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Sustainable supplier development of wood product manufacturing

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Abstract

The plywood industry is one of the manufacturing industries whose raw materials are based on the sustainability of natural resources. The challenges that arise are difficulties in obtaining raw materials especially Sengon wood, low quality wood, delays in delivery, and a critical land crisis in forest areas. This drives the need for supplier assessments that focus on sustainability and recommends developmental steps and ensures supplier compliance with requested sustainability standards. This study aims to formulate supplier performance evaluations based on sustainability aspects. The steps taken are through supplier segmentation using the Triple Bottom Line (TBL) approach to ensure supplier criteria are aligned with sustainability aspects. Furthermore, using TOPSIS, the selected suppliers will be determined according to the established criteria. The supplier development strategy is developed based on the characteristics of each supplier segmentation, namely compiling a written guidebook; company visits to transfer knowledge and share experiences; company reviews; regular oversight for the provision of feedback; and long-term contracts. This study contributes a framework for addressing raw material challenges and applying sustainability principles in supplier selection and development, aligned with the company's mission of sustainable growth.

Keywords: Sustainable Supplier Development; Triple Bottom Line (TBL); Analytical Hierarchy Process (AHP); TOPSIS

1. Introduction

Manufacturing industry is a company that creates something by hand or with machines to produce a product (Heizer and Render, 2004). The sustainability of the manufacturing industry relies on the performance of both internal and external supply chains. According to the SCOR framework, the parties involved include suppliers, the company itself, and customer (ASCM, 2023). Collaboration among these parties in the process is referred to as supply chain management. Therefore, each involved party needs to maintain and improve their respective performances to ensure effective supply chain management within a company (Oliver and Webber, 1982).

In recent years, sustainability has become a critical issue in supply chain management due to increasing environmental concerns, regulatory pressures, and stakeholder expectations. Companies are required not only to ensure operational efficiency but also to integrate environmental and social considerations into their supply chain strategies. According to recent studies, sustainable supply chain practices significantly enhance long-term resilience and competitiveness, particularly in resource-based industries such as wood manufacturing (World Economic Forum, 2021; Khan et al., 2020; Tseng et al., 2022).

PT XYZ is a company engaged in the manufacturing of wood products commonly known as plywood. In its production activities, PT XYZ is committed to creating sustainable growth in the natural resource-based industry, adding value to all stakeholders through effective governance. Particularly in the production of plywood products, PT XYZ heavily relies on the supply of raw materials. The main raw material used for production is wood, which must be sorted according to company specifications and standards. However, during the plywood production process, PT XYZ has encountered a

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shortage of Sengon wood material in 2023, attributed to the presence of low-quality wood (rotten, uneven, severely cracked, diameter <20 cm) and delays.

Some suppliers are inadequate in meeting PT XYZ's demands due to the company's lack of awareness that the selected supplier's performance does not meet the company's standards. To address this, PT DSN demands that suppliers ensure not only the fulfilment of raw material requests but also guarantee the sustainability aspect of the sent materials. This is crucial due to the critical land situation in the Temanggung forest region, which reached 13,110.1 Ha out of the total surveyed forest area of 13,218.65 Ha in 2022, signifying a 99% critical land rate in Temanggung (BPS, 2023). Therefore, PT XYZ insists that suppliers ensure sent raw materials align with the company's sustainability mission.

2. Literature review

2.1. Supply chain management

Supply chain is a network of companies or vendors that collaborate to produce and deliver a product until it reaches the hands of consumers. The companies within this network include suppliers, retailers, distributors, factories, and other supporting entities such as logistics service providers. To manage the supply chain effectively, a proper approach, tool, or method known as Supply Chain Management (SCM) is required (Pudjawan, 2005).

Supply Chain Management is the best solution for enhancing productivity among interconnected companies. The main objectives of SCM are to ensure timely product delivery for customer satisfaction, reduce costs, improve overall performance across the entire supply chain (not just one company), decrease lead times, and centralize planning and distribution activities (Carter and Rogers, 2008). Recent developments in SCM emphasize digital integration, resilience, and sustainability as key performance drivers in modern supply chains (Queiroz et al., 2020).

