Sustainable supply chain in the cement sectors: Implications for environmental policy and education in Indonesia

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Abstract
Implementation of Sustainable Supply Chain Management (SSCM) is crucial for cement manufacturers to enhance competitive advantage while minimizing economic, social, and environmental impacts. As a result, cement companies must assess, manage, and report the sustainability performance of their supply chains. However, there is no appropriate measurement framework to evaluate SSCM performance. This study designs a specific and relevant SSCM performance measurement framework, referring to global cement industry indicators, empirical indicators of Indonesian manufacturers, and validation of seven cement supply chain specialists. A systematic literature search was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method, and the Analytical Hierarchy Process (AHP) was used to assign weights to performance indicators. This study develops an SSCM framework that integrates three aspects of sustainability: environmental, social, and economic. The framework consists of 22 performance indicators, including six environmental indicators, eight social indicators, and eight economic indicators. Testing the framework on leading cement company in Indonesia resulted in a strong performance score of 80.7. This study addresses the existing gap in research related to supply chain sustainability and, for the first time, provides locally developed SSCM performance indicators that are aligned with the context of the Indonesian cement industry. This study also discusses the implications of the developed SSCM framework for sustainability education and capacity building within the Indonesian cement industry, highlighting the importance of integrating environmental, social, and economic performance indicators into training programs and educational curricula to foster sustainable business practices.

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1. Introduction

The cement industry is currently facing intense competition and pressure from various stakeholders regarding emissions, waste management, health and safety, and the needs of local communities (Wang et al., 2021). Although there is potential for increased demand for cement due to higher government infrastructure budgets, this demand is not matched by the national cement production capacity. In 2024, the national cement production capacity is projected to be 122 million tons per year, while the expected cement requirement is around 66 million tons per year (SIG, 2024). This indicates that the factory utilization rate is only 54%. The low utilization rate of cement factories adversely affects energy efficiency and contributes to higher greenhouse gas (GHG) emissions. In 2022, the cement industry was identified as the largest industrial contributor to GHG emissions, accounting for 47.8% of total emissions (Ministry of Environment and Forestry, 2023).

Environmental policies that priorities sustainable development and consider economic, social, and environmental aspects are essential to achieving long-term sustainability goals (Leal Filho et al., 2021). Increased industrial activity in developing countries exacerbates natural resource scarcity and environmental problems (TA et al., 2020) because it focuses more on the benefits of economic development while neglecting environmental conservation (Effendi et al., 2021). This situation forces industries to change their supply chain strategies to be more environmentally oriented (Sugandini et al., 2020). Lee & Ha (2020) state that sustainability in the supply chain can be achieved through management that focuses on environmental and social issues to maximize the benefits of the entire supply chain. Therefore, the cement industry must priorities environmental protection while focusing on economic growth and social responsibility (Mardani et al., 2020) for business sustainability. By integrating environmental and social factors, cement production can remain economically viable (Suhaib et al., 2023).

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Environmental protection can be achieved by implementing sustainability practices throughout the supply chain (SSCM). Companies that adopt SSCM practices enjoy significant competitive and economic advantages over those that do not (Shekarian et al., 2022). As a result, businesses are increasingly focused on developing robust supply chains that enable them to deliver their products more quickly, efficiently, and cost-effectively than their competitors. In the 21st century, sustainability has become a top priority in supply chain operations, particularly within in the cement sector. Consequently, there is a growing emphasis on integrating economic, social, and environmental performance in supply chain management (SCM) to enhance competitiveness (Uemura Reche et al., 2020). Companies utilizing SSCM practices gain substantial competitive and economic benefits compared to those that overlook them (Shekarian et al., 2022).

