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Green Manufacturing Excellence in Fiber Cement Production: Leveraging Green SCOR and AHP for Enhanced Environmental Performance Times

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ABSTRACT

Green manufacturing has become key strategy in improving environmental sustainability and operational performance in industry. This research evaluates the implementation and performance of green manufacturing activities in the Fiber Cement industry, using the Green SCOR framework integrated with AHP. This method allows for an in-depth assessment of the effectiveness of existing practices and provides a foundation for the development of targeted improvement strategies. The results indicated that the company was in the unsatisfactory performance category, with a score of 58.6. Of the 12 KPIs evaluated, there were 5 that required significant improvement, including the addition of a water pool, waste reduction, improved order management, additional labor, and training on green production. This research contributes to the green manufacturing literature by providing valuable insights for companies to evaluate their performance in improving green manufacturing practices specific to the Fiber Cement industry.

Key words: AHP, Green Manufacturing, Green SCOR, Fiber Cement, Performance.

1. INTRODUCTION

Increased global awareness of environmental issues has encouraged growing consumer demand for more environmentally friendly products. One innovative approach in the production process that emphasizes the use of green strategies and technology in reducing environmental impacts is green manufacturing[1]. The green manufacturing approach not only helps in preserving the environment, that during the manufacturing process at each stage of the process activity it does not harm the environment[2], Govindan [3], however, it can improve operational efficiency and reduce long-term costs.

Thus according to Purnomo [4], green manufacturing (GM) is increasingly needed by industry and society. This is because at all stages of production the environmental impact is taken into consideration and any hazardous materials must not be used[5]. Even though manufacturing process activities are the main focus, according to D'Angelo [6]. In an effort to prevent environmental hazards, it is not enough just to implement GM without carrying out proper evaluation and assessment. This is in line with the research results Hebaz et al., [7] argued that it is important to measure and monitor the impact of environmentally friendly manufacturing practices in ensuring that green manufacturing is truly effective in reducing negative impacts on the environment [8].

Therefore, it is important for the Fiber Cement industry, which has a significant impact on the environment, to implement an effective performance measurement system. This system will not only assess the success of existing green manufacturing efforts but will also help identify areas requiring improvement and establish best practices for future implementation[9]. This will ensure that the Fiber Cement industry continues to innovate and improve its environmental performance, in line with global sustainability practices.

However, in general, research related to green manufacturing focuses more on certain industries, as carried out by Munawir al., [10] highlighting a local batik industry that can improve GSCM's performance. As well as Rehman [2], revealed that implementing green manufacturing can influence a company's economic performance. This is in line withToke & Kalpande [8], states that adopting green manufacturing practices in developing countries can improve operational performance. Whereas Tsai [11] to increase the value of green manufacturing by using environmentally friendly manufacturing technology. On the other hand Amrina [12] revealed that measuring green manufacturing performance in the cement industry has limited opportunities and there is a lack of awareness of environmental problems in cement production. Various studies discussing green manufacturing tend to focus on more general or popular industries such as automotive, electronics, or products with high demands from consumers and strict regulations regarding environmental sustainability. Meanwhile in the Fiber Cement Industry there is a lack of visibility and public pressure, this has resulted in limited literature examining performance measurement of green manufacturing activities in the Fiber Cement Industry

Thus, although quite a lot of research related to green manufacturing has been carried out, research that specifically measures the performance of green manufacturing activities in the Fiber Cement industry is still rarely found. Therefore, this research aims to measure green manufacturing activities in the Fiber Cement industry, using the green Supply Chain Operation Reference (SCOR) and Analytical Hierarchy Process (AHP) approaches. Green SCOR is believed to be able to integrate environmental management elements into every process, including planning, procurement, production, delivery and returns, as well as activation [13]. Apart from that, Geen SCOR also plays an important role in optimizing operational efficiency while minimizing environmental impact. Meanwhile, the Analytical Hierarchy Process (AHP) is used to determine how important each criterion is in determining its priority weight by relying on subjective assessments from experts [14]. In addition, AHP can be used to evaluate and compare elements in pairs in complex and multi-hierarchical situations[15].