2.2. Sustainable supply chain management

Sustainable Supply Chain Management (SSCM) encompasses more dimensions compared to traditional SCM, as SSCM is not solely focused on profit attainment (Seuring and Müller, 2008). SSCM has evolved to incorporate circular economy principles, carbon footprint reduction, and stakeholder engagement as core components of sustainable operations (Govindan et al., 2019; Carter et al., 2021).

In traditional SCM, profit and cost are the primary focuses, whereas in SSCM, companies also need to consider the environmental and social impacts when designing and optimizing their supply chains (Dubey et al., 2017). In the operational aspect of sustainable supply chain management (SSCM), the concept of Triple Bottom Line (TBL) is employed. The dimensions contained within the TBL concept are economic, environmental, and social (Carter and Rogers 2008).

Sustainable Supply Chain Management (SSCM) can be defined as the management of material, information, capital flow, and collaboration with various companies within the supply chain to achieve sustainable economic, environmental, and social dimensions (Seuring and Müller, 2008). There are five key ideas in SSCM, which include environmental management implementation, operational execution, supply chain integration, implementation of inclusive social aspects for employees and communities (Das, 2018). For initiators of SSCM, it is essential to prioritize four fundamental implementations, which are sustainable procurement, sustainable production, sustainable distribution, and reverse logistics (Esfahbodi et al., 2016).

2.3. Sustainable supplier

The approach of considering economic, environmental, and social aspects is often interpreted as sustainability or commonly known as the Triple Bottom Line (TBL) approach (Bai and Sarkis, 2010). The concept of sustainability can be applied to various business processes of a company, including procurement. Companies typically have relationships with other businesses as their partners, one of which is the supplier of raw materials or production materials. The concept of a sustainable supplier becomes crucial as a step towards achieving sustainability (Sarkis and Dhavale, 2014).

A sustainable supplier is a company's partner that has been selected and meets the standards of the TBL approach, which includes economic, environmental, and social aspects (Bai and Sarkis, 2010). The TBL approach used requires suppliers to meet all three sustainability standards comprehensively. The parameters used to measure a sustainable supplier are the criteria used to assess suppliers (Luthra et al., 2017). Recent studies highlight that sustainable supplier selection increasingly incorporates ESG (Environmental, Social, Governance) metrics alongside traditional cost and quality criteria (Neji et al., 2025).

2.4. Sustainable supplier development

The term "supplier development" was first used in 1966 to describe a company's effort to increase the number of suitable suppliers and improve the performance of these suppliers (Paybarjay et al., 2023). Nowadays, supplier development is known as the efforts undertaken by the procurement department of an industry to enhance the performance and capabilities of suppliers (Krause et al., 2007) Supplier development can also be understood as an effort to improve the performance and capabilities of suppliers by the buying company to meet its short-term and long-term needs (Krause and Ellram, 1997). Therefore, sustainable supplier development itself means all initiatives taken by the buying company to enhance the sustainability capabilities of their suppliers, ensuring they fulfil two or more aspects of the Triple Bottom Line (TBL) concept for various stakeholders involved along the company's supply chain (Bai and Satir, 2022). Sustainable supplier development has shifted from transactional improvements to strategic collaboration, focusing on innovation, capability building, and long-term sustainability performance (Mani et al., 2022).

2.5. Supplier segmentation model

The supplier segmentation model used is based on the concept of the Triple Bottom Line (TBL) with sustainability criteria. This model takes into account the performance of the three dimensions of sustainability: economic, environmental, and social aspects (Paybarjay et.al, 2023).

Suppliers can be segmented according to their performance in each dimension based on the segmentation model below as follows:

- Segment 1: Low Economy, Low Environmental, Low Social
- Segment 2: High Economy, Low Environmental, Low Social
- Segment 3: Low Economy, High Environmental, Low Social
- Segment 4: Low Economy, Low Environmental, High Social
- Segment 5: High Economy, High Environmental, Low Social
- Segment 6: High Economy, Low Environmental, High Social
- Segment 7: Low Economy, High Environmental, High Social
- Segment 8: High Economy, High Environmental, High Social

