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Performance Measurement of Green Manufacturing in the Refined Sugar Industry Using the Green Supply Chain Operation Reference Approach at PT. ABC

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ABSTRACT

The manufacturing industry, including the refined sugar industry, faces challenges in minimizing environmental impact and enhancing operational sustainability. The implementation of the green manufacturing concept is essential to achieving these goals. This study aims to evaluate the green manufacturing performance of PT. ABC, focusing on environmental, economic, and social aspects. The research methodology employed is a qualitative and quantitative descriptive analysis using relevant frameworks and metrics based on the Green SCOR. The findings indicate that PT. ABC has implemented several green manufacturing practices; however, there are still areas that need improvement, such as high energy consumption and a high defect rate. This study provides recommendations to enhance green manufacturing performance at PT. ABC, including optimizing energy use, reducing waste, and improving production process efficiency. The results of this study are expected to serve as a reference for PT. ABC in developing strategies and improvement plans to achieve better operational and environmental sustainability.

INTRODUCTION

The manufacturing industry plays a crucial role in a country's economic growth, as this sector not only creates employment opportunities but also contributes significantly to national income and exports [1]. However, the rapid and large-scale expansion of the manufacturing industry often has adverse environmental impacts. These impacts may include air pollution caused by factory emissions, water contamination due to improperly treated liquid waste, and unsustainable resource utilization, such as deforestation and excessive exploitation of natural raw materials [2]. The adoption of green manufacturing practices has become increasingly urgent to address these environmental challenges and mitigate their negative effects [3].

Green manufacturing is a concept that encompasses a systematic approach to reducing the environmental impact of production processes [4]. This approach involves more efficient resource utilization, reduction of emissions and waste, and improvement of energy efficiency [5]. In the context of the refined sugar industry, the implementation of green manufacturing is not only essential for complying with environmental regulations but also plays a crucial role in enhancing operational efficiency and industrial competitiveness in the global market [6].

Sugar is a strategic commodity for Indonesian society. As the primary sweetener, its use has not been entirely replaced by alternative sweetening agents [7]. Generally, sugar consumption is categorized into two types: sugar for direct consumption and sugar for industrial use. Sugar for direct consumption is commonly known as White Crystal Sugar (WCS), while sugar used for industrial purposes is referred to as refined sugar [8].

The Supply Chain Operations Reference (SCOR) model is a tool used to map supply chain activities within a company [9], [10]. SCOR serves as a framework for understanding, measuring, and improving supply chain performance and is widely utilized by leading companies worldwide, including several companies in Indonesia [11]. The SCOR model encompasses key processes such as planning (Plan), sourcing (Source), manufacturing (Make), delivery (Deliver), and return management (Return). SCOR was developed by the Supply Chain Council (SCC) and has evolved from version 5.0 to version 12.0 [12].

The Green Supply Chain Operations Reference (Green SCOR) is an enhanced version of the SCOR model that integrates environmental considerations into each stage of supply chain management [13]. The Green SCOR method is expected to provide benefits for both companies and the environment. It categorizes the supply chain into six key processes: Plan, Source, Make, Deliver, Return, and Enable, facilitating a more comprehensive supply chain analysis. In addition to these six fundamental components, Green SCOR also incorporates the same performance attributes as the SCOR model, including reliability, responsiveness, agility, cost, and asset management [14].

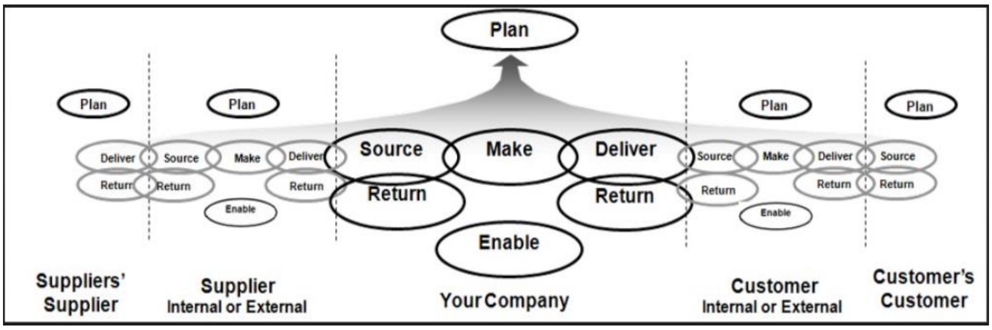

Figure 1. SCOR Model 11.0

The SCOR model also defines performance attributes and metrics for supply chain measurement. Performance attributes refer to supply chain criteria that enable analysis and evaluation of supply chain performance [15]. The metrics used in SCOR performance measurement are structured into three levels (Level 1–3) and are modeled using a hierarchical and structured analytical approach [16].

