Identifying and Explaining Green Supply Chain Management Practices with a Focus on Technical Perspectives for Performance Improvement

Ali Nourizadeh Firouzabadi[1], Hassan Dehghan Dehnavi[2*] Mohammad Taghi Honary[3] Mozhde Rabbani[3], Abolfazl Sadeghian[3]

[1] PhD student, Department of Industrial Management, Yazd Branch, Islamic Azad University, Yazd, Iran.
[2] Associate Professor, Department of Industrial Management, Yazd Branch, Islamic Azad University, Yazd, Iran (Corresponding Author).
[3] Assistant Professor, Department of Industrial Management, Yazd Branch, Islamic Azad University, Yazd, Iran.

*** Corresponding author email address**: hasanehghanehnavi@yahoo.com

Received: 2024-11-02 **Reviewed:** 2024-11-16 **Revised:** 2024-12-20 **Accepted:** 2025-01-19 **Published:** 2025-03-18

Abstract

The objective of this study is to design a model for green supply chain management practices with an emphasis on technical factors for localized performance improvement in the tile and ceramic industry. The research methodology is based on the interpretive paradigm, developmental in purpose, and employs an inductive approach with an exploratory-analytical nature. It is conducted as a mixed-method study, drawing on a target population of industry and academic experts and using purposeful sampling. The research consists of three steps. The first step identifies green supply chain management practices emphasizing technical factors for performance improvement through content analysis of national and international publications. The second step localizes the extracted practices, focusing on the tile and ceramic industry, using the Delphi method. The third step involves ranking the factors and presenting a model. The study introduces green supply chain management practices with a focus on technical factors for performance improvement and explores the relationships between these practices to provide managers with actionable insights. The proposed model encourages managers to prioritize factors such as research and development, continuous analytical review of machinery operational status, and comprehensive analytical evaluation of all stages of production processes, which are identified as the most influential practices.

Keywords: *Supply Chain Management, Green Supply Chain Management, Technical Factors, Performance Improvement, Tile and Ceramic Industry*.

How to cite this article:

Nourizadeh Firouzabadi A, Dehghan Dehnavi A, Honary M.T, Rabbani M, Sadeghian A. (2025). Identifying and Explaining Green Supply Chain Management Practices with a Focus on Technical Perspectives for Performance Improvement. Management Strategies and Engineering Sciences, 7(4), 50-60.

1. Introduction

Historically, it can be argued that managers in companies and organizations worldwide have always sought to enhance and improve organizational performance. Consequently, in most management and organizational theories, performance assessment and improvement have been significant and common objectives. In managerial discussions and research, organizational performance is considered a fundamental concept. Managers are judged based on their performance, and high performance is deemed essential for survival and success in competitive environments [1]. Performance can be defined as the set of activities carried out by individuals and groups to achieve predetermined organizational goals. It also reflects an organization's efficiency. In other words, the success of employees and their strategies determines the success of any business in any environment [2].

Awareness of the supply chain, its components, and effective management can significantly contribute to organizational performance improvement. Developing and enhancing relationships within the supply chain boosts the performance of all its members. In today's competitive market, companies no longer compete individually but as part of a supply chain, seeking to enhance its performance and maximize the overall profit for the chain [3]. Market transformations and increased global competition have changed how goods are supplied and how buyers interact with suppliers. Reducing costs, improving flexibility in response to market changes, and developing collaborative and sustainable relationships within the supply chain have become essential (Mahdavi Goluje & Esmailian, 2016).

Given the globalization of competition, adopting appropriate management models, such as supply chain management, has become a top priority. This topic has received considerable attention in recent scientific research. However, it is important to note that an organization's success and well-being depend on the health of its environment and the individuals interacting with it [4]. Environmental pollution leads to diseases and weakens individuals, creating a vicious cycle where pollution transfers from the environment to the organization, then to individuals and other organizations. The extent of its impact on organizational performance is uncertain, and its long-term consequences remain unknown [5].

The addition of "green" to supply chain management has introduced a transformation that considers an organization's broader responsibilities. Green supply chain management (GSCM) aligns with environmental compatibility and adopts practices such as green purchasing, customer collaboration, environmentally friendly product design, and internal environmental management to improve organizational performance while addressing environmental concerns [6-8].

