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An Integrated SCOR-AHP Framework for Evaluating Sustainable Supply Chain Performance of Palm Oil Mills

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Abstract. The current status of the palm oil industry holds significant strategic importance in Indonesia, being the leading contributor to the country's Gross Domestic Product (GDP). It is imperative and pressing to evaluate and gauge the performance of the palm oil industry's supply chain, utilizing the three performance categories outlined in the SCOR (Supply Chain Operation Reference) method, namely resilience, economic efficiency, and sustainability. This study analyzed the sustainable supply chain performance of Indonesia's palm oil industry. Secondary data from eight mills in East Kalimantan was collected and analyzed. Primary data through expert questionnaires for SCOR metric weights were analysis using AHP analysis. The highest weights were attributed to the environmental aspect at 0.3995, followed by responsiveness at 0.169, reliability at 0.139, agility at 0.134, cost at 0.082, and asset management at 0.074. The integrated metrics assessed reliability, responsiveness, agility, cost, asset management, and environmental sustainability. Results showed Mills E, H and C exhibited the highest overall performance, driven by technology adoption and emissions reduction initiatives. The framework provides strategic insights to strengthen supply chain management and advance environmental sustainability across the industry. According to expert assessments, it is anticipated that environmental and sustainability factors will serve as pivotal determinants of success for these companies in the foreseeable future.

Keywords: SCOR, Supply chain, Sustainability, Palm oil mill, Performance

1. Introduction

According to Fauzi et al., (2012), Indonesia is currently the largest producer of palm oil with the largest plantation area in the world. The production of Indonesian Crude Palm Oil (CPO) in 2021 amounted to 45.1 million tons (BPS Statistics Indonesia, 2021). According to Azahari et al., (2020), throughout the COVID-19 pandemic, the palm oil industry has proven to be resilient and has made the largest contribution to Indonesia's Gross Domestic Product (GDP), in 2021 the agricultural sector contributed 13.28% to the GDP, with the plantation sector making the largest contribution at 29.67% to the agricultural sector (BPS Statistics Indonesia, catalog 5504003, 2021). The palm oil industry is a national flagship industry in Indonesia, and some reasons for this are as follows: (a) Palm oil, through its Crude Palm Oil (CPO) and derivatives, serves as a significant and largest foreign exchange earner for Indonesia. (b) It provides employment opportunities for millions of people.

The palm oil industry has a long supply chain, starting from independent farmers, private and government-owned plantations, harvesting labor, loading palm fruits onto trucks, transporting Fresh Fruit Bunches (FFB) from the plantation to the factory, transporting Crude Palm Oil (CPO) from the factory to bulking/refinery facilities, and the various supporting materials required in palm oil processing, among others. (c) Palm oil is a crop that thrives and develops well in tropical climates (Aryanti, 2008). In this current era, palm oil industry face many challenges. Previous research has explored many potential problems arisen, including sustainability (Asrol et al. 2023), supply chain performance (Hadiguna and Tjahyono, 2017), deforestation impact to environmental (Cineros et al. 2021), food vs energy trade-off (Brown et al. 2021), and products down-streaming strategy. Palm oil industry needs a comprehensive approach to solve multiple problems.

According to Sulisworo, (2009), performance measurement in a company or organization is a tool used to understand, manage, and improve the results achieved by the organization. Performance measurement in palm oil factories is crucial because many palm oil factories in Indonesia face financial difficulties and even bankruptcy due to their inability to detect early performance decline and take corrective measures. Bankruptcy in palm oil factories will significantly affect the performance of other supply chains (Hidayat et al., 2018).

There are many methods used for performance measurement in an industry or company. According to Alda et al., (2013), performance measurement systems in the industry can utilize integrated performance measurement methods combined with Analytic Hierarchy Process (AHP), Objective Matrix (OMAX), and Traffic Light System. The measurement parameters used are based on stakeholders in the company. For customers, the measured parameters include customer satisfaction, ease of transaction, and the number of customer complaints. For suppliers, the parameters include supplier satisfaction level, volume purchase increases, and adherence to contractual agreements. Employee performance parameters include employee complaints, work accidents, and work achievements. Parameters related to the community include the number of social activities conducted by the company, available job opportunities, and feedback from the community. Moreover, since palm oil industry face a huge challenge, it is not satisfied if it is solve using performance measurement approaches only. A comprehensive approach using a sustainable supply chain and performance measurement approach is required to solve and recommends solutions.

In palm oil factories, there are several parameters that can be used to assess the factory's performance, such as the quantity and quality of Fresh Fruit Bunches (FFB) received and processed, factory throughput, oil losses during processing, product quality, quantity of produced Crude Palm Oil (CPO), processing costs, emissions generated during processing, community empowerment activities, and more. According to Shirley Mo-Ching Yeung, (2015), the SCOR (Supply Chain Operations Reference) model can be used for evaluating the performance of an organization. We will employ the SCOR model approach in this research to measure the performance of palm oil factories. The attributes and metrics utilized in the SCOR model can be integrated with the measurement parameters in palm oil factories, making it easy to use and familiar to stakeholders in the palm oil industry in Indonesia. Furthermore, Palma-mendoza (2014) suggests that SCOR needs to integrated with the weighted technique to define the relative importance of each metrics in performance measurement.

With the vast potential of palm oil in Indonesia, there are many challenges that will be faced in the future, including competition with other producers and other vegetable oils. The era of Industry 4.0 and consumer awareness of sustainability are factors to consider. Given the current intense competition and the need for performance certainty and quality in the palm oil industry, monitoring and evaluating the sustainable palm oil industry's supply chain performance using the latest methods such as SCOR (Supply Chain Operation Reference) is necessary.