This research consists of seven parts consisting of: Part 1 explains the background of the research problem and research objectives that were previously stated. Section 2, Research Methods which will explain the research stages, Section 3, Results and discussion where this section will discuss the research findings in detail and relate them to relevant literature. Section 4, Research conclusions and limitations, presents the conclusions of the research that has been carried out, as well as discussing limitations that may arise during the research process.

2. LITERATURE SURVEY

Green manufacturing is an approach to industrial production that focuses on reducing waste and energy efficiency to minimize environmental impact [16]. This concept involves the use of environmentally friendly processes, materials and technologies throughout the product life cycle, from design, production, distribution, to the end of the product's life cycle [17]. The goal is to reduce the carbon footprint, reduce the use of natural resources, and increase sustainability. Green manufacturing is often integrated with initiatives such as the use of renewable energy, efficient waste processing, and recycling of materials to create cleaner and greener production processes [18].The main goal of green manufacturing is to support environmental sustainability in maintaining operational efficiency and market competitiveness.

Implementing green manufacturing can involve various strategies such as:

1. Recycling and Reuse: Maximize the reuse of materials and recycle the waste generated.
2. Eco-friendly Materials: Using raw materials that have a low impact on the environment.
3. Energy Efficiency: Using technology that reduces energy consumption.
4. Waste Management: Implementing an effective waste management system to reduce waste discharge into the environment.
5. Pollution Reduction: Reducing harmful emissions from the production process.

Green manufacturing not only helps in maintaining ecological balance but can also improve a company's image and meet increasing regulatory and consumer expectations for sustainable products [19]. The diagram shown in Figure 1, depicts a green manufacturing framework that illustrates how inputs, processes, outputs and expected results are interrelated in explaining sustainable practices in the manufacturing industry. Following is a detailed analysis of each component in the Figure 1 diagram.

1. Input, Input refers to the resources, technology and policies used in production which include: a) Use of sustainable resources such as raw materials that can be renewed or that have minimal impact on the environment [18]. These conditions are the foundation of green manufacturing, which aims to minimize the ecological footprint. b) Technology by implementing advanced and energy efficient technology that supports sustainable manufacturing processes. These technologies may include automation to reduce waste or systems

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that optimize the use of energy and raw materials [20] Environmental Regulations and Internal Policies represent compliance with strict environmental regulations and internal policies designed to strengthen the company's commitment to sustainability. This creates a compliance framework that all company operations must follow.

2. Process, Processes in green manufacturing not only include production activities but also methods to reduce environmental impacts which include a) Energy Efficiency is an effort to reduce energy consumption per unit of production. This includes using more efficient equipment and modernizing facilities to minimize energy losses[17]. b) Waste Reduction, where strategies are designed to reduce, reuse and recycle waste generated during production. This phenomenon can take the form of efforts to reduce waste at the source or technologies that convert waste into valuable resources. c) Management of Emissions and Water Use, by implementing systems that reduce harmful emissions and optimize water use, ensuring that water resources are used efficiently and that waste water is managed well[21].
3. Output and Results, The output of this process is the product and direct profits from operations, while the results are the long-term impact of implementation which includes: a) Sustainable Products, Products produced from this process not only meet consumer needs but also provide solutions that more environmentally friendly. b) Environmental Performance, which is a reflection of how the company's operations affect the environment, including reducing emissions, increasing sustainability, and reducing negative impacts. c) Operational Costs and Company Image means that green manufacturing is often more efficient which can reduce long-term costs and improve the company's image in the eyes of the public and stakeholders.
4. Outcomes, The results of green manufacturing determine the ultimate impact on business sustainability, regulatory compliance, and customer satisfaction: a) Business Sustainability aims for increased sustainability to help ensure that companies can survive in an increasingly demanding regulatory and market environment. b) Regulatory Compliance can meet or exceed regulatory standards which can avoid fines and sanctions. c) Customer Satisfaction can meet the expectations of modern customers who increasingly prioritize products and companies that are socially and environmentally responsible.

The entire diagram underlines that green manufacturing aims not only to minimize negative impacts on the environment but also to improve overall operations through responsible innovation and compliance.