Technical factors are a critical approach to successfully implementing GSCM and improving organizational performance, as highlighted in this research. To optimize processes, organizations must focus on enhancing equipment and addressing technical aspects such as information infrastructure and supply chain information management. Supply chain actors with strong collaboration aimed at shared goals perform better, as effective information management reduces decision-making risks within the chain [9, 10].

Traditionally, organizational performance metrics have focused on financial outcomes and profit margins. However, with increasing societal attention to environmental issues, non-financial aspects such as social responsibility and environmental performance have gained prominence in performance assessments. Globalization, intense competition, diverse customer needs, and shorter product cycles present organizations with significant challenges and pressures in today's competitive market [11].

The tile and ceramic industry in Yazd Province has made significant advancements as one of Iran's largest hubs in this sector, contributing to employment and the number of active companies. However, recent years have witnessed a decline or bankruptcy of several companies in this industry due to economic and managerial challenges. A major cause of this decline has been the inability to identify and adapt to market demands, despite significant investments in selecting appropriate suppliers, which has exposed weaknesses in supply chain management [12].

With growing concerns about environmental issues and sustainability, organizations are striving to redesign their supply chains to reduce environmental impacts and enhance sustainable performance. GSCM emphasizes environmentally compatible methods to minimize resource consumption and waste throughout the supply chain. However, many organizations face challenges in implementing GSCM practices due to the lack of a comprehensive and suitable model [9]. A key aspect of GSCM is the focus on utilizing technology and technical innovation to enhance performance and reduce environmental impacts. Yet, designing a comprehensive model that integrates GSCM practices from a technical perspective remains an unresolved issue. This gap has led to the misalignment of technical and environmental actions, reducing organizational effectiveness and efficiency in achieving sustainability goals [11].

While many studies have explored GSCM, the absence of a practical and scientifically grounded model remains evident. By designing a model that addresses GSCM practices from a technical perspective, organizations can adopt more effective approaches for implementing green initiatives and improving performance. Therefore, it is essential to develop a comprehensive and scientific model for GSCM practices that optimizes the use of technology and innovation, ultimately enhancing organizations' economic, social, and environmental performance.

This research seeks to answer the following questions:

1. What are the GSCM practices emphasizing technical factors for performance improvement?
2. What are the localized GSCM practices emphasizing technical factors for performance improvement in the tile and ceramic industry?
3. What is the model of localized GSCM practices emphasizing technical factors for performance improvement in the tile and ceramic industry?

2. Methodology

To achieve the research objectives, the study is divided into three phases. The first phase involves identifying green supply chain management (GSCM) practices emphasizing technical factors for performance improvement. The second phase focuses on tailoring these practices to the tile and ceramic industry. The third phase presents a model of localized GSCM practices emphasizing technical factors for performance improvement in this industry.

From a philosophical standpoint, this research is interpretive and developmental in nature, following an inductive approach. It is exploratory-analytical and employs a mixed-methods approach for data collection. The data gathering methods include both library and field studies. Given the three distinct phases, the research strategy varies across phases.

In the first phase, the strategy is based on qualitative content analysis. In the second phase, the Delphi technique with a survey approach is employed to tailor GSCM practices for the tile and ceramic industry. In the third phase, interpretive structural modeling (ISM) is used to develop the model. Data collection tools include note-taking in the first phase and questionnaires in the second and third phases.

The statistical population in the first phase consists of all articles related to the identification of GSCM practices emphasizing technical factors for performance improvement, with no defined limits. Using purposive sampling, 31 articles were selected for content analysis, including 12 Persian articles from the SID database and 19 international articles published between 2015 and 2023 from the Emerald (11 articles) and ScienceDirect (8 articles) databases.

In the second phase, the statistical population includes academic and industry experts knowledgeable about GSCM practices with an emphasis on technical factors for performance improvement in the tile and ceramic industry. A purposive sample of 12 experts was selected.

In the third phase, the statistical population includes the same experts from the second phase to develop the model for localized GSCM practices in the tile and ceramic industry.

In the first phase, data were collected through a library study, and note-taking was the primary tool for extracting information from relevant articles. In the second and third phases, questionnaires were used as the main data collection tool.