This research aims to evaluate supply chain sustainability performance of the palm oil industry in Indonesia. A SCOR framework adopting sustainability approaches will be conducted the supply chain sustainability evaluation. Supply chain metrics and indicators are defined based on the framework and enriched with field observations and expert discussion.

2. Literature Review

2.1. Supply Chain Operation Reference (SCOR version 14.0)

According to Arif, (2018), in the current era of free trade, competition no longer exists solely between individual companies but rather at the level of competition between supply chains. Therefore, a supply chain management approach is crucial for industries and businesses worldwide if they want to develop and sustain themselves. According to the Council of Logistic Management (CLM), supply chain management is a coordinated system consisting of organizations, human resources, activities, information, and other resources that work together to move products or services from suppliers to customers. According to Schroeder (2003), supply chain management is the planning, design, and control of the flow of information and goods throughout the supply chain, aimed at efficiently meeting customer requirements in the present and future.

Currently, SCOR 14.0 (Digital Standard) is being used (scor.ascm.org, 2022). Companies can adopt the SCOR DS model if they desire rapid and dramatic changes in their supply chain processes because SCOR 14.0 provides methodologies and tools for diagnostics and comparisons. SCOR DS is composed of seven primary management processes: (1) Orchestrate, (2) Plan, (3) Order, (4) Source, (5) Transform, (6) Fulfill, and (7) Return, as depicted in Figure 1.

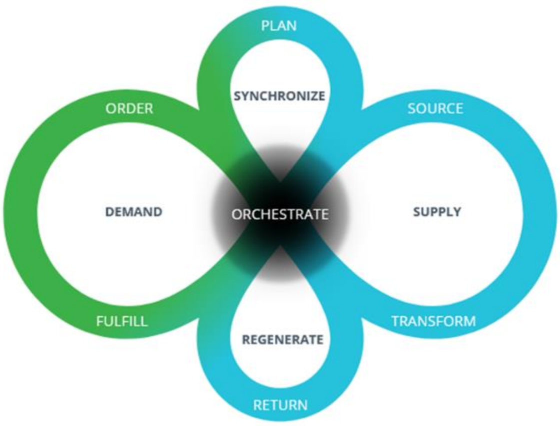

Fig.1: Primary process management in supply chain by SCOR 14

SCOR DS (scor.ascm.org, 2022) introduces Level 0 in the orchestrate process at the top of the hierarchy, which focuses on the essential activities needed to connect the external supply chain to suppliers, customers, and stakeholders. The Level 0 process represents the strategic level that informs and influences all levels below it. SCOR also identifies six Level 1 processes that represent the main activities of the supply chain: (1) Plan, (2) Order, (3) Source, (4) Transform, (5) Fulfill, and (6) Return. Furthermore, Level 2 represents the major process categories within Level 0 and Level 1, and Level 3 consists of the process elements. By using these process building blocks, the SCOR model can depict both simple and highly complex supply chains using common definitions understood across different industries. The model focuses on processes from Level 0 to Level 3. It does not provide a perspective on how an organization runs its business or adjusts its systems and information flows. However, Level 3 processes can be used to identify activities that can be performed and supported by the business system.

2.2. Supply chain performance measurement with sustainability using SCOR

According to (Bolstorff et al., 2007), performance measurement using the SCOR model focuses on the outcomes of supply chain execution. To understand and diagnose supply chain performance, three elements are involved: performance attributes, metrics, and process or practice maturity. Performance attributes are strategic characteristics of supply chain performance used to prioritize and align supply chain performance with business strategies. Metrics are discrete performance measures that exist at different hierarchical levels and are interconnected. Process maturity is a reference tool based on specific objectives and descriptions that can be used to evaluate how well the supply chain processes and practices incorporate and execute best practice process models and accepted work practices.

SCOR introduces three performance categories, eight performance attributes, and twenty strategic metrics, which can be seen in Table 1.

Table 1. Supply chain performance attribute and metrics for sustainable palm oil production

T1.4 TRANSFORM PRODUCT - Palm Oil Mill			
Categories	**Attribut**	**Level 1 Metrics**	**Measurement Data at the Palm Oil Mill**
Resilience	Reliability	RL.1.1 Perfect Order Fulfillment	Harvest value (harvest quality) of fresh fruit bunches sent to the mill
		RL.1.2 Perfect Supplier Order	Fresh fruit bunch (FFB) tonnage sent to the mill in accordance with the budget
		RL.2.4 Customer Order Perfect Condition	The quality of the CPO product (Crude Palm Oil) (Moisture, Impurities, and FFA).
	Responsiveness	RS.2.3 Transform Cycle Time	The processing capacity of FFB per hour is obtained by dividing the total tonnage of FFB processed by the total time required to complete the processing
		RS.2.5 Return Cycle Time	The time required to manage and complete the product return process from customers back to the manufacturer or supplier.
	Agility	AG.1.1 Supply Chain Agility	The company's ability to respond to additional processing time in the event of oversupply.
		AG.2.5 Return Supply Chain Agility	The company's ability to quickly and effectively manage the process of returning products or goods from customers back into the supply chain.
Economic	Cost	CO.1.2 Cost of Goods Sold (COGS)	Total factory cost divided by the total CPO product produced.
		CO.3.6 Order Fullfillment Cost	The total cost required for the procurement of fresh fruit bunches (FFB).
	Asset Management Effeciency	AM.2.4 Revenue	Oil Extraction Effectiveness
			Kernel Extraction Effectiveness
Sustainability	Environmental	EV.1.2 Energy Consumed	The total kilowatt-hours (kWh) of electricity used for processing palm oil.
		EV.1.3 Water Consumed	The amount of water used for processing palm oil.
		EV.1.4 GHG Emissions	GHG emissions resulting from the processing of palm oil.