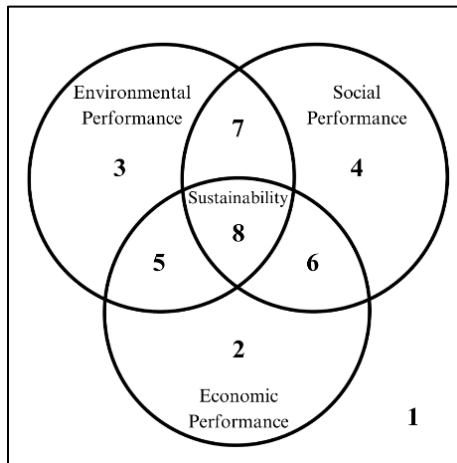


Figure 1 Supplier segmentation model

2.6. Content validity indeks

Content Validity Index (CVI) is the degree to which a particular item can adequately represent a measurement instrument (Thomas et.al, 2015). CVI is used to select or choose which items are relevant to be included in a measurement instrument based on the agreement of relevant experts.

The initial step in calculating CVI is to divide the number of respondents who agree or answer "yes" by the total number of respondents, using the following formula.

$$CVI = \frac{n}{N} \quad (1)$$

Where: n = number of respondents who agree or answer “yes”

N = total number of respondents

Next is to select the chosen items based on the results of the CVI according to the following criteria (Polit and Beck, 2006).

Table 1 CVI Acceptance Value

Number of Respondents	Accepted CVI Value
≤ 5	1
6 – 8	≤ 0.83
9	≤ 0.78

2.7. Analytical hierarchy process

The Analytical Hierarchy Process (AHP) is a method developed by Saaty in 1977. This method is used as a decision support tool to tackle complex or unstructured problems where the available data is qualitative and based solely on perceptions, experiences, and intuition. In AHP, the model relies on inputs by experts in the relevant field (Saaty, 1997). AHP is a qualitative measurement tool for processing quantitative information.

The deviation will then affect the value of lambda max or eigenvalue. Eigenvalue represents the value that indicates the extent of influence of a variable on the formation of characteristics of a vector or matrix.

$$\lambda_{max} = \frac{\sum \lambda_{Matrix\ c}}{n} \tag{2}$$

The deviation is expressed by the Consistency Index (CI), which is formulated as follows:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{3}$$

Where: λ_{max} = maximum eigen value

$\lambda_{Matrix\ c}$ = eigen value of each criteria in matrix c

n = matrix size

The parameter used to assess the consistency of the pairwise comparison questionnaire conducted by selected experts is by calculating the Consistency Ratio (CR). The formulation of the consistency ratio is as follows:

$$CR = \frac{CI}{RI} \tag{4}$$

Where: CI = Consistency Index

RI = Ratio Index

Next, the calculation will be performed to find the Priority Vector, which represents the actual weight values of the factors. This can be achieved by dividing the average of a factor by the sum of the averages in the same column. The formulation is as follows:

$$Vp = \frac{RT_n}{\sum RT\ of\ same\ column} \tag{5}$$

Where: n = factor n

In AHP, where each criterion has sub-criteria, the results of priority weights are still calculated as relative local weights with respect to their parent criteria. Therefore, the local weight values need to be transformed into global weight values that represent the overall weights as follows:

$$W_j = Vp \text{ subcriteria } x_{mn} \times Vp \text{ criteria } x_{mn} \quad (6)$$

Technique to Order Preference by Similarity to Ideal Solution

TOPSIS is one of the Multiple Criteria Decision Making (MCDM) methods based on the selection of the best alternative, which is the alternative with the shortest distance to the positive ideal alternative and the longest distance to the negative ideal alternative. TOPSIS was developed by Hwang and Yoon in 1981 and is used to obtain ranking values and rank suitable alternatives. Generally, TOPSIS helps decision-makers in solving problems and conducting comparison and ranking analysis of alternatives. Thus, appropriate alternative selection will be made (Hwang and Yoon, 1981). Hybrid multi-criteria decision-making methods such as AHP-TOPSIS remain widely used due to their robustness in handling complex sustainability evaluation problems (Kumar et al., 2021).

