[26] Jun-Ki Choi, Dillip Thangamani & Kelly Kissock (2019) A systematic methodology for improving resource efficiency in small and medium-sized enterprises, *Resources, Conservation and Recycling*, *147*, 19–27, https://doi.org/10.1016/j.resconrec.2019.04.015

[27] Joan Manuel F. Mendoza, Simona Andreea Popa, Francesco D'Aponte, Diego Gualtieri & Adisa Azapagic (2019) Improving resource efficiency and environmental impacts through novel design and manufacturing of disposable baby diapers, *Journal of Cleaner Production*, *210*, 916–928, https://doi.org/10.1016/j.jclepro.2018.11.046

[28] Amzan Alsabri Furqan Tahir & Sami G. Al-Ghamdi (2022) Environmental impacts of polypropylene (PP) production and prospects of its recycling in the GCC region, *Materials Today: Proceedings*, 2245–2251, https://doi.org/10.1016/j.matpr.2021.11.574

[29] Hafiz Miqdad Masood, Sajjad Haider, Umair Javed, Najaf Ali, Sadiq Hussain &Muhammad Ashraf (2021) A Technical Feasibility Study and Environmental Impacts of Green Cement Production from Recycled Fly Ash in Pakistan, *Journal of the Pakistan Institute of Chemical Engineers*, *49(1)*, 33–39, https://doi.org/10.54693/piche.04914

[30] Mingxue Ma, Vivian WY. Tam, Khoa N. Le & Robert Osei-Kyei (2022) Factors affecting the price of recycled concrete: A critical review, *Journal of Building Engineering*, *46*, https://doi.org/10.1016/j.jobe.2021.103743

[31] Malek Batayneh, Iqbal Marie & Ibrahim Asi (2007) Use of selected waste materials in concrete mixes, *Waste Management*, *27(12),* 1870–1876, https://doi.org/10.1016/j.wasman.2006.07.026

[32] Kamal Hosen & Alina Bărbulescu (2026) Cement Industry Pollution Mitigation: A Comprehensive Review on Reducing Environmental and Health Impacts, *Toxics, 14(2),* 138, https://doi.org/10.3390/toxics14020138

[33] Kinga Korniejenko, Janusz Mikuła, Karolina Brudn, Lyazat Aruova, Alibek Zhakanov, Assel Jexembayeva & Lailya Zhaksylykova (2025) A Review of Industrial By-Product Utilization and Future Pathways of Circular Economy: Geopolymers as Modern Materials for Sustainable Building, *Sustainability, 17(10),* 4536, https://doi.org/10.3390/su17104536

[34] Mohsen Tavakol & Reg Dennick (2011) Making sense of Cronbach's alpha, *International Journal of Medical Education*, *2*, 53, https://doi.org/10.5116/ijme.4dfb.8dfd

[35] Andreas Christmann &Stefan Van Aelst (2006) Robust estimation of Cronbach's alpha, *Journal of Multivariate Analysis*, *97(7),* 1660-1674, https://doi.org/10.1016/j.jmva.2005.05.012

[36] Keith S. Taber (2018) The use of Cronbach's alpha when developing and reporting research instruments in science education, *Research in science education*, *48(6),* 1273-1296, https://doi.org/10.1007/s11165-016-9602-2

[37] Gogtay Nithya J. & Urmila M. Thatte (2017) Principles of correlation analysis, *Journal of the Association of Physicians of India*, *65(3)*, 78-81.

[38] Monica Franzese & Antonella Iuliano (2018) Correlation analysis, *Encyclopedia of bioinformatics and computational biology: ABC of bioinformatics*, *1*, 706-721, https://doi.org/10.1016/B978-0-12-809633-8.20358-0

[39] Amir Shirkhani, Hamed Kouchaki-Penchah & Afshin Azmoodeh-Mishamandani (2018) Environmental and exergetic impacts of cement production: A case study, *Environmental Progress & Sustainable Energy, 37(6)*, 2042–2049, https://doi.org/10.1002/ep.12894

[40] Ammar Ali Gull, Muhammad Atif, Tanveer Ahsan & Imen Derouiche (2022) Does waste management affect firm performance? International evidence, *Economic Modelling, 114*, 105932, https://doi.org/10.1016/j.econmod.2022.105932

[41] Azfar Uddin, Yousaf Ali, Muhammad Sabir, Antonella Petrillo & Fabio De Felice (2023) Circular economy and its implementation in cement industry: A case point in Pakistan, *Science of the Total Environment*, *898*, 165605, https://doi.org/10.1016/j.scitotenv.2023.165605

[42] Yasmine Rhaouti, Yassine Taha & Mostafa Benzaazoua(2023) Assessment of the environmental performance of blended cements from a life cycle perspective: a systematic review, *Sustainable Production and Consumption*, *36*, 32-48, https://doi.org/10.1016/j.spc.2022.12.010