To ensure validity and reliability in the first phase, the Lincoln and Guba evaluation method, commonly applied in qualitative research, was used. Mohsen Pour (2015) highlights that this method relies on four criteria: credibility, confirmability, dependability, and transferability. Initially, 10 articles were analyzed, documented, and reviewed by experts, confirming the validity and reliability of the extracted items [13]. The same method was applied in the second phase, utilizing the Delphi technique. In the third phase, a paired comparison questionnaire was used, and the consistency index was calculated. If the inconsistency index exceeds 0.1, the comparisons require revision. According to Khaki (2008), since all model factors are considered in the questionnaire, the possibility of excluding a variable is eliminated [14]. Moreover, because the questionnaire involves pairwise comparisons of all criteria, it allows for comprehensive and unbiased analysis, negating the need for reliability assessment.

In the first phase, qualitative content analysis was performed using NVivo software. Content analysis systematically, objectively, quantitatively, and generalizably examines communication messages.

In the second phase, the Delphi method was used for analysis, with results processed using Excel software. In the third phase, interpretive structural modeling (ISM) was used for data analysis, leveraging Excel and MICMAC software.

3. Findings and Results

The analysis method employed in this phase is qualitative content analysis. At this stage, GSCM practices emphasizing technical factors for performance improvement were examined using both international and domestic articles. Qualitative analysis was conducted to establish an initial framework for the researcher. Using content analysis and NVivo software, the following GSCM practices emphasizing technical factors for performance improvement were identified. Table 1 presents the qualitative analysis results derived from the articles.

Table 1. Green Supply Chain Management Practices Emphasizing Technical Factors for Performance Improvement Identified from International and Domestic Articles

No.	Practice	Sources
1	Implementation of Green Innovation	(11), (13), (17), (20)
2	Strategic Planning	(8), (11), (15), (17), (22)
3	Strategic Execution	(12), (13), (18), (21)
4	Cost Management and Raw Material Purchasing	(10), (12), (17), (21)
5	Implementation of Green Logistics	(8), (12), (19), (22)
6	Development of Industrial Networks	(11), (14), (20), (23)
7	Utilization of New Technologies	(8), (10), (14), (16), (21)
8	Compliance with Required Standards	(8), (11), (12), (18), (22)
9	Continuous Analytical Review of Machinery Operational Status	(8), (12), (17), (19), (23)
10	Analytical Review of All Production Process Stages	(11), (13), (15), (16), (20)
11	Recycling of Waste and Pollutants (Water, Soil, Air)	(8), (12), (16), (17), (22)
12	Comprehensive Environmental Quality Management	(12), (14), (18), (23)
13	Establishment of Control and Monitoring Systems	(8), (9), (13), (18), (21), (24)
14	Energy Consumption Optimization	(11), (13), (15), (16), (18)
15	Research and Development (R&D)	(9), (12), (14), (17), (19), (22)
16	Product Lifecycle Improvement	(8), (12), (13), (18), (20)

Through a systematic review of theoretical literature and qualitative content analysis using NVivo software, 16 GSCM practices emphasizing technical factors for performance improvement were identified as the output of this phase.

In the second phase, the researcher engaged with experts to identify and localize GSCM practices emphasizing technical factors for performance improvement in the tile and ceramic industry. Using the Delphi method and through a designed questionnaire, the experts responded to the question: "What are the GSCM practices emphasizing technical factors for performance improvement in the tile and ceramic industry?"

The 16 practices identified in the previous phase were presented to the experts in a questionnaire. To determine the level of agreement among experts, Kendall's coefficient of concordance (W) was used. A Kendall's W value equal to or greater than 0.5 was considered as an indicator of consensus among participants.

Table 2. First-Round Delphi Results and Mean Calculation

No.	Criterion	Mean of Round 1 Responses
1	Implementation of Green Innovation	3.33
2	Strategic Planning	3.42
3	Strategic Execution	3.58
4	Cost Management and Raw Material Purchasing	3.92
5	Implementation of Green Logistics	3.50
...	...	...
15	Research and Development	3.83
16	Product Lifecycle Improvement	2.25

In the second round, the Delphi questionnaire was redistributed with the mean scores from Round 1. After collecting responses, the mean for each criterion and the difference between the means from the two rounds were calculated. According to Myrick (2020), factors with a mean difference of less than 0.15 were considered to have reached consensus and were excluded from subsequent rounds.