The initial step in TOPSIS calculation is to normalize the performance values of each criterion as follows:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}} \quad (7)$$

Where: r_{ij} = normalized performance value of supplier i criteria j

x_{ij} = performance value of supplier i criteria j

Next, the weighted normalized performance values are calculated based on the previously obtained weights as follows:

$$V_{ij} = r_{ij} \times W_j \quad (8)$$

Where: r_{ij} = normalized performance value of supplier i criteria j

W_j = weight of criteria j

Next, the positive ideal solution (PIS) and negative ideal solution (NIS) values need to be determined using the following formulas:

$$\begin{aligned} PIS &= V_j^+ = MAX_i(V_{ij}) \text{ for Benefit} \\ &= V_j^+ = MIN_i(V_{ij}) \text{ for Cost} \\ NIS &= V_j^- = MIN_i(V_{ij}) \text{ for Benefit} \\ &= V_j^- = MAX_i(V_{ij}) \text{ for Cost} \end{aligned} \quad (9)$$

Where: V_{ij} = normalized performance value of supplier i criteria j

After obtaining the PIS and NIS values for each criterion, the geometric distances of each alternative with respect to PIS (S_i^+) and NIS (S_i^-) are calculated as follows:

$$\begin{aligned} S_i^+ &= \sqrt{\sum_{j=1}^n (V_j^+ - V_{ij})^2} \\ S_i^- &= \sqrt{\sum_{j=1}^n (V_j^- - V_{ij})^2} \end{aligned} \quad (10)$$

Where: V_{ij} = normalized performance value of supplier i criteria j

The final step is to calculate the preference values or relative distances of each supplier to the ideal solutions as follows:

$$V = \frac{S_i^-}{S_i^- + S_i^+} \quad (11)$$

3. Methodology

The research used both qualitative and quantitative descriptive methods as it aims to describe the issues occurring at researched company to find answers and recommendations through analysis and mathematical calculations. Qualitative research was used for surveys and validation questionnaire, paired comparisons, and supplier evaluation. The questionnaire was then used for quantitative research in the calculations and analysis of CVI, AHP, and TOPSIS.

Data collection was conducted through interviews and questionnaires with relevant stakeholders, as well as observation of the company's historical data. Primary data was obtained from interviews and questionnaires, while secondary data was obtained from the company's historical records. The time dimension in this research is cross-sectional as data collection was carried out within a specific time frame.

The identified criteria for sustainable supplier selection based on validation results with relevant stakeholders were discussed. Next, the analysis of criteria weighting from the AHP calculations was conducted to determine the priority according to the company's requirements. Subsequently, the TOPSIS calculation results were analysed to determine the overall performance values of each Sengon wood supplier. Finally, recommendations were provided regarding supplier development for the company using TOPSIS preference values and a qualitative approach based on the TBL segmentation model.

3.1. Data collection and processing

The data collection in this research was conducted to identify the selected sustainable criteria using CVI, to weight each criterion using AHP, and to assess supplier performance using TOPSIS based on the gathered data from validation questionnaires, paired comparisons, and performance evaluations.

3.2. CVI validation

In this section, validation will be conducted using CVI to determine which sustainable supplier criteria are relevant for this research based on literature (Menon and Ravi, 2022) and according to the relevant academic, business, community, and government side answer. The following table provides a summary of the calculations.

Table 2 CVI validation result

Aspect	Criteria	CVI Value	Decision
Economy	Quality	1	Passed
	Cost	1	Passed
	Delivery	1	Passed
	Flexibility	1	Passed
Environment	Eco – design	1	Passed
	Resource reduction and consumption	1	Passed
	Pollution control	1	Passed
	Environment management systems	1	Passed
	Green image	1	Passed
Social	Human rights	1	Passed
	Safety and Occupational Health System	1	Passed
	Corporate Social Responsibility	1	Passed
	Education and Training	1	Passed

3.3. AHP weighting

In this section, weighting using AHP will be conducted to determine the level of importance or priority of criteria according to the company. The following is a summary of the calculation results.

Table 3 AHP weighting result

Aspect	Criteria	Local Weight	Global Weight
Economy	Quality	0.625	0.184
	Cost	0.053	0.016
	Delivery	0.269	0.079
	Flexibility	0.053	0.016
Environment	Eco – design	0.534	0.346
	Resource reduction and consumption	0.032	0.021
	Pollution control	0.060	0.039
	Environment management systems	0.105	0.068
	Green image	0.270	0.175
Social	Human rights	0.442	0.025
	Safety and Occupational Health System	0.234	0.013
	Corporate Social Responsibility	0.168	0.010
	Education and Training	0.155	0.009

3.4. TOPSIS performance assessment

Performance evaluation using TOPSIS was conducted to determine the supplier performance level in each aspect. The following is a summary of the calculation results.