2.3. General supply chain performance attribute at the palm oil mill

According to Wambeck et al., (2005), there are several parameters that can be monitored to measure the performance of palm oil factories, which are considered as best practices. These parameters include: FFB Processed, Processed TBS, Plant availability, Oil extraction efficiencies (OEE), Kernel losses, Kernel extraction rate (KER), Kernel extraction efficiencies (KEE). The detail of attributes is described as followed:

- FFB Processed: The amount of raw material in the form of fresh fruit bunches (FFB) processed in the factory, processed TBS is measured in tons. The weight of processed palm fruit is obtained by dividing the factory's weighing data by the number of containers (such as lorries/cages for horizontal sterilizers or digesters for vertical sterilizers) filled with TBS.
- Processed TBS refers to the total amount of ripe TBS processed in the factory. Plant availability: the ratio of the factory's operating hours to the total available hours. Mill throughput is the amount of TBS processed per unit of time (hours).
- Oil losses refer to the amount of crude palm oil (CPO) lost during the processing process.
- Oil extraction rate (OER) is the percentage of CPO produced relative to the processed TBS.

- Oil extraction efficiencies (OEE) is the ratio of OER to the total oil potential (OER + oil losses). Kernel losses refer to the amount of kernels lost during the TBS processing process.
- Kernel extraction rate (KER) is the percentage of palm kernels produced relative to the processed TBS.
- Kernel extraction efficiencies (KEE) is the ratio of KER to the total potential kernels (KER + kernel losses).

2.4. Analytical Hierarchy Process

Analytical hierarchy process (AHP) is proposed by Saaty (2008) as one of the techniques used for decision-making is the Analytical Hierarchy Process (AHP). AHP is developed by creating a hierarchical decision structure to reduce complexity and show the relationships between objectives/criteria and various possible alternative solutions. This allows AHP to incorporate elements of experience, subjective preferences, and intuition in a logical and structured manner through expert assessments.

AHP has been widely used as a tool for analysis to aid in decision-making and has been successfully applied in various fields such as evaluation, assessment, forecasting, employee selection, product concept evaluation, and more. The success of using the AHP method is determined by the respondents who are asked to make assessments. The minimum number of respondents is two, and the accuracy of the AHP results is highly dependent on the expertise of the respondents being surveyed. The main principles of AHP include decomposition, comparative judgment, synthesis of priorities, and legal consistency.

2.5. Related Research

There have been numerous previous studies related to the assessment of palm oil supply chain performance using the SCOR method. The discussions conducted in previous research include business processes of palm oil from sourcing, sortation, payment, processing. Metrics used in previous research include volume of CPO production, FFB quality, CPO quality, raw material supply cycle, duration of processing, work hours per day, maintenance cycle, safety stock, raw material cost, energy cost, payment system (Asrol, 2020). Several papers also specifically address green objectives in their research, such as minimizing water usage, reducing emissions handling, environmentally friendly plantation management, waste management, maximizing the use of renewable energy, and customer satisfaction related to CPO products from an environmental perspective (Rangga, 2020).

Previous research has explored supply chain performance of palm oil with any approach. Marimin and Safriyana (2018) evaluated palm oil supply chain using SCOR version 12 and provide added value analysis and supply chain improvement recommendations. Kusrini and Maswadi (2021) provide an integrated analysis of palm oil industry during covid-19 era. Wolf (2014) provide a comprehensive framework to analyze the effect of stakeholder performance to sustainable palm oil performance. Mareeh et al. (2022) analyze the supply chain profitability and sustainability using system dynamic approach.

There has been no research that addresses balanced performance across all SCOR attribute parameters, including sustainability, using secondary data from companies. Some studies specifically address sustainability aspects separately but still use primary data for weighting. The current research reviews all categories (resilience, economic, sustainability), attributes, and several metrics from secondary data of companies. However, there are difficulties faced, namely the limited sample size of secondary data from companies due to challenges in accessing such data in Indonesian companies. Therefore, the secondary company data we obtained was limited to a few companies in the East Kalimantan region.

3. Research Method

3.1. Research stages

Figure 2 illustrates the stages of the research. The stages are including problem identification and analysis in the palm oil supply chain, goal setting, performance measurement of the palm oil supply chain using integrated metrics with SCOR, performance measurement results, gap analysis, and strategy formulation. In the next section, the detail of the stages described.