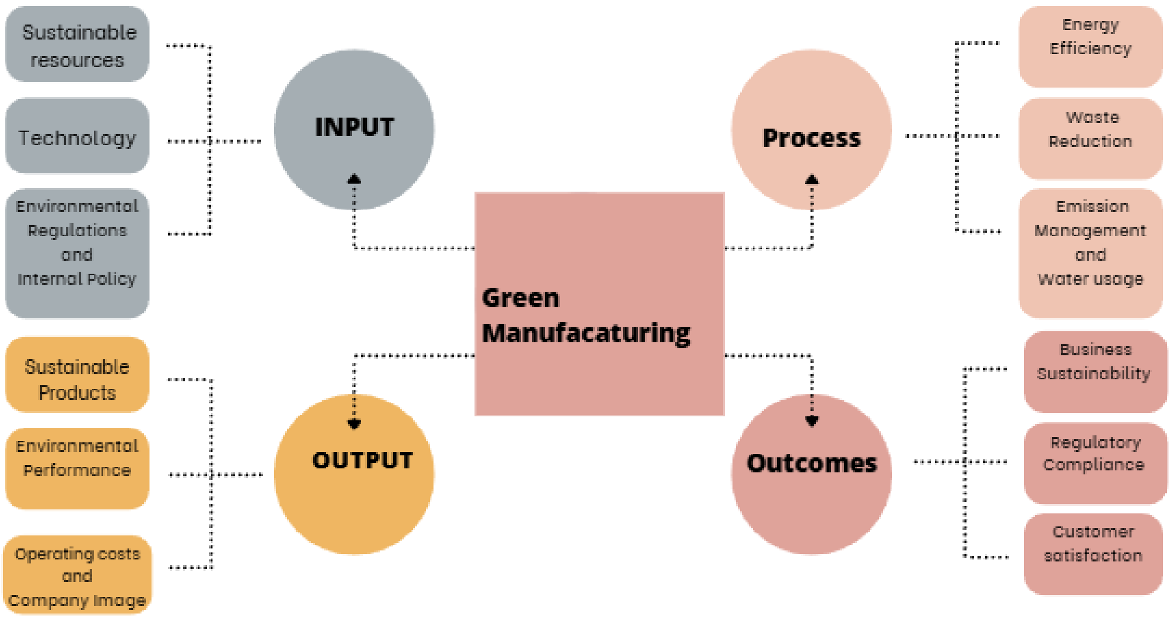

Figure 1. Conceptual Framework for the Green Manufacturing Process

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3. OBJECTIVE OF RESEARCH

Measuring green manufacturing activities in the Fiber Cement industry using a combined approach from the Green Supply Chain Operation Reference (SCOR) and Analytical Hierarchy Process (AHP). This approach allows companies to assess and optimize sustainable operations by considering various environmental aspects and operational efficiency. Through the use of SCOR, industry can integrate sustainable practices in procurement, production, and distribution processes, while AHP helps in making structured decisions and prioritization between various green initiatives based on predetermined criteria, such as emission reduction, energy efficiency, and waste management.

4. RESEARCH METHODOLOGY

This research measures the performance of green manufacturing activities in the Fiber cement industry. The determination of the object of this research in the Fiber cement industry was due to a lack of awareness of environmental issues [12]. Therefore, the focus of this research specifically measures how green manufacturing practices are implemented and their effectiveness in the context of the Fiber Cement industry. The method used in this research adopts the Green SCOR and AHP models. The stages in this research are divided into six stages, including stage I identifying green manufacturing, stage II designing business processes, stage III designing key performance indicators, stage IV conducting an assessment with AHP for each KPI, then stage V calculates the performance value, Stage VI results and discussion, in full, are shown in Figure 2.

Stage I: Identification of green manufacturing activities, at this stage conducting a literature review of papers related to green manufacturing activities, performance in green manufacturing and implementation of green SCOR in manufacturing. Apart from that, this stage involves professional and academic experts to validate green manufacturing activities. The number of experts consists of 3 people, consisting of 2 professionals with experience in waste management and 1 academic whose area of expertise is green supply chain and sustainability. This stage produces green manufacturing activities

Stage II: Designing key performance indicators and Validation, at this stage designing key performance indicators is based on the results of identifying company activities related to manufacturing activities that are in accordance with Green manufacturing based on green SCOR. The results of the KPI design were validated by experts with the aim of determining the accuracy and suitability of the KPI in assessing green manufacturing performance, in full can be seen in Figure 3. Meanwhile, the indicators used in measuring key performance indicators in Green Manufacturing activities consist of eleven indicators, namely:

1) Yield, yield or efficiency of materials used by the company which functions as a measuring tool used in the production process. The data required for this indicator is input data and output data for raw materials obtained from the production department. Yield = Output/Input x 100%
2) Water Usage, this indicator requires data on the total water used for one production unit. The data needed by researchers in measuring this indicator are; Water Usage = (Amount of Water Used)/(Number of Products Produced)
3) Energy Usage, in this Energy Usage indicator the data required by researchers to measure the total energy used in one production unit in one period is, Energy Usage = (Total Amount of Electrical Energy Used)/(Number of Products Produced)
4) Recyclable Waste. In this indicator, researchers need data regarding the percentage of waste that can be recycled from the total existing waste. %Recycable = (Amount of Recycled Waste)/(Total Amount of Waste) x 100%
5) Waste Produced as % Product Produced, this indicator requires data on the total amount of waste (solid, liquid and gas) from the total products produced by the company for measurement. Waste Producted as = (Total Amount of Waste)/(Total Amount of Products) x 100%
6) Product Produced, this indicator requires direct interviews with the company regarding the amount of waste disposed of in the environment.
7) Make Cycle Time, the make cycle time indicator is the time required for employees to make a product starting from mixing until it becomes a finished product.
   Make Cycle Time = Hydra Pulper Time + Grinding Mixing Time + Mixer Time + Sheet Time + Pilling Time + Curing Time + Demolding Time

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8) Upside Make Flexibility. The aim of measuring this indicator is to determine the percentage increase in demand for finished products that will occur at any time in the company. To obtain data on this indicator, interviews were conducted with the company.

9) Waste Processing Costs, Waste processing costs are the costs required by a company to manage waste by installing or creating a waste processing system. This indicator also requires interviews with the company to carry out measurements.

10) Production Schedule. This indicator is defined as the percentage of products that are completed on time each month. Production Schedule = (Number of Finished Products)/(Number of Products Should) x 100%

11) Asbestos Efficiency This indicator is defined as the percentage of the actual number of products divided by the effective capacity of the products that can be produced by the machine. Effective capacity can be determined from multiplying working hours by the number of working days and the amount of output produced. Asbestos efficiency = (Actual Number of Products)/(Effective Capacity) x 100%.