Table 3. Second-Round Delphi Results and Mean Difference Calculation

No.	Criterion	Mean of Round 1	Mean of Round 2	Mean Difference
1	Implementation of Green Innovation	3.33	3.00	0.33
2	Strategic Planning	3.42	3.25	0.17
3	Strategic Execution	3.58	3.79	0.21
4	Cost Management and Raw Material Purchasing	3.92	3.90	0.02
5	Implementation of Green Logistics	3.50	3.69	0.19
...	...	...	...	...
15	Research and Development	3.83	3.50	0.33
16	Product Lifecycle Improvement	2.25	2.19	0.06

Based on the mean differences between Rounds 1 and 2, four factors achieved consensus and were excluded from further rounds.

In the third round, the Delphi questionnaire was distributed again, with the mean scores from Round 2. The mean scores and differences between Rounds 3 and 2 were calculated. Factors with a mean difference of less than 0.15 were considered to have reached consensus and were excluded from subsequent rounds.

Table 4. Third-Round Delphi Results and Mean Difference Calculation

No.	Criterion	Mean of Round 2	Mean of Round 3	Mean Difference
1	Implementation of Green Innovation	3.00	3.12	0.12
2	Strategic Planning	3.25	3.29	0.04
3	Strategic Execution	3.79	3.63	0.16
4	Implementation of Green Logistics	3.69	3.76	0.07
5	Utilization of New Technologies	4.27	4.36	0.09
...	...	...	...	...
11	Energy Consumption Optimization	3.42	3.61	0.19
12	Research and Development	3.50	3.69	0.19

Based on the mean differences between the third and fourth Delphi rounds, six factors achieved consensus and were not re-evaluated in subsequent rounds.

In the fourth round, the Delphi questionnaire included six factors, along with the mean scores from the third round and scores provided by the experts in the previous round. After collecting the data in the fourth round, the mean for each factor and the difference between the means from the fourth and third rounds were calculated. Factors with a mean difference of less than 0.15 were considered to have reached consensus and were excluded from subsequent rounds (Habibi & Jalalnia, 2022).

Table 5. Fourth-Round Delphi Results and Mean Difference Between the Fourth and Third Rounds

No.	Factor	Mean of Third Round	Mean of Fourth Round	Mean Difference
1	Strategic Execution	3.63	3.57	0.06
2	Compliance with Required Standards	4.38	4.27	0.11
3	Continuous Analytical Review of Machinery Operational Status	3.68	3.55	0.13
4	Comprehensive Environmental Quality Management	4.69	4.55	0.14
5	Energy Consumption Optimization	3.61	3.61	0.00
6	Research and Development (R&D)	3.69	3.69	0.00

Based on the results of the fourth round, all six factors achieved consensus and did not require further rounds. The experts reached consensus for all 16 identified practices, eliminating the need for additional Delphi iterations. Factors with a mean score of less than 3 were excluded at this stage.

Table 6 summarizes the Kendall's W coefficient results across all Delphi rounds. The results indicate that except for the first round, where the Kendall's W coefficient was below 0.5, the subsequent rounds showed coefficients greater than

0.5, reflecting an appropriate level of agreement among experts.

Table 6. Kendall’s Coefficient of Concordance Results

Delphi Round	Sample Size	Kendall’s W Coefficient	Chi-Square Statistic	Degrees of Freedom	Significance Level (p-value)
Round 1	12	0.487	437.108	15	0.000
Round 2	12	0.517	512.009	15	0.000
Round 3	12	0.534	514.234	11	0.000
Round 4	12	0.564	521.004	5	0.000

Based on the results, out of the initial 16 practices, two factors were eliminated. Fourteen practices were identified as the final GSCM practices emphasizing technical factors for performance improvement in the tile and ceramic industry, as shown in Table 7.