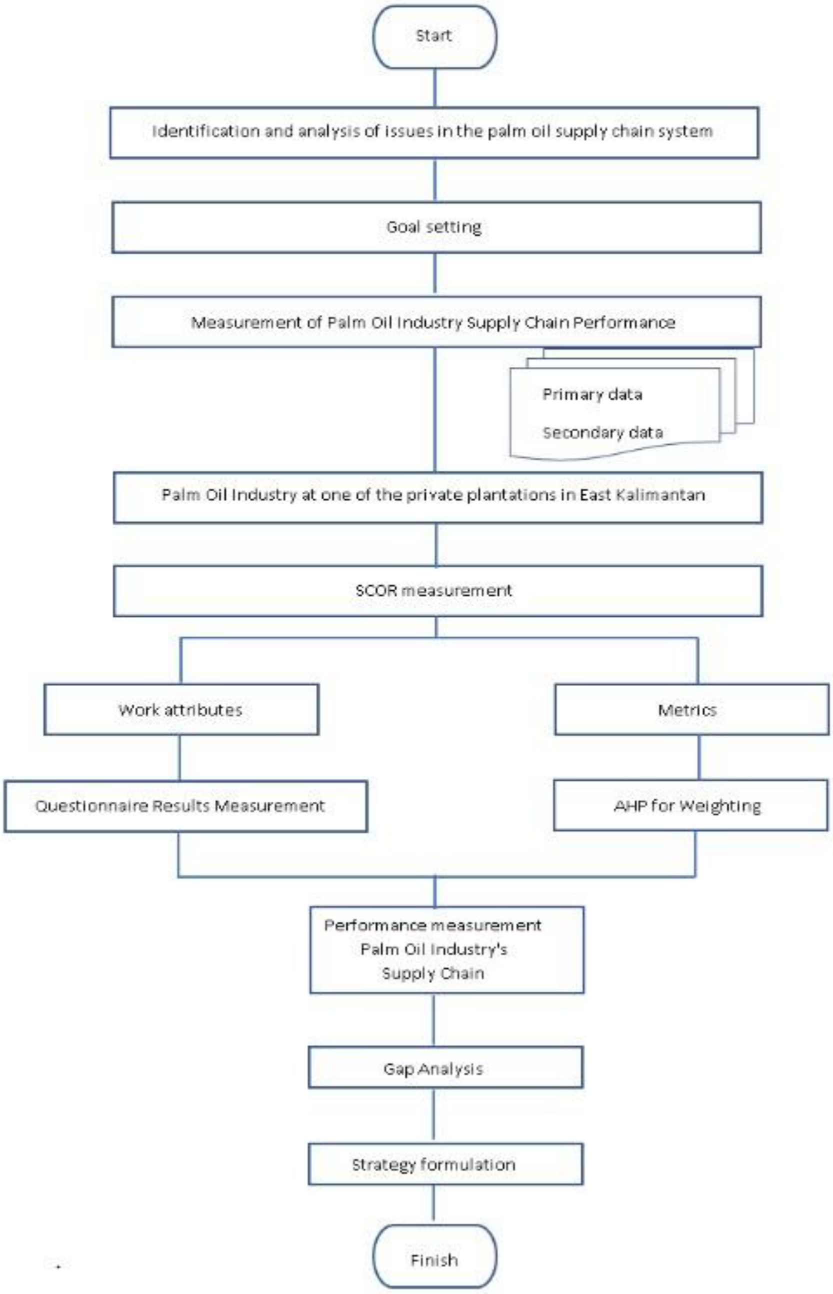

Fig.2: Research stages

3.2. Goal setting and supply chain sustainability metrics mapping

The mapping of the SCOR model has three main aspects of the system metrics: Resilience, which consists of three performance attributes (Reliability, Responsiveness, and Agility); Economic, which consists of three performance attributes (Cost, Profit, and Asset); and Sustainability, which consists of two performance attributes (Environment and Social). Environmental factors are crucial attributes for measurement to ensure the sustainability of the palm oil agribusiness in Indonesia. Level 1 metric measurements are performed for the following metrics: RL 1.1, RL 1.2, RS 2.3, AG 1.1, CO 1.2, AM 2.4, EV 1.2, EV 1.3, and EV 1.4. The specific level 1 metrics for performance measurement are stated at Table 1.

Further, the supply chain sustainability metrics are decomposed into AHP hierarchy to identify the relative importance of each metrics. The Hierarchy is depicted to Figure 3.

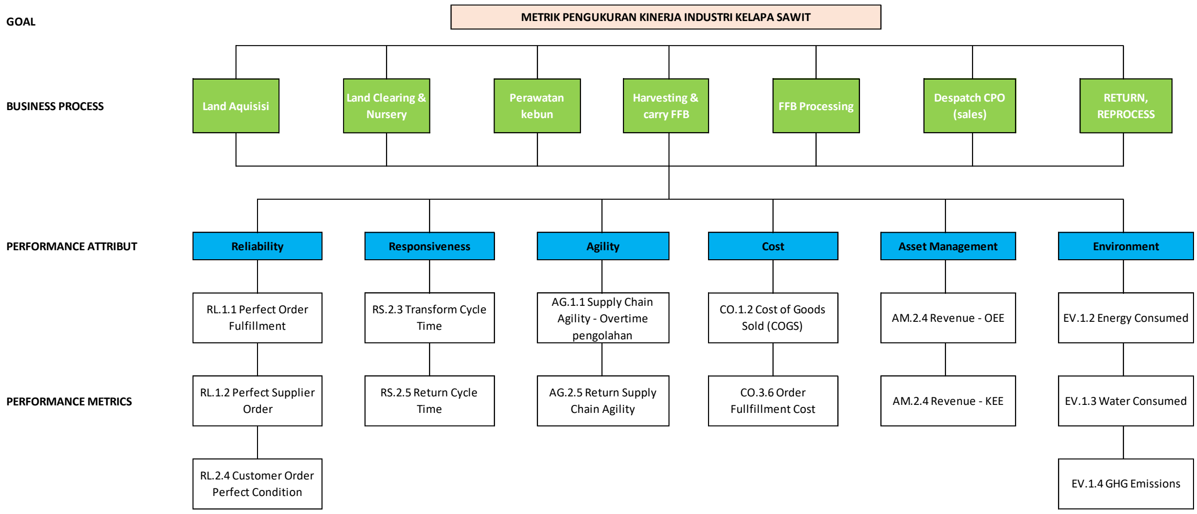

Fig.3: SCOR attributes and metrics mapping to AHP hierarchy

Supply chain attributes and metrics level of importance are analyzed using Analytical Hierarchy Process (AHP) to establish the significance of individual attributes. To ascertain these weightings, experts from various domains, including government officials, academics, and palm oil mill management, are engaged through the distribution of questionnaires. Subsequently, data is collected from multiple operational palm oil mills in East Kalimantan to perform measurements. These measurement outcomes enable the mills to be compared in terms of their performance and facilitate gap analysis to enhance the performance of mills that do not meet the established standards.

3.3. Data acquisition and collection

To enrich the analysis, this research requires secondary and primary data. Secondary data was collected from a palm oil company in East Kalimantan during the time period of 2022. Subsequently, primary data was gathered through questionnaires distributed to experts who have a deep understanding of the palm oil industry, including individuals from the government, companies, and academia. The expert background is described in Table 2.