Refined sugar is a pure sugar with a sucrose content of 98%, processed from raw sugar as the main raw material and undergoing decolorization purification stages to achieve a color of <45 Icumsa and a color range of 45-80 Icumsa. As a result, refined sugar is primarily used as a sweetener in the food, beverage, and pharmaceutical industries.

The implementation of green manufacturing is crucial for industrial players, including the refined sugar industry, as it is one of the sectors with significant environmental impacts, ranging from water and energy usage to waste management [17]. This company has generally adopted the concept of green manufacturing, but in reality, it faces various challenges, such as the high level of defective products. While defective products can be reprocessed, this leads to increased consumption of energy and water resources, which contradicts the goals of green manufacturing to minimize resource and energy use as well as the environmental impact of company operations. Furthermore, the energy used is non-renewable [18].

Performance measurement can help identify production process activities that are optimized and those that are not [19]. By understanding the performance of each green manufacturing activity, the company can develop more effective strategies and improvement plans to drive enhanced operational and environmental sustainability in the refined sugar industry at PT ABC.

Snorm De Boer is a formula used for normalization. Normalization is necessary in research because each indicator may have different parameters with varying weights. Therefore, it is essential to standardize or equalize the parameters through normalization [20].

The Snorm De Boer normalization can be performed using the following equation:

The Large is Better Snorm Category (score) = $(SI - Smin)\ Smax - Smin\ x\ 100$ (1)

The Small is Better Snorm Category (score) = $(Smax - SI)\ Smax - Smin\ x100$ (2)

Explanation:

SI = Actual indicator value that can be achieved

Smax = Best performance value achieved

Smin = Worst performance value achieved

In this normalization, each performance indicator will be converted into an interval ranging from 0 to 100. A value of zero is considered the worst, while a value of one hundred is considered the best. The following is the performance rating interval:

Table 1. Performance Rating Interval

Monitoring System	Performance Indicator
< 40	Poor
40 – 50	Marginal
50 – 70	Average
70 – 90	Good
> 90	Excellent

RESEARCH METHODS

The focus of this research is to determine the performance level of green manufacturing through the Green SCOR approach, as this model is suitable for managing the environmental impacts of green manufacturing implementation. The research consists of several stages. The first stage is conducting a literature review related to the Green SCOR method, and the second stage is a field study to collect data. The field study is conducted at a refined sugar industry company. The collected data includes: the company's manufacturing processes, the results of the literature review, and field study, which will be used to design Key Performance Indicators (KPIs), manufacturing process data based on KPI requirements, and the targets for each KPI.

The design of KPIs for measuring Green Manufacturing in the refined sugar industry is done in several steps. First, the supply chain model of the refined sugar industry is identified. Second, the supply chain is mapped using the Green SCOR model. This modeling is more objective in correlating production activities with environmental aspects through the performance attributes of Green SCOR. In the Green SCOR model, the company's business processes are divided into six processes: Plan (P), Source (S), Make (M), Deliver (D), Return (R), and Enable (E). Each of these processes has sub-processes that must be implemented to reduce potential impacts on the surrounding environment. Plan is the initial stage in the entire supply chain. Source focuses on the procurement of raw materials. Make involves the product manufacturing process, considering its environmental effects. After KPIs are determined, the next step is to calculate the actual value of each KPI and normalize it to standardize the parameters, allowing the overall performance score to be calculated. To facilitate the identification of KPIs, a Traffic Light System is used, which represents the KPI values with colors.

RESULTS AND DISCUSSION

PT ABC is the first and only refined sugar producer operating in the Eastern Indonesia region. Located in the Parangloe Indah Industrial Warehouse area, Makassar City, South Sulawesi, ABC is capable of producing 1,800 tons of refined sugar per day. Refined sugar is pure sugar with a sucrose content of 98%, used as a sweetener in the food, beverage, and pharmaceutical industries.