Supply chains require continuous performance assessment for simultaneous improvement of environmental, social and economic performance (Narimissa et al., 2020). Therefore, evaluation of supply chain sustainability practices in facing various environmental, social and economic challenges is very necessary (Yosef et al., 2023). However, comprehensive and tailored models for measuring SSCM practices in the cement industry, particularly in developing countries like Indonesia, are lacking (Benhelal et al., 2021; Rukuni et al., 2022). Both industry and academia have highlighted the necessity for a common and manageable set of key performance indicators (KPIs) to assess SSCM performance (Neri et al., 2021). The absence of a consensus on how to evaluate SSCM performance underscores the demand for practical guidance in this field (Saeed & Kersten, 2020). Identifying and categorizing KPIs can enhance the evaluation and improvement of SSCM practices, particularly in tackling sustainability challenges within the cement industry (Yosef et al., 2023).

This study aims to develop a Sustainable Supply Chain Management (SSCM) framework for cement producers in Indonesia, driven by the urgent need for a conceptually sound and empirically validated model. The absence of relevant measurement models and performance indicators creates uncertainty regarding the strategies, policies, and environmental education required for sustainable improvement in the cement supply chain. Environmental education is one of the pathways to building a sustainable society (Parmawati et al., 2023), making it crucial for enhancing awareness of environmentally friendly practices. The findings from this study are expected to contribute to sustainable supply chain management that can influence environmental policies and education to create an environmentally friendly and competitive cement industry. This is important given that environmental issues often become side effects of economic development in many developing countries (Cai & Choi, 2020).

2. Method

The analysis involved the use of both primary and secondary data sources. Primary data were collected through direct observation within the company and through questionnaires distributed to industry experts for the validation process and weighting of performance indicators. Seven industry experts were selected using a purposive sampling method. Employing an odd number of experts helps ensure consistency in the comparison matrix, making decision-making easier by increasing the likelihood of identifying dominant choices. Meanwhile, secondary data were gathered through a systematic literature review of publications and scientific reports from cement manufacturers in Indonesia, following the PRISMA method. Structurally, the research method is depicted in Figure 1.

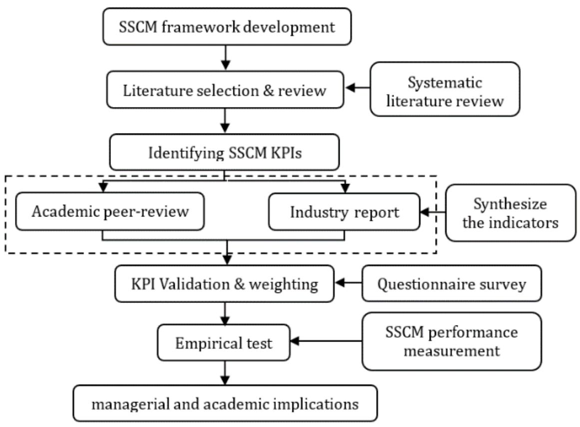

Figure 1. Research methodology

2.1. Choosing SSCM performance indicators

The initial phase of constructing the SSCM performance framework involves the identification of performance indicators. This process necessitates data triangulation from three distinct sources to enhance both validity and. The three sources comprised a review of the scientific literature, sustainability reports from Indonesian cement producers, and expert opinions collected through questionnaires.

The literature review aimed to identify the proposed performance indicators in the SSCM performance assessment framework. This search was conducted using Google Scholar and focused on journal articles, conference papers, books, and research published in English from 2015 to 2024. The focus is on SSCM performance indicators, key performance indicators (KPIs), metrics, models, and frameworks pertinent to the cement industry, utilizing keywords such as indicators, metrics, KPIs, models, frameworks, and sustainable supply chains.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guideline was employed as the tool for conducting the literature search. PRISMA provides a flowchart that delineates the number of records identified, included, and exclude, along with the reasons for exclusion. This flowchart displays how information progresses through the various phases of a systematic review (Page et al., 2021). The literature review process following the PRISMA method was divided into several critical stages such as identification, screening, eligibility, and inclusion.

Following the identification of performance indicators from the literature, the subsequent step involved synthesizing these indicators before their selection by experts. This synthesis involves analytical techniques for extracting useful ideas without duplicating previously identified indicators (Saeed & Kersten, 2020).

