Green supply chain management strategy in the Indonesian construction industry using analytic network process to improve sustainability

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Abstract. The construction industry is among the sectors associated with high environmental risks, with the construction supply chain process being a primary concern due to its potential for environmental damage. The absence of green practices in the Indonesian construction industry has led to an ongoing increase in energy consumption and greenhouse gas emissions, posing a significant environmental threat. Green supply chain management (GSCM) is a concept that integrates the environmental aspect into traditional supply chain processes and can provide benefits not only on environmental performance but also on economic and organizational performance. This study aims to derive a suitable GSCM strategy in the Indonesian construction sector and investigate the relationship of GSCM strategy on sustainability performance. This study employed ANP to select the GSCM strategy and correlation analysis to examine the relationship involving professionals and practitioners in construction. The findings revealed that the efficiency-based strategy had the highest weight among the various GSCM strategies, and sensitivity analysis demonstrated that this strategy was not significantly affected by changes, making it the most suitable GSCM strategy. Also, the result indicates that the efficiency-based strategy moderately impacts sustainability performance. Therefore, the implementation of efficiency-based strategy can improve the sustainability of the Indonesian construction industry.

1 Introduction

In the third quarter of 2022, the Indonesian economy managed to record a growth of 5.72%, with 5,091.2 trillion rupiahs of total gross domestic product. Indonesian construction industry contributed to the economic growth of 9.45% [1]. To deliver the product of construction, the construction industry needs components and materials from other industries. Hence, the construction supply chain has a role in improving the economy of a country [2]. Nevertheless, the construction industry is known for its negative impact on the ecology, especially the consumption of natural resources, energy, waste, and pollution [3–5].

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Based on the report of the United Nations Environmental Program [6], the global consumption of energy and greenhouse gas emissions from the building and construction industry account for 36% and 37%, respectively. In Indonesia, the consumption of energy and greenhouse gas emissions of the construction and manufacturing industry recorded an increase of 329 million Barrel of Oil Equivalent (BOE) of energy and 137.040 Gg CO2e of greenhouse gas in 2019 [7].

Those environmental problems can worsen global warming and contribute to climate change, the impacts of which are already becoming apparent. There were 3.233 cases of hydrometeorological disasters, namely drought, heat waves, floods, and wildfires in Indonesia throughout 2022 [8]. These problems also affect in company’s reputation and competitiveness of a company in organizational/social aspects, as well as increased environmental management costs and decreased profits from the economic perspective [9,10]. One of the primary concerns within the Indonesian construction industry is the limited adoption of green practices, including top management’s lack of commitment to green practices implementation, inadequate waste management, the absence of guidelines for using materials with high recycled content, and excessive energy consumption [9,11–13].

Businesses must start paying attention and acting by reviewing their business procedures and supply chains to prevent continuous environmental problems [14]. Green supply chain management (GSCM) is a viable solution for making a company's supply chain activities more environmentally sustainable. The incorporation of GSCM can yield beneficial environmental outcomes, such as reduced energy consumption, minimized waste generation, substitution of toxic materials with environmentally friendly alternatives, and lowered greenhouse gas emissions [14,15]. In addition, adopting GSCM can result in cost reduction through energy conservation, waste reduction, and an improvement in the company’s reputation [9,12].

Several studies have been conducted regarding GSCM practices in industries, and it was found that the implementation of GSCM practices can improve overall sustainability [12,14–16]. According to Malviya & Gupta [17], the concept of GSCM has been widely discussed, but the right strategy for its implementation remains unclear. Few studies have discussed the selection and evaluation of the GSCM strategy. In this regard, Chan et al. [18] studied the selection of GSCM strategy in the Taiwanese electronic industry using the product life-cycle management viewpoint. They found that this industry needs to be more concerned about environmental issues by increasing innovation capabilities, strengthening green competencies, and decreasing hazardous waste. Khan et al. [19] integrated CODAS and internal-valued q-rung to find the best strategy for the food supply chain, the findings elucidated that the food industry needs to integrate its supply chain with a closed-loop strategy that linked environmental performance with entire supply chain processes to attain sustainability. To date, there have been no studies regarding GSCM strategy in construction, and thus, it is necessary to derive a suitable GSCM strategy to be implemented in the construction industry. Therefore, the study aims to achieve two primary objectives: the first objective is to formulate a suitable Green Supply Chain Management (GSCM) strategy for the construction industry, which can subsequently be implemented in Indonesia. The second objective is to investigate the impact of the GSCM strategy on sustainability performance. In selecting the GSCM strategy based on construction GSCM practices, the Analytic Network Process (ANP) was employed. This method focuses on dependent and feedback relationships among factors within the network, allowing it to emulate the actual decision-making environment. The GSCM strategy is expected to serve as a valuable recommendation, aiding decision-makers and managers in the Indonesian construction industry to make their supply chains more environmentally sustainable.
2 Literature study