A. Refined Sugar Process Flow

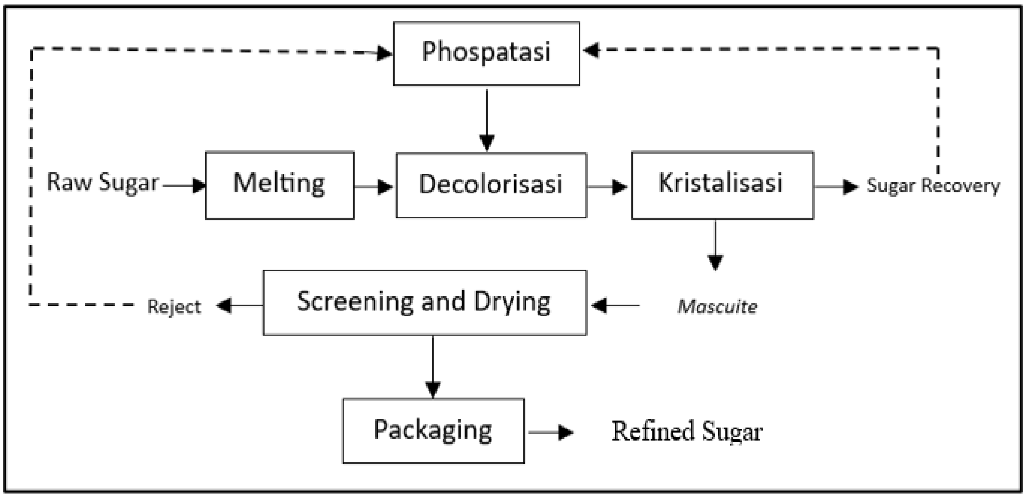

Figure 2. Refined Sugar Process Flow

B. Key Performance Indicator (KPI)

The green manufacturing performance indicators are derived from the identification of the company's manufacturing process activities and are structured based on the Green SCOR model framework, which consists of Plan, Source, and Make, further divided according to performance attributes such as reliability, responsiveness, and flexibility. These indicators are then validated by company experts, as shown in Table 1.

Table 1. Validated KPIs Based on the Green SCOR Model Framework

Process	Attribute	Key Performance Indicator	Code KPI
Plan	Reliability	Energy used	P1
	Reliability	Water used	P2
	Reliability	% production accuracy	P3
(Planning for the improvement of resource and material usage efficiency)	Reliability	Melting Volume accuracy	P4
Source	Reliability	% of chemical used	S1
	Reliability	% orders received damage free	S2
(Procurement and use of environmentally friendly materials)	Reliability	% of hazardous material in inventory	S3

Process	Attribute	Key Performance Indicator	Code KPI
Make (Efficiency and productivity of the production process as well as waste management)	Reliability	Yield / Material use efficiency	M1
	Reliability	% Defect	M2
	Reliability	% of recycleable / reusable materials	M3
	Reliability	% of recycleable waste from the total waste	M4
	Reliability	% of not feasible package	M5
	Flexibility	% of upside make flexibility	M6
	Flexibility	Time to reschedule order changhes	M7

C. Designing Key Performance Indicator Metrics

This design is used to determine the actual value of the Key Performance Indicator.

Table 2. Draft KPI Measures

Key Performance Indikator	Code KPI	Satuan	Formula	Characteristics
Energy used	P1	Kwh/ton	$\frac{\text{Total Energy Used}}{\text{Total product produced}}$	Smaller Better
Water used	P2	m3/ton	$\frac{\text{Total water used}}{\text{Total product produced}}$	Smaller Better
% production accuracy	P3	%	$\frac{\text{Production planning amount}}{\text{Production yield}} x100$	Higger Better
Melting Volume accuracy	P4	%	$\frac{\text{Rauliquor planning amount}}{\text{Rawliquor yeild}} x\ 100$	Higger Better
% of chemical used	S1	%	Total Chemical Usage	Smaller Better
% orders received damage free	S2	%	$\frac{\text{Rawliquor planning amount}}{\text{Rawliquor yeild}}$	Smaller Better
% of hazardous material in inventory	S3	%	Total Hazardous Material Usage	Smaller Better
Yield / Material use efficiency	M1	%	$\frac{\text{Raw material amount}}{\text{Total product produced}}$	Higger Better
% Defect	M2	%	$\frac{\text{Defective material}}{\text{Total material produced}}$	Smaller Better
% of recycleable / reusable materials	M3	%	$\frac{\text{Recycled Material}}{\text{Total material produced}}$	Higger Better

 http://dx.doi.org/10.30656/jisem.v3i2.38

Key Performance Indikator	Code KPI	Satuan	Formula	Characteristics
% of recycleable waste from the total waste	M4	%	Percentage of Waste Recycled	Smaller Better
% of not feasible package	M5	%	$\frac{\text{Number of failed packaging}}{\text{Total product packaging}}$	Smaller Better
% of upside make flexibility	M6	%	$\frac{\text{Number of requests fulfilled}}{\text{Total increase in demand}}$	Higger Better
Time to reschedule order changhes	M7	Jam	$\frac{\text{Time required}}{\text{Maxsimum time}}$	Smaller Better

C. Snorm De Boer Normalization

After obtaining the actual values for each performance indicator, a Scoring System is applied to standardize the performance measurement parameters. Table 3 presents the data from the calculation of the actual values and the scoring system.