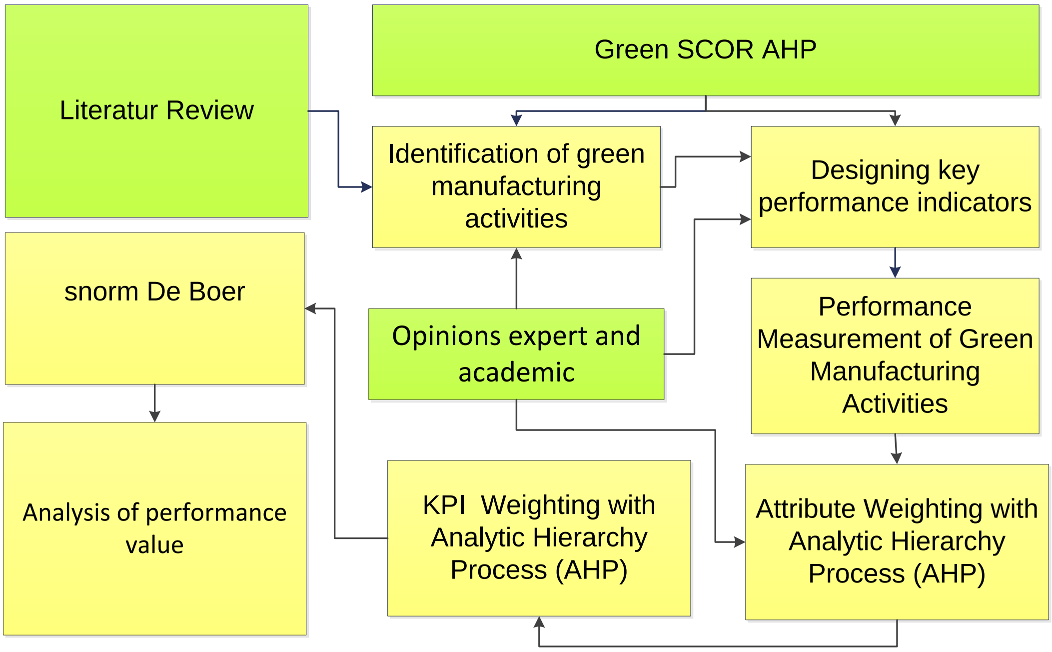

Figure 2. Research Stages

Stage III: AHPAssessment, weighting at this stage is carried out at level 1 of Green SCOR, namely process, at Green SCOR level 2, namely performance attribute level, and at Green SCOR level three, namely indicators. The weighting starts from the Green SCOR Process, namely by carrying out pairwise comparisons on make aspects along with attributes and indicators. carry out weighting on indicators.

Stage IV: Calculation of Green Manufacturing Performance Values

Calculation of the final Green Manufacturing value based on each performance attribute. Next, carry out calculations at level 1 of the Green SCOR Process, then calculate the overall score by multiplying the final score of the Green SCOR Process with the level 2 weights for each aspect

Stage VI: Analysis of performance value, at this stage carry out analysis using the Traffic Light System method to identify indicators that require improvement.

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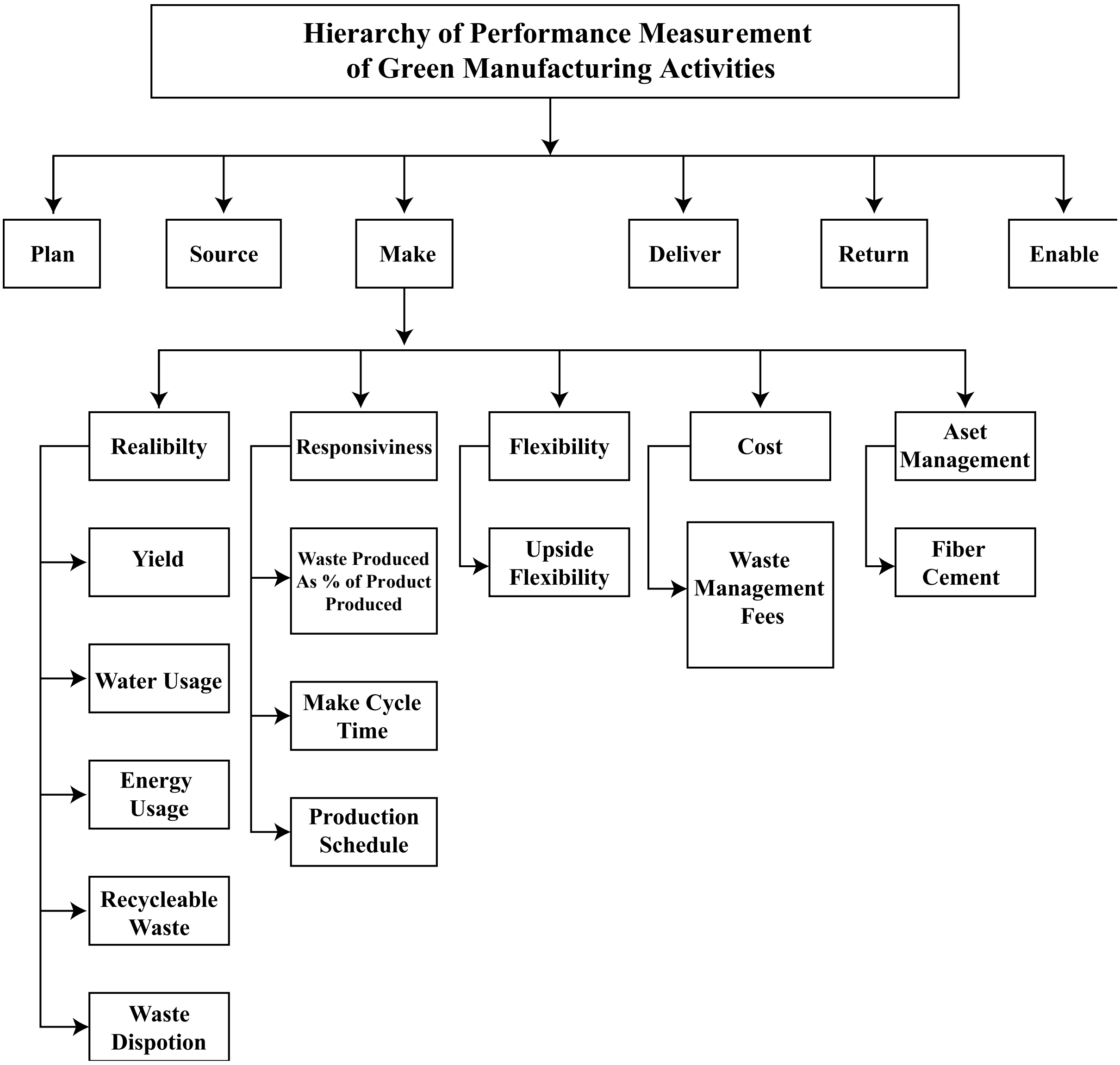