2.1 Construction supply chain

A supply chain in construction is defined as an organization and relationship network that includes material, finances, and information flow between construction partners (owners, consultants, contractors, and suppliers) [20]. Meanwhile, Balasubramanian and Shukla [16] described the construction supply chain as a network with information and material flow. Information flow regarding tasks and orders occurs from the project owner to suppliers (downstream to upstream). Whereas, from suppliers to the project owners (upstream to downstream), there is the flow of material from raw material to create a finished construction product.

Supply chain management of construction is an activity for managing resources and interactions between construction partners (upstream and downstream) to produce construction products, such as buildings, bridges, roads, etc [21]. Supply chain management implementation is not a novel concept in the manufacturing sector. Previous studies showed that it can enhance overall company performance, including profit and competitiveness within the manufacturing industry [22,23]. According to Othman & Rahman [24], the construction supply chain is more difficult due to the complex, diverse, and fragmented nature of this industry’s supply chain. It involves many organizations and professional groups participating in the project and finishing their area of expertise’s work. The project owner (downstream actor), contractors (main actor), consultants, and subcontractors or suppliers (upstream actor) are the supply chain management actors involved in the construction industry [9].

2.2 Green supply chain management

Green supply chain management (GSCM) is a concept incorporating environmental factors into the design phase of a traditional supply chain to the end-of-life of a product [25]. GSCM, as an environmentally-based idea, integrates both upstream and downstream of the traditional supply chain [26]. The goal of implementing GSCM in construction is to make the project life-cycle management environmentally friendly from the design stage through the building’s operation and end-of-life [2].

The implementation of GSCM in the manufacturing industry can reduce environmental damage caused by this sector. It is anticipated that each phase’s application of environmentally friendly practices will reduce waste and energy usage [2]. Handayani [9] argued that there remains a deficiency in implementing green practices within the Indonesian building construction sector. The major factors affecting the adoption of GSCM in Indonesian building construction include top management’s lack of commitment to green practices implementation, environmental regulation, a scarcity of suitable suppliers, and the limited awareness and understanding of the environmental impact of construction activities [13].

The need for GSCM Implementation arises from its potential to enhance sustainability performance. The reduction of greenhouse gas, energy usage, waste generation, and toxic material usage is the benefit of GSCM practices in the environmental aspect [9]. In addition, GSCM implementation can also benefit the economy by lowering the cost of energy usage, waste management, and material use [12]. Additionally, it has a positive effect on the company’s reputation, influencing the competitiveness of the company over time [14].
2.3 Green supply chain management practices

GSCM practices are implemented to mitigate the environmental impact of the company’s operations. GSCM practices discussed in this study are based on project life-cycle management (PLM) in construction, covering green design, green purchasing, green construction, internal environmental management, and green operation and maintenance.

2.3.1 Green design

Green design involves the development of environmentally friendly products or processes to minimize their environmental impact throughout their entire life cycle, from production to usage [27]. In the construction context, green design includes consideration of air conditioning and lighting systems, consideration to reduce hazardous materials, and environmental impact assessment [16].

2.3.2 Green purchasing

Green purchasing is a green practice aimed at ensuring that materials and components purchased meet environmental standards, which include the use of recycled materials and the avoidance of toxic substances [11]. Environmental factors, such as supplier ISO 14001 certification, the use of eco-labelled materials, and experience in green construction projects, are employed as criteria during the tender stage [16].

2.3.3 Green construction

The term “green construction” describes onsite practices in construction to minimize the negative effects of construction on the environment and involve consideration, such as the use of fuel-efficient equipment, prefabricated components, and waste management [2,16]. Balasubramanian and Shukla [9] discovered that green construction can be advantageous by reducing waste, water use, and energy use, which lowers overall construction costs.

2.3.4 Internal environmental management

Internal environmental management is the creation of a company to ensure the protection of the environment, such as the development of environmental policies and environmental targets [14]. This practice includes ISO 14001 certification, an environmental audit program, and top management commitment to green practices implementation [12]. Farradia et. al [27] said that this particular practice can influence the adoption of other green practices, making it the main factor in environmentally friendly practices.