Table 7. Finalized Green Supply Chain Management Practices Emphasizing Technical Factors for Performance Improvement in the Tile and Ceramic Industry

No.	Finalized Practices	No.	Finalized Practices	No.	Finalized Practices
1	Implementation of Green Innovation	6	Development of Industrial Networks	11	Recycling of Waste and Pollutants (Water, Soil, Air)
2	Strategic Planning	7	Utilization of New Technologies	12	Establishment of Control and Monitoring Systems
3	Strategic Execution	8	Compliance with Required Standards	13	Energy Consumption Optimization
4	Cost Management and Raw Material Purchasing	9	Continuous Analytical Review of Machinery Operational Status	14	Research and Development (R&D)
5	Implementation of Green Logistics	10	Analytical Review of All Production Process Stages		

In this step, the researcher sought to rank and model the green supply chain management (GSCM) practices emphasizing technical factors for performance improvement in the tile and ceramic industry. To achieve this, experts were consulted, and a questionnaire containing the 14 identified factors was used. The questionnaire employed pairwise comparisons, asking respondents to determine the relationships between the factors (no relationship, one-way relationship, mutual relationship).

Table 8. Codes for GSCM Practices Emphasizing Technical Factors for Performance Improvement in the Tile and Ceramic Industry

No.	GSCM Practices	Code
1	Implementation of Green Innovation	C1
2	Strategic Planning	C2
3	Strategic Execution	C3
4	Cost Management and Raw Material Purchasing	C4
5	Implementation of Green Logistics	C5
6	Development of Industrial Networks	C6
7	Utilization of New Technologies	C7
8	Compliance with Required Standards	C8
9	Continuous Analytical Review of Machinery Operational Status	C9
10	Analytical Review of All Production Process Stages	C10
11	Recycling of Waste and Pollutants (Water, Soil, Air)	C11
12	Establishment of Control and Monitoring Systems	C12
13	Energy Consumption Optimization	C13
14	Research and Development (R&D)	C14

Using an ISM-based iterative questionnaire and forming a self-interaction matrix based on the highest frequencies, an initial reachability matrix was created (Table 9).

Table 9. Initial Reachability Matrix

Var.	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1		A	X	O	X	A	A	A	A	A	X	A	X	A
C2			V	V	V	X	X	X	A	A	V	O	V	A
C3				X	X	A	A	A	A	A	X	A	X	A
C4					O	A	A	A	A	A	X	A	X	A
C5						A	A	A	A	A	O	A	X	A
C6							X	O	A	A	V	X	V	A
C7								X	A	A	V	X	V	A
C8									A	A	V	X	V	A
C9										X	V	V	V	A
C10											V	V	V	A
C11												A	X	A
C12													V	A
C13														A
C14														

Following the ISM process, the final reachability matrix was developed, as detailed in Table 10.

Table 10. Final Reachability Matrix

Var.	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
C1	1	0	1	*1	1	0	0	0	0	0	1	0	1	0
C2	1	1	1	1	1	1	1	1	0	0	1	*1	1	0
C3	1	0	1	1	1	0	0	0	0	0	1	0	1	0
C4	*1	0	1	1	*1	0	0	0	0	0	1	0	1	0
C5	1	0	1	*1	1	0	0	0	0	0	*1	0	1	0
C6	1	1	1	1	1	1	1	*1	0	0	1	1	1	0
C7	1	1	1	1	1	1	1	1	0	0	1	1	1	0
C8	1	1	1	1	1	*1	1	1	0	0	1	1	1	0
C9	1	1	1	1	1	1	1	1	1	1	1	1	1	0
C10	1	1	1	1	1	1	1	1	1	1	1	1	1	0
C11	1	0	1	1	*1	0	0	0	0	0	1	0	1	0
C12	1	*1	1	1	1	1	1	1	0	0	1	1	1	0
C13	1	1	1	1	1	*1	*1	*1	0	0	1	0	1	0
C14	1	1	1	1	1	1	1	1	1	1	1	1	1	1

To determine the levels, it was necessary to identify the reachability set, antecedent set, and intersection set for each factor. The results are presented in Table 11.