The identified performance indicators serve as a baseline for performance measurement models, as no single indicator is universally applicable. Prior to their incorporation into these models, indicators were validated through expert opinions to avoid conflicts and improve decision making strategies (Suhaib et al., 2023). The final selection of performance indicators included gathering expert opinions through data triangulation and refining the synthesized indicators.

To gather opinions, an online survey was conducted using a closed questionnaire format with ‘yes’ or ‘no’ response options shared through personal chats with experts in the cement industry. The selection process adhered to the SMART criteria for effective Key Performance Indicators (KPIs) (Sudaryanto, 2024). The SMART framework (Specific, Measurable, Achievable, Relevant, and Time bound) has been implemented by approximately 70% of private organizations (Kurniati & Abbas, 2023). The outcomes derived from the experts' responses were evaluated, with "Yes" responses being selected through the cut-off method, which includes only those indicators scoring above the 75th percentile. This methodology seeks to achieve high validity in the selection outcomes, permitting a variance of one vote from seven expert votes.

2.2. Weighting of SSCM performance indicators

The process of weighting the dimensions and performance indicators was conducted to evaluate the importance of each criterion within the established hierarchical framework. The weighting procedure used the AHP method by developing a pairwise comparison questionnaire to ascertain the relative importance of each level in the hierarchy. The questionnaire was completed by seven SCM experts from the cement industry online using Google Forms. The experts provided their responses by comparing the importance value of each criterion on a Likert scale ranging from one to nine. The AHP framework is organized in the form of a hierarchy diagram, starting with the overall goal, followed by criteria, sub-criteria, and alternatives. This method assists decision makers in identifying the best choice among various options. By intuitively weighing these elements through pairwise comparisons, AHP creates a matrix that describes the relationship between one element and another.

To calculate the weight of each criterion within the AHP decision-making hierarchy, inputs were collected from multiple participants, typically seven experts who completed a questionnaire. The weights from their assessments are combined using the geometric mean, which helps determine the level of importance for each dimension, attribute, and indicator criterion in SuperDecision software. The resulting geometric mean was then rounded to establish the final level of importance for each dimension, attribute, and indicator criterion. The geometric mean can be calculated using (eq. 1).

$$\text{Geometric mean} = (X_1 \times X_2 \times X_n)^{\frac{1}{n}} \quad (1)$$

where Xn is the value of the nth respondent and n is the number of respondents.

SuperDecision software was used to calculate the weight values for each hierarchy, assess the consistency ratio (CR) of expert responses, and identify the priorities of Key Performance Indicators (KPIs) using the AHP method. According to Saaty (2002), it is essential to assess the consistency of expert responses by ensuring that the consistency ratio (CR) remains below 10% ($CR < 0.1$). Therefore, we can conclude that the data from the KPI weighting questionnaire can be utilized to establish the weight and priority of Supply Chain Management (SCM)

KPIs. The first step in this process is to create a decision model that establishes a network of relationships among goal clusters, dimensions, attributes, and indicators within SuperDecision software.

The modeling results in SuperDecision are presented as a pairwise comparison matrix that must be evaluated to determine the weights and priorities of the KPIs. In SuperDecision software, comparison values are input as integer values rounded to the geometric mean. Subsequently, the hierarchy of priority KPIs in the SSCM performance measurement model can be established based on their weight values. A KPI with the highest weight indicates that it has the highest priority for SSCM performance.

2.3. Sustainable supply chain performance measurement

Empirical testing of the SSCM framework was conducted in performance measurement at the largest cement producer in Indonesia and Southeast Asia. Empirical testing was conducted at the company by comparing KPI targets with KPI realization data during 2023. Performance was evaluated at the lowest hierarchical level, specifically using sustainability performance indicators. The weight values assigned to these indicators were aggregated to the higher hierarchy levels, culminating in a total weight score for the SSCM KPI indicators.