2.3.5 Green operation and maintenance

The final phase of the project life-cycle involves green operation and maintenance, including running every part of a building in a way that results in the least amount of environmental harm possible [28]. The adoption of green buildings is an example of green operation and maintenance practice in building construction.
2.4 Green supply chain management strategy

The application of the strategy has benefits in cost reduction, more efficiency in resource consumption reduced environmental depletion, and also further can improve the firm competitiveness in the market [27, 28]. Simpson and Samson [30] proposed GSCM strategies based on resource commitment and complexity, namely risk-based strategy, efficiency-based strategy, innovation-based strategy, and closed-loop strategy.

A risk-based strategy is the simplest strategy that minimizes risk by complying with environmental requirements to suppliers, such as ISO 14001. An efficiency-based strategy is a strategy that not only allows for environmental benefits, such as waste reduction and efficient resource consumption but also increases economic benefits. Innovation-based strategy is a more complex strategy because it is more environmentally specific, such as specialized processes, technologies, and stricter environmental requirements for suppliers. On the other hand, the closed-loop strategy is the most complex strategy, requiring integration with many stakeholders to green the entire supply chain. The simplest form of this strategy is reverse logistics or recycling and remanufacturing.

2.5 Sustainability performance

Sustainability can be described as an effort to fulfil current needs without sacrificing the needs of future generations [14]. Sustainability is divided into three dimensions called the triple bottom line: environmental, economic, and social performance. The environmental performance focuses on environmental depletion caused by industry activities. Environmental performance is measured by the reduction in greenhouse gas, reduction in energy use, waste, and hazardous material use [16]. Economic performance is related to the cost reduction affected by the purchasing of materials, reduced energy consumption, and waste management costs [12]. Social performance emphasizes the impact of activities carried out on the community, such as employees and stakeholders [31].

2.6 Analytic network process

The analytic network process (ANP) is one of the multi-criterion decision-making methods introduced by Saaty [32]. ANP uses the structure of a network by considering dependencies between elements in the model. This approach proves highly effective in simplifying complex decision-making problems by representing them as network models and assigning subjective importance to determine the highest priority solution. In the context of this study, the aim is to rank the Green Supply Chain Management (GSCM) strategies in construction [32]. The advantage of using ANP lies in its capacity to assess which elements wield the most influence on the chosen GSCM strategy [18].

3 Research methodology

A literature study was conducted to identify GSCM strategy alternatives and GSCM practices in construction as the selection criteria. This study utilized the analytic network process (ANP) methodology and correlation analysis. ANP was conducted to create the ANP network model for choosing a green supply chain management strategy and run the analysis to find the ranking of the GSCM strategies in the construction industry, especially in high-rise buildings. In addition, correlation analysis using IBM SPSS Pearson product-moment was conducted to examine the correlation between the selected GSCM strategy and sustainability performance (environmental, economic, and social performances).
This study conducted four questionnaires. The first questionnaire was administered to five experts to validate applicable GSCM practices identified in the construction industry in Indonesia, especially high-rise building construction. Next, based on the result of the first questionnaire, the second and third questionnaires were conducted on the same five experts. These questionnaires aimed to identify dependencies among GSCM practices and GSCM strategy and for pairwise comparison. Finally, the fourth questionnaire examined the correlation between GSCM strategy and sustainability. Project owners, consultants, contractors, and suppliers were among the professionals or practitioners who participated as respondents and experts in this study.

4 Result

4.1 Analytic network process

Criteria in this ANP network were GSCM practices in construction and GSCM strategies obtained from a literature review and validated by the experts through structured interviews. To determine the network, this study involved five experts or professionals in the construction industry to ask about dependencies between each element.

4.1.1 ANP model

Based on the second questionnaire conducted to obtain the relationships (inner and outer dependencies) between GSCM practices and GSCM strategies, an ANP network was made using Super decisions software. Figure 1 displays the proposed framework of this study.