Table 11. Determination of Model Levels

Symbol	Factors	Achievable Set	Preceding Set	Common Set	Level
C1	Green Innovation Implementation	1, 3, 4, 5, 11, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 3, 4, 5, 11, 13	First

C2	Strategic Planning	2, 3, 4, 5, 6, 7, 8, 11, 12, 13	2, 6, 7, 8, 9, 10, 12, 13, 14	2, 6, 7, 8, 12, 13	Second
C3	Strategic Implementation	1, 3, 4, 5, 11, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 3, 4, 5, 11, 13	First
C4	Cost Management and Raw Material Purchasing Costs	1, 3, 4, 5, 11, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 3, 4, 5, 11, 13	First
C5	Green Logistics Implementation	1, 3, 4, 5, 11, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 3, 4, 5, 11, 13	First
C6	Industrial Network Development	1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13	2, 6, 7, 8, 9, 10, 12, 13, 14	2, 6, 7, 8, 12, 13	Second
C7	Adoption of New Technologies	1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13	2, 6, 7, 8, 9, 10, 12, 13, 14	2, 6, 7, 8, 12, 13	Second
C8	Adherence to Required Standards	1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13	2, 6, 7, 8, 9, 10, 12, 13, 14	2, 6, 7, 8, 12, 13	Second
C9	Continuous Analytical Evaluation of Machine Operation Status	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	9, 10, 14	9, 10	Third
C10	Analytical Evaluation of All Stages of the Production Process	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13	9, 10, 14	9, 10	Third
C11	Recycling of Water, Soil, and Air Pollutant Waste	1, 3, 4, 5, 11, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 3, 4, 5, 11, 13	First
C12	Creation of Control and Monitoring Systems	1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13	2, 6, 7, 8, 9, 10, 12, 14	2, 6, 7, 8, 12	Second
C13	Energy Consumption Optimization	1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	1, 2, 3, 4, 5, 6, 7, 8, 11, 13	First
C14	Research and Development	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14	14	14	Fourth

Based on Table 11, the factors of Green Innovation Implementation, Strategic Implementation, Cost Management and Raw Material Purchasing Costs, Green Logistics Implementation, Recycling of Water, Soil, and Air Pollutant Waste, and Energy Consumption Optimization were identified at Level One as the most influential Green Supply Chain Management actions with a focus on technical factors for performance improvement in the ceramic industry. Additionally, Research and Development was identified at Level Four as the most influential Green Supply Chain Management action with a focus on technical factors for performance improvement in the ceramic industry. Furthermore, the actions of Continuous Analytical Evaluation of Machine Operation Status and Analytical Evaluation of All Stages of the Production Process were placed at Level Three, while Strategic Planning, Industrial Network Development, Adoption of New Technologies, Adherence to Required Standards, and Creation of Control and Monitoring Systems were positioned at Level Two. Based on the identified levels, the interpretive structural model is illustrated in Figure 1.

Zone One (Influential): This zone includes variables with the highest influence and the lowest susceptibility. These variables have a significant impact on the system's dynamics and are decisive in determining the system's behavior. This action includes Research and Development.

Zone Two (Bilateral): These variables have both high influence and high susceptibility. In this study, the actions of Strategic Planning, Industrial Network Development, Adoption of New Technologies, Adherence to Required Standards, Creation of Control and Monitoring Systems, Continuous Analytical Evaluation of Machine Operation Status, and Analytical Evaluation of All Stages of the Production Process fall into this zone.

Zone Three (Dependent Variables): The factors in this zone, located in the southeastern part of the diagram, have low influence but high susceptibility. These variables are called susceptible and play a decisive role in improving performance in the future of the ceramic industry based on Green Supply Chain Management actions with a focus on technical factors. Green Innovation Implementation, Strategic Implementation, Cost Management and Raw Material Purchasing Costs, Green Logistics Implementation, Recycling of Water, Soil, and Air Pollutant Waste, and Energy Consumption Optimization are included in this group.

Zone Four (Independent Variables): The variables in this zone, located in the southwest part of the diagram, have both low influence and low susceptibility. These variables indicate trends that involve minimal changes.

Figure 1. Final Model of The Study

4. Discussion and Conclusion

Given the intense competition in global markets, organizations are seeking strategies to distinguish themselves from their competitors. Implementing green supply chain management (GSCM) with an emphasis on advanced technologies not only improves environmental performance but also enhances efficiency, reduces costs, and increases brand reputation, thereby improving organizational competitiveness. In recent years, concerns about environmental issues and climate change have significantly increased. Governments and international organizations have introduced stricter regulations and standards, driving organizations to reduce their environmental impact.