Table 2. Expert background

Expert background	Number of experts
The General Manager of the palm plantation is responsible for all operational aspects of the plantation, including the palm oil mill. They have more than 15 years of work experience.	2 persons
The Training Centre Manager in the palm oil plantation company is responsible for conducting refresh training and upgrading the skills of plantation workers at all levels.	1 person
An instructor in industrial engineering at one of the state universities in Central Sulawesi, with expertise in, among other things, supply chain management.	1 person
Environmental supervisor from the government agency, the Department of Environment, in East Kalimantan.	1 person

Experts were selected through purposive sampling. The data was collected using in-depth interview and questionnaire distribution. The questionnaire was distributed through online tool to each expert, and then the data was averaged using the geometric mean and further processed using the Superdecisions software. These data sources were then processed to obtain an overview of the performance of the selected palm oil mills, which would be further evaluated for performance enhancement.

4. Result and Discussion

4.1. Palm oil supply chain

The palm oil sector comprises a supply network that originates with palm fruit producers, involves the conveyance of fresh fruit bunches (TBS), palm oil processing facilities, transportation of crude palm oil (CPO), CPO processing facilities, and finally extends to various industrial consumers and households. Figure 4 illustrates the supply chain of palm oil mills. At present, it remains uncertain whether the performance of palm oil mills aligns with the criteria for excellence as assessed by the SCOR model performance evaluation.

The SCOR model efficiently charts the palm oil mill hierarchy by assessing mill performance through various attributes and metrics. This empowers companies to perform competitive analyses, pinpoint opportunities for business growth, establish frameworks for transformation, synchronize strategies, material, workflow, and information flow, and concentrate on constructive alterations aimed at enhancing financial profitability. Implementing these changes leads to the attainment of sustainable competitive advantages.

Fig.4: Palm oil supply chain

4.2. SCOR attributes and metrics weighting using AHP

In this research, questionnaires were distributed to experts in the field of oil palm operations, educators, and government agencies. The data was processed using the Analytic Hierarchy Process (AHP) method with the SuperDecision software. In the supply chain of the oil palm industry, several business processes were identified, including land acquisition, land clearing, oil palm seedling and planting, plant maintenance, harvesting and delivery to the factory, palm oil processing, CPO sales, and product return processes. Table 3 illustrates how the data was obtained from the expert.

Table 3. Expert assessment from the questionnaire using the importance level of the AHP scale.

	R1	R2	R3	R4	R5	GeoMean
A.1.1. Land Acquisition vs A.2.1. Land Clearing/Nursery	2.0	0.2	0.3	3.0	9	1.3
A.1.1. Land Acquisition vs A.3.1. Plant Care	2.0	0.2	7.0	0.3	9	1.5
A.1.1. Land Acquisition vs A.4.1. FFB Harvesting/Carry	1.0	0.1	2.0	0.3	9	1.0
A.1.1. Land Acquisition vs A.5.1. FFB Processing	1.0	0.1	3.0	0.2	9	0.9
A.1.1. Land Acquisition vs A.6.1. Despatch CPO/sales	1.0	0.1	0.1	0.1	9	0.5
A.1.1. Land Acquisition vs A.7.1. CPO return/reprocess	1.0	0.3	1.0	0.2	9	0.9

Figure 5 shows the weighting of the business processes in the oil palm industry supply chain. CPO Dispatch has the highest weight at 28.37%, followed by FFB processing at 23.94%, while plant care has the lowest weight. The inconsistency value is 0.048 which means that experts have provided consistency assessment.

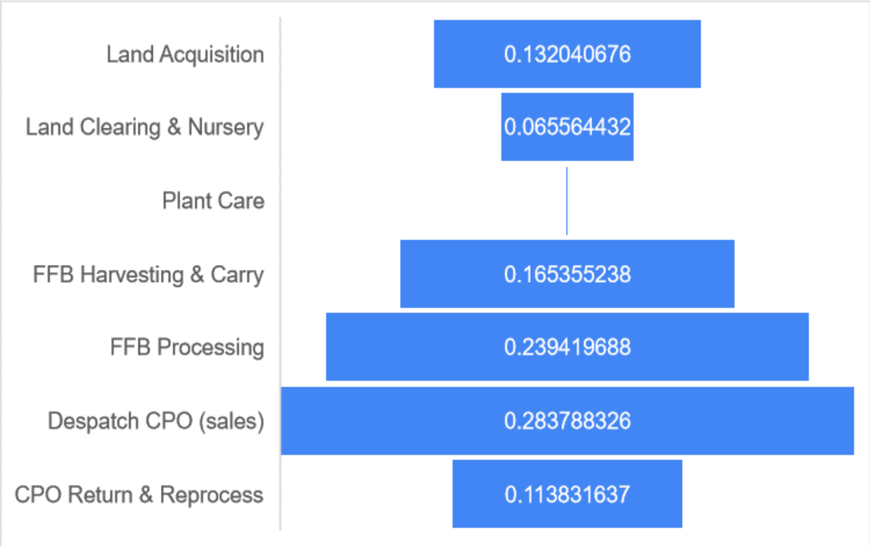

Fig.5: Supply chain business process weight by group of experts

Furthermore, the elements within the SCOR attributes, namely reliability, responsiveness, agility, cost, asset management, and environment, were weighted to obtain results as seen in Figure 5. In sequence, the highest to lowest weights obtained were environment, responsiveness, reliability, agility, cost, and asset management.