Tabel 3. KPI Normalization Results.

Key Performance Indicator (KPI)	Actual (Si)	Normalization SNORM
% Energy used	87,4	36
% Water used	11,6	68
% of chemical used	0,9	75
% production accuracy	94,7	82
Melting accuracy	97,3	96
% orders received damage free	0,91	90,9
% of hazardous material in inventory	0	100
% of not feasible package	0,013	87,00
Yield / Material use efficiency	92,2	76,25
% Defect	35,37	29,26
% of recycleable / reusable materials	60	60
% of recycleable waste from the total waste	33,3	33,3
% of upside make flexibility	100	100
Time to reschedule order changhes	16	80
Nilai Keseluruhan Kinerja		**73**

D. *Traffic Light System*

To facilitate the identification of KPIs that require improvement, the Traffic Light System will be used in this discussion. A red indicator is assigned if the Snorm value shows a performance score ≤ 50, indicating an unsatisfactory or poor score. A yellow indicator is given if the Snorm value shows a performance score between 50 and 80, indicating a marginal score. A green indicator is given if the Snorm value shows a performance score ≥ 80, indicating a satisfactory or good score. Table 4 presents the performance measurement results based on the Traffic Light System classification..

Table 4. Traffic Light System Results

Key Performance Indicator (KPI)	Actual (Si)	Normalization SNORM
Energy used	87,4	36
Water used	11,6	68
% production accuracy	94,7	82
Melting accuracy	97,3	96
% of chemical used	0,9	75
% orders received damage free	0,91	90,9
% of hazardous material in inventory	0	100
Yield / Material use efficiency	92,2	76,25
% Defect	35,37	29,26
% of recycleable / reusable materials	83,3	66,6
% of recycleable waste from the total waste	33,3	33,3
% of not feasible package	0,013	87,00
% of upside make flexibility	100	100
Time to reschedule order changhes	16	80

DISCUSSION

Based on the calculation of the company's performance using Green SCOR, the final score for the Green Manufacturing performance calculation is 73. This score indicates that the performance falls within the 'good' category.

In Table 3, it is shown that out of 14 KPIs, 7 KPIs are categorized as green, indicating satisfactory performance. 4 KPIs are categorized as yellow, meaning their performance is average; these KPIs must be maintained to prevent them from turning red and improved to achieve green status. Additionally, 3 KPIs are categorized as red, indicating unsatisfactory performance, and therefore require intervention and improvement.

Indicators that fall into the red category, or need improvement, will be given recommendations based on interviews with experts. Table 5 presents the analysis results and proposed improvements that the company can implement to enhance the performance of the indicators in the red category.

Table 5. Proposed Improvements

KPI	Penyebab	Rekomendasi Perbaikan
% Defect	Contamination with foreign objects and suboptimal performance of the drying machine, which causes the sugar to become lumpy (defective).	Implementing strict inspections on the received materials, including testing for impurities and foreign objects. Optimizing the use of the drying and screening machines or improving the performance of the

KPI	Penyebab	Rekomendasi Perbaikan
		centrifugation machine to separate sugar crystals from molasses. Ensuring that the temperature and humidity of the drying air are controlled.
Energy Used	The company's high and inefficient energy consumption due to the extensive recycling of defective products, as well as the company's lack of renewable energy utilization in its operational processes.	Minimizing defective products to eliminate the need for reprocessing. Utilizing waste heat from the evaporator system for subsequent heating stages. Conducting energy audits to identify opportunities for energy savings.
% of recycleable waste from the total waste	The lack of recycling infrastructure for solid waste and the low prioritization of solid waste management.	Developing comprehensive policies and regulations by enhancing coordination among the government, industry, and communities. Enhancing facilities for the sorting, processing, and utilization of solid waste.

CONCLUSION

Based on the performance measurement of green manufacturing at PT ABC, the results indicate that the green manufacturing performance falls within the “Good” category, with a score of 73 out of 100. Using the green SCOR model, 14 indicators were identified: 7 of these fall into the green category, 4 are classified as yellow, and 3 are classified as red, indicating that they require improvement. Improvement recommendations have been provided for the indicators in the red category to enhance their performance, thereby enabling the company’s operations to contribute to sustainable manufacturing.

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