4.1.2 GSCM strategy selection

The third questionnaire was conducted on five experts in construction for pairwise comparison. The result of the pairwise comparison was then processed using Super decisions software by inputting all the importance level into the software. Table 1 presents the resulting weights and ranking of the GSCM strategy in construction.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Normalized By Cluster</th>
<th>Idealized</th>
<th>Limiting</th>
<th>Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closed-loop strategy</td>
<td>0.10869</td>
<td>0.3412237</td>
<td>0.006766</td>
<td>4</td>
</tr>
<tr>
<td>Efficiency-based strategy</td>
<td>0.31853</td>
<td>1</td>
<td>0.019828</td>
<td>1</td>
</tr>
<tr>
<td>Innovation-based strategy</td>
<td>0.30984</td>
<td>0.9727184</td>
<td>0.019287</td>
<td>2</td>
</tr>
<tr>
<td>Risk-based strategy</td>
<td>0.26293</td>
<td>0.8254481</td>
<td>0.016367</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 1 shows that the GSCM strategy with the highest weight is the efficiency-based strategy, followed by the innovation-based strategy, risk-based strategy, and closed-loop strategy. Based on the analysis with ANP, there are five GSCM practices in construction with a strong influence on efficiency-based strategy, namely ‘consideration for energy-efficient air conditioning system’ and ‘consideration for the energy-efficient lighting system’ in green design, ‘purchasing materials with recycled content’ in green purchasing, ‘fuel-efficient equipment are used in construction project’ and ‘the use of prefabricated components in projects’ in green construction.
4.1.3 Sensitivity analysis

Sensitivity analysis in this study was conducted to determine whether the chosen strategy is stable in response to changes. The consideration of conducting this analysis is whether these changes alter the order of the outcome of ANP [18]. Table 2 displays the result of the sensitivity analysis. It shows no significant change in the strategy after the weights adjustment of the ‘Consideration for energy-efficient air conditioning system’ practice. The efficiency-based strategy remains with the highest weight on the GSCM strategy. It can be concluded that the efficiency-based strategy is not sensitive to changes, and the rank of the strategies is stable.

<table>
<thead>
<tr>
<th>GSCM Strategy</th>
<th>Weights</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency-based Strategy</td>
<td>0.318</td>
</tr>
<tr>
<td>Innovation-based Strategy</td>
<td>0.317</td>
</tr>
<tr>
<td>Risk-based Strategy</td>
<td>0.264</td>
</tr>
<tr>
<td>Closed-loop Strategy</td>
<td>0.109</td>
</tr>
</tbody>
</table>

Percentage change in weight
-80% -60% -40% -20% 0% 20% 40% 60% 80%
4.2 Correlation analysis

The fourth questionnaire was conducted to respondents to examine the correlation between the chosen GSCM strategy and sustainability performance using the Likert scale. This questionnaire involved 80 respondents from owners, consultants, contractors, and suppliers. Correlation analysis in this study was conducted using Pearson product-moment with IBM SPSS 24. The resulting correlation between the chosen GSCM strategy and sustainability performance (environmental, economic, and social performances) can be seen in Table 3.

Table 3. Correlation analysis between efficiency-based strategy and sustainability performance

<table>
<thead>
<tr>
<th>Pearson correlation</th>
<th>Environmental performance</th>
<th>Economic performance</th>
<th>Social performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency-based strategy</td>
<td>0.668</td>
<td>0.604</td>
<td>0.655</td>
</tr>
</tbody>
</table>

Based on the correlation analysis, the correlation coefficient (r) of the efficiency-based strategy and environmental performance is 0.668, indicating that the efficiency-based strategy moderately impacts environmental performance. Also, a moderate and positive impact was found between efficiency-based strategy on economic performance, with a correlation coefficient (r) of 0.604. The analysis was also conducted between efficiency-based strategy and social performance, showing that efficiency-based strategy also positively and moderately impacts social performance (r=0.655).

5 Discussion

The analysis reveals that the efficiency-based strategy holds the highest weight of 0.31853 within the GSCM strategy cluster. Consequently, the efficiency-based strategy is the most suitable choice for adoption in the construction of high-rise buildings in Indonesia. Insights from expert interviews indicate that green management has already been introduced in construction, particularly building projects. However, its implementation has been less than optimal, and it is observed that only a limited number have incorporated these practices into their operations. Consequently, there is a dearth of discernible innovations, such as methods, products, and policies, about green practices within the supply chain activities in the construction industry in Indonesia, particularly in the context of high-rise buildings. Based on the definition, an efficiency-based strategy is focused on efficiency and can provide dual benefits in the environmental and economic aspects. The implementation of this strategy can support the construction industry to improve environmental performance through GSCM practices and maximize economic benefit through cost savings from reduced waste and energy savings. The finding of this study is in contrast with previous studies about the GSCM strategy conducted in other industries. Malviya & Gupta [17] studied GSCM strategy in the Indian automotive industry and found that 'resource-based strategy’ is the best strategy to be applied in this industry. The application of this strategy can lead organizations to maximize resource utilization to increase productivity. In the Indonesian cosmetics manufacturing industry, the most suitable GSCM strategy to implement is an innovation-based strategy [33]. Its application in firms can strengthen innovation and support the implementation of GSCM and environmental sustainability.