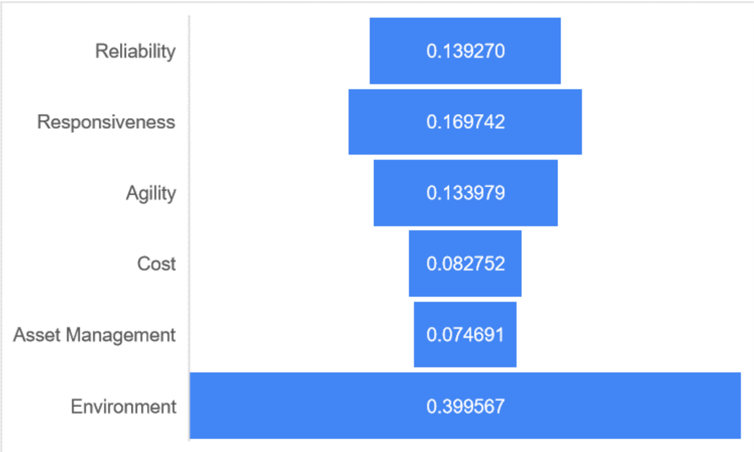

Fig.6: Supply chain attributes weight by group of experts

Finally, the supply chain metrics weight by group of experts are provided in Table 4. The identification of reference performance metrics from the SCOR model that would be used to evaluate the performance of the selected palm oil mills as the research object has been conducted. In the next section, the supply chain performance of palm oil related to sustainability process are described.

Table 4 Supply chain performance metrics weight

RELIABILITY	Weight
RL.1.1 Perfect Order Fulfillment	0.2859
RL.1.2 Perfect Supplier Order	0.3016
RL.2.4 Customer Order Perfect Condition	0.4125
Inconsistency	0.0463

RESPONSIVENESS	Weight
RS.2.3 Transform Cycle Time	0.7662
RS.2.5 Return Cycle Time	0.2338
Inconsistency	0.0000

AGILITY	Weight
AG.1.1 Supply Chain Agility - Overtime pengolahan	0.7662
AG.2.5 Return Supply Chain Agility	0.2338
Inconsistency	0.0000

COST	Weight
CO.1.2 Cost of Goods Sold (COGS)	0.5994
CO.3.6 Order Fullfillment Cost	0.4006
Inconsistency	0.0000

ASSET MANAGEMENT	Weight
AM.2.4 Revenue - KEE	0.3333
AM.2.4 Revenue - OEE	0.6667
Inconsistency	0.0000

ENVIRONMENT	Weight
EV.1.2 Energy Consumed	0.3402
EV.1.3 Water Consumed	0.4752
EV.1.4 GHG Emissions	0.1846
Inconsistency	0.0008

4.3. Supply chain performance analysis

The identification of reference performance metrics from the SCOR model that would be used to evaluate the performance of the selected palm oil mills as the research object has been conducted. Table 1 has displayed attributes and metrics used in the performance measurement.

Rather than utilizing the data directly for each indicator, we apply normalization to standardize them, ensuring a consistent scale for simpler comparation across all metrics. Let vi represent the data value of indicator i, min(s) and max(s) denote the minimum and maximum values for this indicator, respectively. The normalized value N(vi) is then computed according to the following method. If the target value T (vi) corresponds to a maximum:

$$N(v_i) = \left\{ \begin{array}{l} \dfrac{v_i - \min(s)}{T(v_i) - \min(s)} \text{ for } v_i \leq T(v_i), \text{ and} \\ 1 \text{ for } v_i \geq T(v_i) \end{array} \right\}$$

If *T (vi)* corresponds to a minimum:

$$N(v_i) = \left\{ \begin{array}{l} 1 \text{ for } v_i \leq T(v_i), \text{ and} \\ \dfrac{\max(s) - v_i}{\max(s) - T(v_i)} \text{ for } v_i \geq T(v_i) \end{array} \right\}$$

If *T (vi)* corresponds to an interval [min*(Tv)*, max*(Tv)*]:

$$N(v_i) = \begin{cases} \dfrac{v_i - \min(s)}{\min T(v_i) - \min(s)} \text{ for } v_i \leq \min T(v_i), \\ 1 \text{ for } v_i \in [\min T(v_i), \max T(v_i)], \text{ and} \\ \dfrac{\max(s) - v_i}{\max(s) - \max T(v_i)} \text{ for} v_i \geq \max T(v_i) \end{cases}$$

Secondary data were gathered and subjected to analysis using a normalization formula. Additionally, benchmarks were supplied, sourced from either the target mill or relevant industries that exhibit the highest performance for each specific metric. Referring to Table 1, there are a total of 16 metrics to be analyzed for assessing the current performance of supply chain sustainability. The example of supply chain sustainability performance for perfect order fulfillment, perfect supplier order and customer perfect order conditions are provided at Table 5-7. The total performance of all palm oil mill (POM) is depicted at Figure 7.

Tabel 5. RL.1.1 Perfect Order Fulfillment

POM	Harvest Quality						
	Min (v)	Max (v)	Min (s)	Max (s)	Target (Tv)	Data (v)	N (v)
POM A	73.45729	86.74415	0	1	90	73.46	0.816
POM B	73.45729	86.74415	0	1	90	80.81	0.898
POM C	73.45729	86.74415	0	1	90	82.28	0.914
POM D	73.45729	86.74415	0	1	90	74.97	0.833
POM E	73.45729	86.74415	0	1	90	86.74	0.964
POM F	73.45729	86.74415	0	1	90	84.09	0.934
POM G	73.45729	86.74415	0	1	90	85.27	0.947
POM H	73.45729	86.74415	0	1	90	80.20	0.891