Performance values were calculated using Microsoft Excel. The sustainable supply chain performance is derived from the sum of the products of each KPI value and its corresponding weight. The calculations focused on the independent variables, which were the KPIs related to the sustainable cement supply chain, to determine the performance value of the sustainable cement supply chain as a dependent variable. The results of the calculation of the performance value can be categorized based on the assessment criteria set by Trienekens and Hvolby, where the value <40 (poor), 40-50 (marginal), 50-70 (average), 70-90 (good), > 90 (excellent). The performance values were processed using Microsoft Excel, and formula (eq. 2) was applied for the computation.

$$\textit{Total performance value} = \sum(a \times b) \quad (2)$$

where a is the KPI performance value, and b is the KPI weight score.

Weight scores must be calculated to assess for assessing the performance of KPIs in SSCM. These calculations were conducted for all performance indicators in relation to sustainability dimensions based on their hierarchy. The weight score represents the total weight derived from multiplying the weights of each indicator by the weights of their corresponding dimensions, following the established hierarchy.

3. Results and Discussion

3.1. Sustainable supply chain performance framework

The identification of literature using the PRISMA method resulted in eight sources, comprising four scientific literature reviews and four sustainability reports from cement producers. The four scientific sources, they are the conference paper from the 4th annual international conference on sustainable energy and environment sciences by Muangpan et al. (2015) available on ResearchGate, the international journal article by Sangwan et al. (2019) from Emerald Insight, the article by Yosef et al. (2023) from the Multidisciplinary Digital Publishing Institute (MDPI), and the journal article by Suhaib et al. (2023) available on ScienceDirect. In addition, four sustainability reports from cement producers were obtained using Google. The sustainability reports for cement producers in Indonesia that were downloaded are from 2023 and were published in 2024. These reports can be found at the following URLs: httpps://www.cemindo.com/en, httpps://sementigaroda. com/, httpps://www.scg. com/en, and httpps://www.sig.id/. A systematic review flow diagram is shown in Figure 2.