The correlation analysis reveals that the efficiency-based strategy positively and moderately influences sustainability performance across environmental, economic, and social dimensions. This implies that implementing the efficiency-based strategy can enhance environmental, economic, and social performance within the construction sector. This finding aligns with Mutingi [5], suggesting that the adoption of an efficiency-based strategy
encourages collaboration among various stakeholders in construction, from owners to suppliers, with the aim of waste reduction, decreased energy consumption, cost savings, and an enhanced corporate image. To effectively implement this strategy for enhancing sustainability, it is crucial to incorporate Green Supply Chain Management (GSCM) practices within construction. This can include using energy-efficient air conditioning and lighting systems during the design phase, sourcing materials with recycled content during procurement, employing fuel-efficient equipment in construction projects, and integrating prefabricated elements in the construction phase.

The use of air conditioning with a low global warming potential refrigerant or water-cooled chiller system can provide benefits, such as reduction in carbon emission and energy consumption in the overall building also in economic aspect can reduce the cost of energy [34–36]. Refaat et al. [37] also investigated smart air conditioning systems using automatic temperature controllers, which reduced energy consumption by 16% and improved the comfort of the consumers. In addition, the use of energy-efficient lighting systems, such as LED (light-emitting diode), can provide a reduction in energy consumption over HPS (high-pressure sodium) by 10% [38]. In the context of green purchasing, acquiring materials with recycled content, such as construction demolition waste, can effectively decrease waste generation and curtail the consumption of natural resources. Additionally, producing such materials typically comes at a lower cost, resulting in cost savings in the procurement process [39]. The applications in construction are prefabricated components with recycled concrete lumps from building demolition as aggregates and architectural components, such as workbenches, shelves, or decorations produced from waste [40,41]. In the construction phase, utilizing fuel-efficient construction equipment and the use of prefabricated components can improve sustainability. Fresia et al. [42] developed a new generation of mobile hydraulics using a hybrid engine which can improve workability and save fuel/energy by 28%. The use of construction equipment with the latest technology can provide benefits in fuel efficiency and cost reduction and improve the level of safety for operators and workers [43]. In addition, the use of prefabricated components in a building can reduce greenhouse emissions by 8.06% and save costs by 6%, the use of these components can also reduce direct physical contact of workers with hazardous substances, so it can improve the safety and health of workers [44,45].

The findings in these studies underscore that the effective implementation of an efficiency-based strategy in construction, facilitated by Green Supply Chain Management (GSCM) practices, can yield substantial benefits by reducing energy consumption and mitigating environmental degradation, thereby leading to cost savings. Moreover, the long-term adoption of green strategies can enhance customer satisfaction, foster stronger customer relationships, and enhance the company's brand image, particularly in terms of its commitment to environmental protection [16,37–39,44,46].

6 Conclusion

The primary objectives of this study are developing a suitable Green Supply Chain Management (GSCM) strategy for high-rise building construction in Indonesia and exploring the relationship between the GSCM strategy and sustainability performance. Analytic network process and correlation analysis were used to find the suitable GSCM strategy in construction and its relationship to sustainability performance. The findings reveal that among various GSCM strategies, the efficiency-based strategy has the highest weight, making it the most fitting choice for the Indonesian construction industry. Several Green Supply Chain Management (GSCM) practices were identified as having a significant influence on the efficiency-based strategy, including considerations for energy-efficient air conditioning and lighting systems in green design, the procurement of materials with recycled
content in green purchasing, the use of fuel-efficient equipment in construction projects, and the integration of prefabricated components in construction processes. Sensitivity analysis demonstrates that the chosen GSCM strategy, namely the efficiency-based strategy, exhibits stability and is not significantly affected by changes.

Furthermore, the results indicate that the efficiency-based strategy has a positive and moderate impact on sustainability performance across environmental, economic, and social dimensions. Therefore, the implementation of the efficiency-based strategy, coupled with GSCM practices, such as the utilization of energy-efficient air conditioning and lighting systems during the design phase, the procurement of materials with recycled content, the use of fuel-efficient equipment in construction projects, and the integration of prefabricated components, can contribute to the enhancement of sustainability within the Indonesian construction industry. However, this study has limitations, which should guide future research efforts. The study's focus on GSCM strategy within the context of Indonesian construction, especially in building projects, and the use of ANP as a decision-making method are noted limitations. Future research endeavours may explore alternative decision-making methods (such as ISM and TOPSIS) to address interdependencies among elements and expand the scope to include various types of construction projects.

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