Figure 3. Hierarchy of Green Manufacturing Activity Performance Measurement

5. RESULT AND DISCUSSION

5.1 Reliability Attribute

The results of the make process with the Reliability attribute consist of five indicators which include: indicators such as measuring material efficiency, water use, energy use, recyclable waste and waste management. The details of green manufacturing activities are as follows:

a) Material Efficiency Measurement

Material Efficiency Measurement is used by companies in the production process to make a comparison between the materials ordered by the company and the materials that have been used in the production process[22]. The following is data on the use of materials needed in the process of making fiber cement. The annual need for cement is 21,879,000 kg, while the usage is 21,405,620 kg, with an average efficiency of 97.9%. The raw material requirement for cement paper is 1,311,350 kg, but the usage is 1,284,488 kg, with an average efficiency of 98%. Purchasing 3,523,700 kg of Crysotile raw materials, 3,463,791 kg were used, resulting in an average efficiency of 98.3%. b) Annual water use is 12,474 m^3, with an average use per product of 0.003 m^3. c) Energy (Electricity) usage per year is 4,460,736 kWh, with an average usage per product of 1.22 kWh. d) recycled waste annually is 98,657 kg, the amount of waste that can be recycled is 92,949 kg, so the average recycling is 94%. e) for waste management based on the results of interviews with companies, it is known that

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15% of waste water is discharged into the environment after processing, and 85% of the water can be reused for activities such as cultivating fish and aquatic plants.

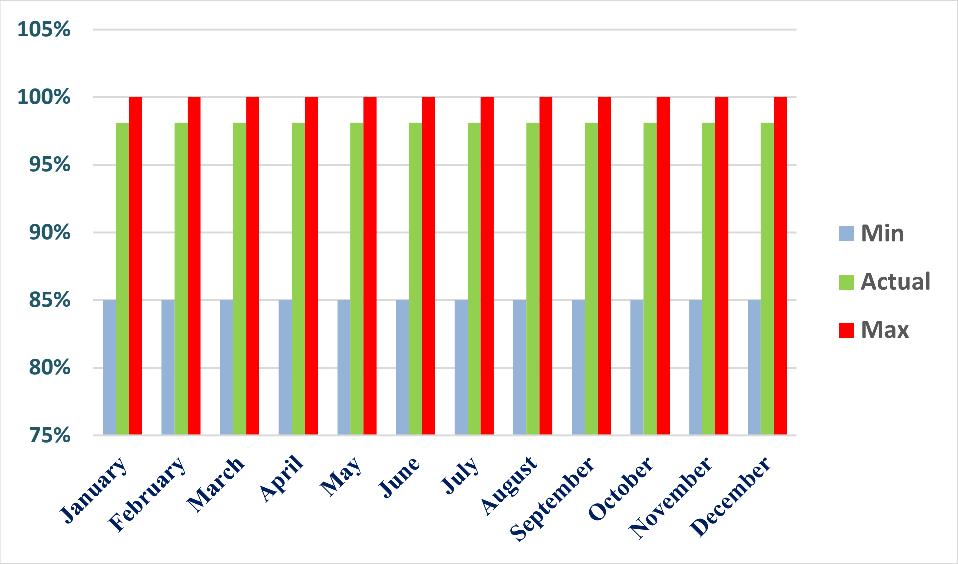

Figure 4. Material efficiency measurement graph

The measurement of material efficiency is shown in Figure 4, which explains that the green line is the material efficiency of the materials used in fiber cement production with a maximum condition of 100%, while the minimum condition of the material efficiency used by the company is 85%. The actual conditions are marked in red, where the actual conditions are at the minimum and maximum limits.