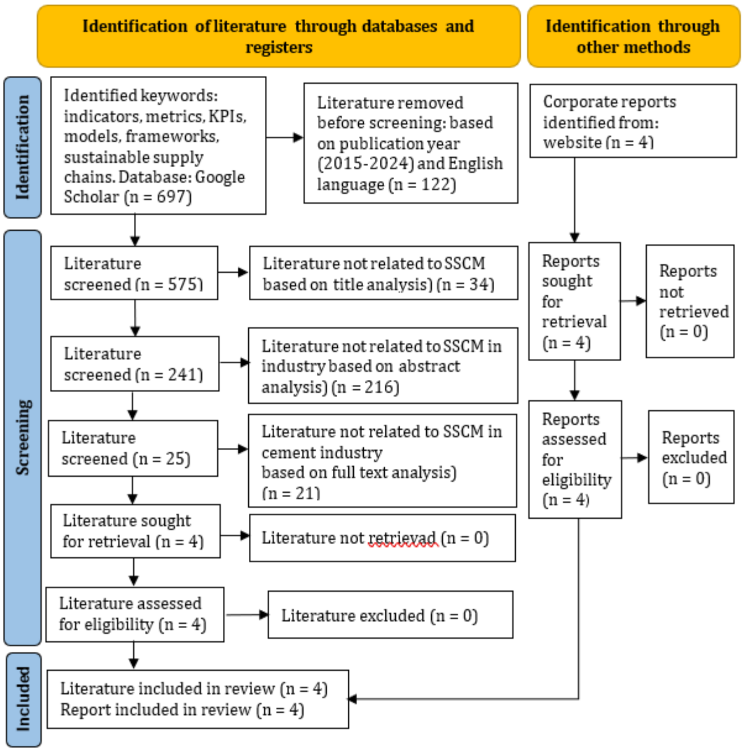

Figure 2. Systematic reviews flow diagram of SSCM performance indicators

The analysis of eight literature sources led to the identification of 203 performance indicators for sustainable supply chain management (SSCM) in cement manufacturing. These indicators include 79 related to environmental performance, 61 related to social performance, and 63 focused on economic performance. Through the synthesis process of these 203 indicators, we narrowed the list down to 141 indicators: 54 environmental, 41 social, and 46 economic. Experts then selected 22 indicators deemed relevant from the list of 141, as assessed in a questionnaire. This final selection consists of 6 environmental indicators, 8 social indicators, and 8 economic indicators. This study successfully identified and validated metrics for SSCM, organized into three dimensions: environmental (6 indicators), social (8 indicators), and economic (8 indicators). In comparison, other studies typically utilize between 17 and 69 indicators, with a greater emphasis on the economic and environmental aspects, often neglecting the social dimension.

The relative significance of each criterion was evaluated by examining the grouping of dimensions and performance indicators in the SSCM of Indonesian cement. Experts determined that the environmental dimension holds the highest importance (0.41). This high value is associated with the significant environmental impact of the cement industry, which greatly affects social and economic aspects. Therefore, Achieving a link between sustainability processes and environmental protection requires greater attention to environmental issues and their impact on environmental problems (Abdulwadood et al., 2024). On the other hand, experts emphasize improving education and professional knowledge in the field of ecology as a platform for sustainable development (Shutaleva et al., 2020). Despite the overall importance of the environmental dimension, the annual net profit KPI has the highest priority among the KPIs, with a weighted score of 0.12. The emphasis on profitability directly reflects the company's ability to generate profits and maintain operational sustainability as it serves as an important metric for investors, creditors and other stakeholders (Ali et al., 2025). The new paradigm of sustainability recognizes the importance of corporate growth and profitability, but at the same time requires businesses to pursue sustainability goals (Tien et al., 2020). These results confirm that the SSCM strategy in the Indonesian cement industry needs to balance environmental compliance, which must be in line with its economic viability. The weights and priorities of the SSCM KPIs are listed in Table 1.

Table 1. Key Performance Indicators for Sustainable Supply Chain in Indonesia's Cement Industry: Weight and Priority

Dimension	Weight	Indicators Performance	Weight	CR	Total Weight	Priority
Environment	0.41	Amount of alternative fuel usage (waste and biomass)	0.19	0.038	0.08	3
		Non-Portland cement production volume	0.23		0.09	2
		Greenhouse gas emission intensity	0.14		0.06	9
		Amount of greenhouse gas emission reduction	0.18		0.07	5
		Amount of energy used	0.18		0.07	4
		Amount of water use reduction	0.09		0.04	13

Dimension	Weight	Indicators Performance	Weight	CR	Total Weight	Priority
Social	0.26	Number of injuries and deaths due to mining	0.21	0.009	0.05	10
		Reduction in accidents, injuries and occupational health problems	0.24		0.06	8
		Number of company and contractor work accidents	0.25		0.06	7
		% of suppliers from local areas	0.04		0.01	20
		Total cost of Social and Environmental Responsibility	0.03		0.01	22
		Average hours of employee training	0.04		0.01	21
		Lost time injury frequency rate (LTIFR)	0.04		0.04	12
		Number of beneficiaries	0.015		0.01	19
Economy	0,33	Total electricity cost	0.04	0.042	0.01	18

This section outlines a structured framework for evaluating supply chain sustainability management (SSCM) performance, as illustrated in Figure 3. At the top level, the framework represents the overall performance of supply chain members, which is determined by the combined value of all performance metrics in the layers below. These metrics are based on the three dimensions of sustainability, known as the Triple Bottom Line: environmental, social, and economic. The second level of the hierarchy details these three dimensions of sustainability, which serve as the key performance indicators (KPIs) for SSCM. Finally, the lowest level of the hierarchy includes a total of 22 KPIs, which are essential for measuring SSCM performance across environmental, social, and economic aspects.