In this context, GSCM serves as a sustainable approach that plays a critical role in reducing pollution and optimizing resource utilization. GSCM, with a focus on technical perspectives, is an essential strategy for organizations aiming to achieve sustainable development and improve overall supply chain performance. Leveraging advanced technologies can reduce environmental impacts, enhance efficiency, and lower operational costs. Emphasizing modern technologies improves transparency and traceability in supply chain processes, enabling organizations to better comply with environmental regulations while increasing trust among customers and stakeholders.

Moreover, designing and implementing GSCM practices with a technical focus helps organizations thrive in dynamic competitive environments and meet the growing demands of environmentally conscious customers.

The results indicate that GSCM with an emphasis on technical factors is a key approach to improving the performance of the ceramic industry. Analysis of various variables revealed that each factor has a unique impact on system dynamics, influencing overall system behavior and outcomes. Influential variables play a pivotal role in shaping the system's future and can positively affect other actions through proper planning.

Bilateral variables, which have high influence and susceptibility, serve as critical tools for system performance regulation and monitoring. On the other hand, dependent variables, which are more susceptible to external factors, impact performance improvement and sustainability achievement. Finally, independent variables showed minimal influence in this system but contribute to its overall stabilization.

Improving GSCM performance in the ceramic industry requires comprehensive planning and attention to all these variables. By optimizing the use of advanced technologies, implementing effective strategies, and closely monitoring influential and dependent variables, sustainability goals and performance improvements can be achieved, creating favorable conditions for the industry's sustainable development. Based on the final results and the proposed model, the following practical recommendations are provided:

- **Research on Recycling Technologies in Production Processes:** Research and development should focus on recycling technologies for ceramic production waste. This includes recycling production waste, water used in processes, and even defective products. Implementing these technologies reduces environmental impacts and material costs.
- **Process Data Analysis for Production Optimization:** Using big data and its analysis to improve machine performance, reduce energy and material consumption, and enhance overall efficiency is recommended. R&D teams can utilize data analysis tools to continuously monitor production performance, identify inefficiencies, and optimize production processes.
- **Integration of Green Approaches in Production Planning:** Strategic planning should ensure that all stages of the supply chain are carried out with a green approach. This includes optimizing transportation schedules, selecting sustainable suppliers, and efficiently managing raw material consumption.
- **Automation and Artificial Intelligence:** Employing robotics and AI for process automation can reduce resource consumption, optimize energy use, and improve the quality of final products. AI algorithms can analyze data collected from machinery to predict failures before they occur and plan maintenance more effectively.
- **Monitoring Compliance with Green Standards:** Developing control systems to monitor compliance with environmental standards at all production stages—from supplier selection to product delivery—can improve the organization’s environmental performance.
- **Energy Consumption Optimization:** Using renewable energy sources such as solar and wind power in production processes and factory operations can reduce reliance on fossil fuels and lower greenhouse gas emissions. Additionally, analyzing production data to identify energy optimization opportunities, such as improving machine performance and reducing downtime, can enhance energy efficiency and reduce costs.
- **Cost Optimization Models:** Employing optimization methods to reduce raw material costs, such as predictive pricing models and optimized procurement planning, can improve cost management. Sourcing materials from suppliers committed to environmental standards and reducing the negative impacts of their production can enhance sustainability and performance.

The findings of this study align with those of Liu et al. (2020), Chen and Shih (2007), Cheng et al. (2016), Zhou et al. (2019), and Ruiz et al. (2019).

Future Research Recommendations:

- Investigating the impact of emerging technologies such as the Internet of Things (IoT), artificial intelligence (AI), and blockchain on improving GSCM performance.

- Developing key performance indicators (KPIs) to evaluate the sustainability of green supply chains.
- Examining the role of information systems in enhancing transparency and performance in green supply chains.
- Proposing a model of GSCM practices emphasizing behavioral perspectives to improve performance.

Authors' Contributions

Authors equally contributed to this article.

Acknowledgments

Authors thank all participants who participate in this study.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethical Considerations

All procedures performed in this study were under the ethical standards.

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