Table 4 TOPSIS assessment result

Alternatives	Overall	Economy	Environment	Social
S1	0.000	0.000	0.000	0.000
S2	0.652	0.681	0.647	0.785
S3	0.580	0.325	0.621	0.213
S4	0.795	0.686	0.822	0.635
S5	0.255	0.686	0.000	0.000
S6	0.589	0.325	0.629	0.697
S7	0.031	0.000	0.000	0.303
S8	0.265	0.681	0.102	0.213
S9	0.000	0.000	0.000	0.000
S10	0.279	0.675	0.154	0.000

4. Result and discussion

Based on the data processing results, segmentation can be conducted according to the previously explained model.

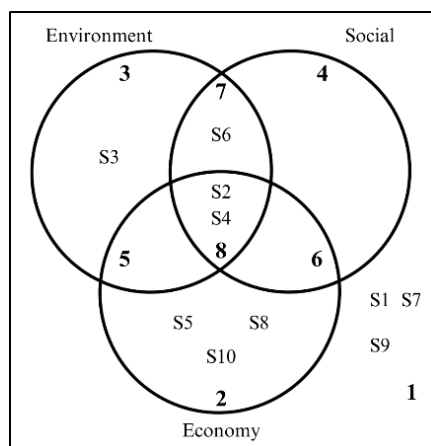


Figure 2 Supplier segmentation result

Suppliers with the worst performance are positioned in segment 1, which includes suppliers with low performance in all aspects of economics, environment, and social. There are 3 suppliers in this segment, namely S1, S7, and S9. The selected alternative strategy is to inform the suppliers about the technical requirements in material procurement according to the company's regulations. In this case, the operational strategy to be implemented is the creation of a written handbook detailing the technical requirements for economic, environmental, and social aspects as a guideline for the suppliers to meet future material procurement demands.

There are 3 suppliers in segment 2, namely S5, S8, and S10. These suppliers are needed by the company due to their economic aspect. As the economic aspect is crucial for the company, there will be no replacement strategy in this segment. The chosen strategy is to invite the suppliers for a visit to the company to transfer knowledge and experiences regarding good environmental and social management, allowing the suppliers to directly see what can be done to improve their performance in environmental and social aspects. The company may also invite the suppliers to participate in internal training or seminars on improving environmental and social aspects within the company. The goal is to raise awareness and implement sustainability practices within the suppliers.

There is 1 supplier in segment 3, namely S3. The selected strategy in this segment is to provide feedback from the company to the supplier in the form of a company review of their performance in economic aspects, such as quality expectations, delivery accuracy, expected costs, as well as social aspects, such as the condition of the supplier's employees visiting the company and the company's expectations for the supplier's social aspects in the future.

In segment 7, there is 1 supplier, namely S6. The appropriate strategy in this segment relates to improving the supplier's performance in economic aspects. Since the performance in environmental and social aspects is already high, seeking replacement suppliers might not be rational, although the economic aspect is crucial for the company. The chosen strategy in this segment is regular monitoring of the supplier's performance. This is done to provide face-to-face feedback to the supplier's top management or through other communication media based on the monitoring results and to put pressure on the supplier to improve their economic performance, especially in quality criteria

This segment is the most important and desired by the company. There are 2 suppliers in segment 8, namely S2 and S4. The company always strives to move suppliers from other segments to this segment. The selected strategy in this segment is to sign long-term contracts with the suppliers. This is done to ensure that the suppliers continue to collaborate with the company and are committed to fulfilling the procurement demands from the company that are bound by the applicable law.

5. Conclusion

The criteria priority order from highest to lowest is Eco-Design, quality, green image, delivery, environmental management system, pollution control, employee rights, resource usage and reduction, cost, health and safety system, CSR, followed by education and training. The best overall supplier is S4, the best in economic aspect are S4 and S5, the best in environmental aspect is S4, and the best in social aspect is S2.

Recommendations for S1, S7, and S9 are to provide a written handbook; for S5, S8, and S10, it is to invite them for company visits to transfer knowledge and experiences; for S3, it is to provide a company review; for S6, it is to conduct regular monitoring for feedback; and for S2 and S4, it is to establish long-term contracts.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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