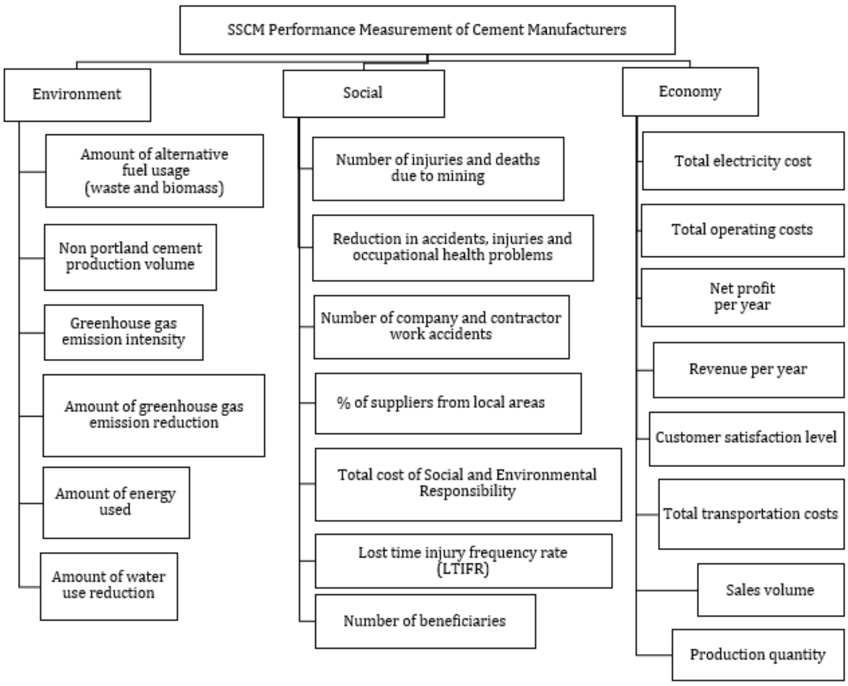

Figure 3. SSCM performance measurement framework of the Cement Industry in Indonesia

3.2. Measuring sustainable supply chain performance in the cement producer

The SSCM framework has been successfully tested empirically at one cement manufacturer. The Company's SSCM performance score is 80.7, which means that the Company's SSCM performance is good (Table 2). The measurement results conclude that the Company has a mature management system in balancing economic growth, social responsibility, and environmental management. Empirical testing shows that the developed SSCM framework can be applied to the cement industry, as prior to this study, a comprehensive and empirically tested SSCM measurement model specifically for the cement industry in Indonesia had not been found. Cement manufacturers can independently assess the sustainability performance of their supply chains using this framework. Self-assessment is preferred by companies because data collection is easier and more efficient in terms of time and cost. Additionally, this framework can serve as a reference for similar industries by adapting specific indicators to align with their characteristics.

The same framework can yield different environmental impact values depending on the efficiency of the cement plant and the quantity of waste processed (Habert et al., 2020). Additionally, achieving the goals of environmental education such as implementing targeted corporate environmental policies and fostering more responsible individual behavior towards sustainability is crucial (Hartani et al., 2021). Environmental education enhances awareness and knowledge of sustainability, enabling organizations to adopt sustainable practices in their supply chain activities (Parmawati et al., 2023).

Table 2. The sustainable supply chain performance of the Indonesia's cement producer