Tabel 6. RL.1.2 Perfect Supplier Order

POM	FFB Received						
	Min (v)	Max (v)	Min (s)	Max (s)	Target (Tv)	Data (v)	N (v)
POM A	146,929	365,237	0	365,237	365,237	282,646	0.774
POM B	146,929	365,237	0	365,237	365,237	227,966	0.624
POM C	146,929	365,237	0	365,237	365,237	306,816	0.840
POM D	146,929	365,237	0	365,237	365,237	254,387	0.696
POM E	146,929	365,237	0	365,237	365,237	365,237	1.000
POM F	146,929	365,237	0	365,237	365,237	262,641	0.719
POM G	146,929	365,237	0	182,619	182,619	146,929	0.805
POM H	146,929	365,237	0	365,237	365,237	276,152	0.756

Tabel 7. RL.2.4 Customer Order Perfect Condition

POM	FFA						
	Min (v)	Max (v)	Min (s)	Max (s)	Target (Tv)	Data (v)	N (v)
POM A	3.24	4.53	0	100.00	2	3.37	0.986
POM B	3.24	4.53	0	100.00	2	3.67	0.983
POM C	3.24	4.53	0	100.00	2	3.84	0.981
POM D	3.24	4.53	0	100.00	2	3.24	0.987
POM E	3.24	4.53	0	100.00	2	3.84	0.981
POM F	3.24	4.53	0	100.00	2	4.16	0.978
POM G	3.24	4.53	0	100.00	2	4.53	0.974
POM H	3.24	4.53	0	100.00	2	3.68	0.983

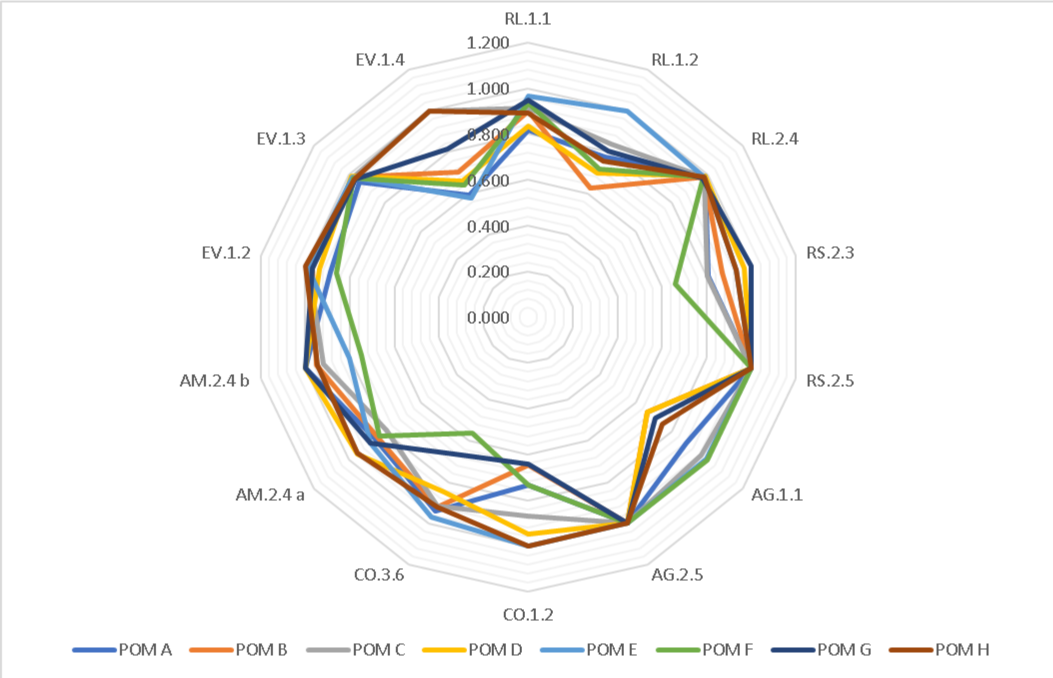

Fig.7: Supply chain sustainability metric's performance in each POM

Further the normalized secondary data in previous stages are combined with the AHP weight which have been provided by the expert assessment. The total performance of the POM using data combination of primary and secondary data is provided at Table 8.

Table 8 Palm oil supply chain performance

Level 1 Metrics	Weight	POM A	POM B	POM C	POM D	POM E	POM F	POM G	POM H
RL.1.1 Perfect Order Fulfillment	0.040	0.032	0.036	0.036	0.033	0.038	0.037	0.038	0.035
RL.1.2 Perfect Supplier Order	0.042	0.033	0.026	0.035	0.029	0.042	0.030	0.034	0.032
RL.2.4 Customer Order Perfect Condition	0.057	0.057	0.056	0.056	0.057	0.056	0.056	0.056	0.056
RS.2.3 Transform Cycle Time	0.130	0.105	0.113	0.104	0.126	0.121	0.086	0.130	0.121
RS.2.5 Return Cycle Time	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
AG.1.1 Supply Chain Agility	0.103	0.091	0.068	0.099	0.068	0.102	0.103	0.073	0.077
AG.2.5 Return Supply Chain Agility	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031	0.031
CO.1.2 Cost of Goods Sold (COGS)	0.050	0.036	0.032	0.043	0.047	0.050	0.036	0.032	0.050
CO.3.6 Order Fullfillment Cost	0.033	0.031	0.030	0.030	0.028	0.032	0.019	0.022	0.030
AM.2.4 Revenue	0.050	0.043	0.042	0.039	0.048	0.044	0.041	0.044	0.047
	0.025	0.025	0.024	0.023	0.025	0.020	0.019	0.025	0.024
EV.1.2 Energy Consumed	0.136	0.121	0.132	0.134	0.127	0.135	0.117	0.131	0.136
EV.1.3 Water Consumed	0.190	0.179	0.187	0.186	0.188	0.187	0.185	0.183	0.184
EV.1.4 GHG Emissions	0.074	0.044	0.052	0.074	0.049	0.042	0.047	0.060	0.074
TOTAL SCOR	**1.000**	**0.867**	**0.868**	**0.932**	**0.896**	**0.940**	**0.847**	**0.899**	**0.937**