KPI	Unit	Realization	Target		KPI value (a)	Total Weight (b)	Performance (a x b)
			Min	Max			
Amount of alternative fuel usage (waste and biomass)	Thousand ton	559	380	491.3	100	0.08	8
Non-Portland cement production volume	Million ton	24.5	18.9	25.7	95.6	0.09	8.6
Greenhouse gas emission intensity	CO_2/Ton cement equivalent	585	590	586	100	0.06	6
Amount of greenhouse gas emission reduction	%	17.2	0	18	95.6	0.07	6.7
Amount of energy used	Million Giga joule	108.7	108.5	94.2	99.8	0.07	6.7
Amount of water use reduction	%	11.5	5.4	11.5	100	0.04	4
Number of injuries and deaths due to mining	Case	4	0	0	0	0.05	0
Reduction in accidents, injuries and occupational health problems	Case	1	4	9	11.1	0.06	0.7
Number of company and contractor work accidents	Case	8	0	0	0	0.06	0
% of suppliers from local areas	%	97	95	97	100	0.02	2
Total cost of social and environmental responsibility	Rp billion	145.1	110.6	1451	100	0.02	2
Average hours of employee training	Hour/ Employee	42.2	18	27	100	0.01	1
Lost time injury frequency rate (LTIFR)	Point	0.3	0.7	0.3	100	0.04	4
Number of beneficiaries	Million people	9	6.1	8.6	100	0.01	1
Total electricity cost	Rp billion	31.9	24.9	31.9	100	0.01	1
Total operating costs	Rp	142.6	112	142.6	78.5	0.02	1.6
Net profit per year	billion	2.3	2.1	3	76.6	0.12	9.2
Revenue per year	Rp trillion	38.6	36.4	42	91.9	0.05	4.6
Customer satisfaction level	Rp trillion	90.7	75	89.7	100	0.07	7
Total transportation costs	Poin	1.6	2.3	2.2	100	0.02	2
Sales volume	Rp trillion	40.6	36.9	43.4	93.6	0.03	2.8
Production quantity	Million ton	34.4	33.5	43.4	79.3	0.02	1.6
Total							80.7

4. Conclusion

The study shows that, despite the increase in infrastructure projects, the national cement production capacity still exceeds the demand for cement. As a result, plant utilization remains low, leading to various economic, environmental, and social challenges in the cement industry. To address these issues and maintain competitiveness, the cement industry should adopt SSCM practices that incorporate economic, environmental, and social dimensions. In this study, 22 indicators (6 environmental, 8 economic, and 8 social) were selected as SSCM KPIs through the elaboration of academic perspectives (research results), empirical data (industry reports) as well as supply chain experts from industry. The mapping of SSCM KPIs makes it easy to identify weak sustainability areas among its social environmental and economic factors. Thus, the KPIs developed in the framework will be used to guide strategies for improving SSCM management, developing environmental education, and developing environmental policy in general.

The results of this study have implications for government policy, as one of the key strategies to align economic growth with sustainability goals is the development of SSCM frameworks by integrating sustainability metrics into the decision-making process (Igwe et al., 2024). Therefore, governments should promote frameworks that combine environmental, social, and economic indicators (Nembe et al., 2024), as well as encourage the adoption of SSCM practices and collaboration among stakeholders through policy incentives (Igwe et al., 2024). The resulting framework can guide the measurement and reporting of SSCM performance, by providing a ready-made scoring system and practical guidance to the industry sector. Thus, the government can monitor the adoption of sustainable practices in a measurable and transparent manner to develop clear environmental policies that can reduce uncertainty and thus promote long-term sustainability.

In terms of educational implications, this research emphasizes the importance of education to improve the understanding of sustainability concepts, sustainability performance measurement, and the impact of industry on the environment. the Because, some literature (Benhelal et al., 2021 and Rukuni et al., 2022) states that there is a significant gap in sustainability literature and practice in developing countries, especially Indonesia. Therefore, this research provides an understanding of environmental education through real case studies, related to the application of sustainability concepts in industry to encourage the development of environmental science through data-based critical and analytical thinking and not just normative or theoretical knowledge. This research shows that comprehensive solutions to environmental problems can be done through a cross-disciplinary approach, namely economic, social and environmental knowledge.

In the future, SSCM performance assessment indicators need to be updated in accordance with advances in knowledge, environmental management dynamics and global policies related to sustainability. This research can be extended to provide an opportunity for the development of environment-related science to select sustainability assessment indicators that better represent critical aspects of environmental sustainability management broadly for all industries.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

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