The top three performance, in order, are achieved by POMs E, H, and C, while the lowest performance is achieved by POM F. Furthermore, to provide an overview of some differences in POMs in terms of the factories and technologies used, please refer to the Table 9. Some advantages of POMs E, H, and C include having high factory utilization, implementing the latest technologies in the factory such as methane capture (C, H), Decanter D3Pro (E, H), 3 phase dry kernel separation (E, H), and full automation (H). From the supplier similarity perspective, the eight palm oil mills are divided into two main clusters. POM A, B, C, D are mills that receive Fresh Fruit Bunches (TBS) only from core and plasma supplier farms, which are managed directly by the company itself. On the other hand, POM E, F, G, H are mills that receive TBS not only from the company's own farms but also from community-owned farms. The management of community-owned farms is independently handled by the owners of the farms. All mills also send their Crude Palm Oil (CPO) production to the refineries of the Sinar Mas, Asian Agri, and Wilmar groups.

Table 9 Technology comparation of POMs

	POM A	POM B	POM C	POM D	POM E	POM F	POM G	POM H
Vertical sterilizer	no	no	no	no	no	no	no	no
Horizontal sterilizer	yes	yes	yes	yes	yes	yes	yes	yes
Using CST	yes	yes	yes	no	no	yes	no	no
Using Decanter D3Pro	no	no	no	yes	yes	no	yes	yes
Using 3 phase dry kernel separation	no	no	no	yes	yes	no	no	yes
Using 2 phase wet kernel separation	no	no	no	yes	yes	no	no	yes
Semi automation	no	no	no	yes	yes	no	yes	yes
Full Automation	no	no	no	no	no	no	no	yes
Using methane capture	no	no	yes	no	no	no	no	yes

To improve and sustain the performance of the oil palm factory supply chain, it is highly recommended to undertake the following actions: Optimizing the production process, including considering the use of the latest technology. Enhancing production efficiency through modernization, process automation, utilizing state-of-the-art technology for oil and kernel extraction efficiency, and reducing waste and GHG emissions (methane capture). Managing FFB (Fresh Fruit Bunch) stocks, planning the supply of TBS to the POM (Palm Oil Mill) efficiently, and devising strategies to purchase TBS from farmers with attractive pricing schemes and incentives. Quality management, ensuring that the received TBS (Fresh Fruit Bunch) has the best quality.

Inspection can be conducted through a well-designed TBS grading mechanism and can consider the use of AI (Artificial Intelligence) grading using camera technology and imaging for accurate and fast grading results. Control of factory parameters, including the quality of CPO (Crude Palm Oil) and losses during processing, and the use of state-of-the-art monitoring tools such as FOSS NIR for real-time quality and loss control. Efficient management of energy and water resources.

The use of capacitor banks in the factory's electrical system to improve power quality, the use of LED lights in residential areas and the factory, the use of AC, inverter refrigerators, efficient water usage in TBS processing, employing principles of re-use and recycling to reduce water consumption, such as using condensate from boiling as a substitute for water dilution, and utilizing a waterless dilution Decanter. Monitoring and evaluation. From the comparison of several papers on sustainable palm oil, the aspects of greenhouse gas emissions handling and management of palm oil waste have the highest weight in influencing palm oil sustainability. Companies that have obtained ISPO (Indonesian Sustainability of Palm Oil) and RSPO (Roundtable on Sustainable Palm Oil) certifications also score high in terms of sustainability (Rangga, 2020). According to (Arif, 2018), Managing PKS waste is a priority activity for companies to ensure the productivity and sustainability of PKS. Conduct periodic assessments of supply chain performance using the SCOR method to evaluate and improve underperforming aspects.

5. Conclusion and Recommendations

This research has successfully analyzed the performance of the oil palm supply chain by combining it with a sustainability approach. The SCOR and AHP frameworks have proven effective in measuring supply chain performance. The analysis results also indicate that 16 metrics have been implemented for measuring palm oil supply chain performance. It was found that there are 3 palm oil mills with the highest scores. However, there are several metrics that need to improve their performance. This study has formulated performance improvement strategies, including optimizing the production process, considering the use of the latest technology, managing Fresh Fruit Bunch (FFB) stocks, quality management, efficient management of energy and water resources, and monitoring and evaluation.

The theoretical implications of this research are significant. It can make a valuable contribution to the body of knowledge in supply chain management and the palm oil industry. This can lead to a deeper understanding of the factors influencing supply chain performance within this industry. Moreover, it has the potential to generate specific theories or models applicable not only to the palm oil industry but also to industries with similar characteristics. Additionally, this study can aid in refining or adapting the SCOR method for more effective implementation within the context of the palm oil industry. The practical implications of this research can assist companies in the palm oil industry to optimize their supply chains. This may involve enhancing operational efficiency, reducing costs, and increasing profits. By comprehending the factors influencing supply chain performance, businesses can pinpoint areas where their operations can be enhanced or modified to achieve better outcomes. The research makes key theoretical and practical contributions regarding sustainable supply chain management in the strategically vital palm oil sector. The integrated SCOR-AHP framework enabled a robust quantitative assessment of mill performance across crucial sustainability dimensions. The methodology and empirically based recommendations can guide managers and policymakers in monitoring progress and targeting interventions to enhance sustainability. Limitations of the study include its localized scope and reliance on secondary mill data. Future research should expand the analytical approach to incorporate additional metrics, larger samples, and primary observational data. Longitudinal assessments could also evaluate sustainability improvements over time. Overall, the findings highlight the imperative of proactive supply chain management strategies to elevate triple bottom line performance for Indonesia's palm oil industry amid pressing environmental challenges.

For future research, there is an opportunity to further develop this study by developing a dashboard for enhancing supply chain performance.

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