Green manufacturing activities on the effectiveness of material use, showing a high level of material efficiency[22]. Cement, cement paper and crysotile are used with an average efficiency of over 97%, reducing material waste and supporting sustainability principles. Likewise, the management of water resources is efficient with a very low average usage per product, indicating sustainable water resource conservation efforts[23]. Electricity usage is still quite high, the average usage per product shows the company's efforts to manage energy efficiently in the production process. In contrast to the condition of recycled waste which shows a high percentage of recycled waste at 94%, this indicates the company's commitment to reducing waste and promoting recycling as part of green manufacturing activities.[24]. The condition of waste water management is 85%, where waste water is reprocessed for activities such as cultivating fish and aquatic plants, showing the company's efforts in responsible and sustainable waste water management.

Thus the fiber crime industry has demonstrated a significant commitment to green manufacturing practices. This is reflected in its efforts to make efficient use of materials, manage water and energy resources, high percentage of waste recycling, as well as innovative approaches in water waste management.

2) Water Usage

Based on Figure 5, it shows efficient underground water management (ABT). Throughout the year, the total water used is 12,474 m^3. Monthly analysis reveals that the average water usage per product is quite low, namely only 0.003 m^3. This shows the company's efforts to optimize the efficient use of water resources, which is an important aspect of sustainable manufacturing practices. Efficient water use not only reduces environmental impact but also supports sustainable operations in the long term[24].

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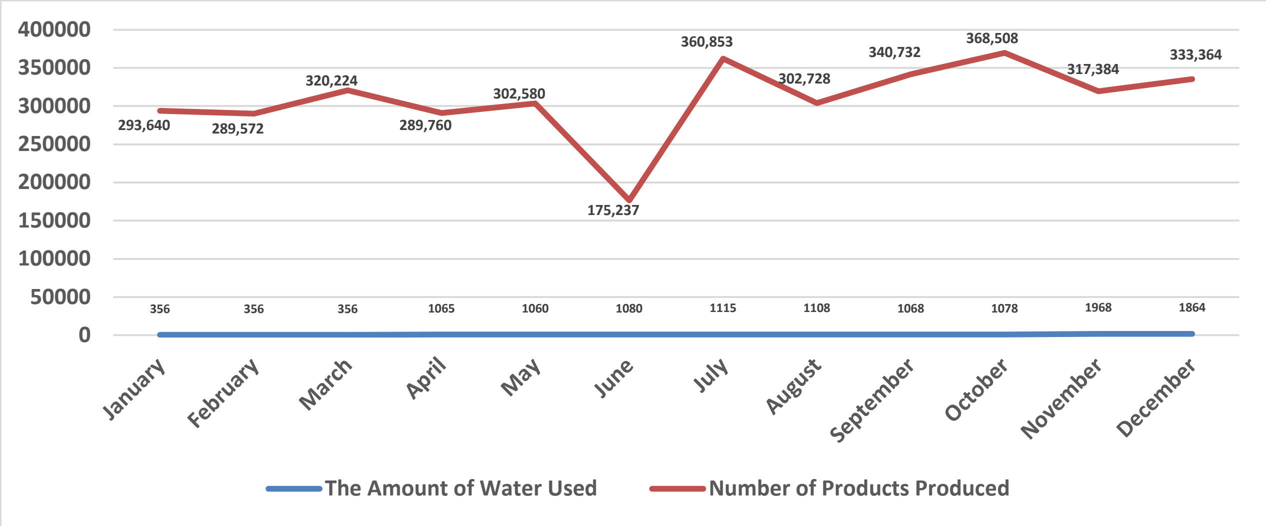

Figure 5. Water Usage Comparison

3. Energy Usage

Electricity usage for fiber crime production is 4,460,736 kWh. Average electricity usage per product is 1.22 kWh. Monthly data depicts electricity usage ranging from 1.06 to 1.38 kWh per product. This indicates the company's efforts to manage electrical energy consumption in the production process. This careful monitoring and management of energy usage shows the company's steps in implementing green manufacturing practices, which not only reduce environmental impact but also increase operational efficiency and reduce energy costs.[25].

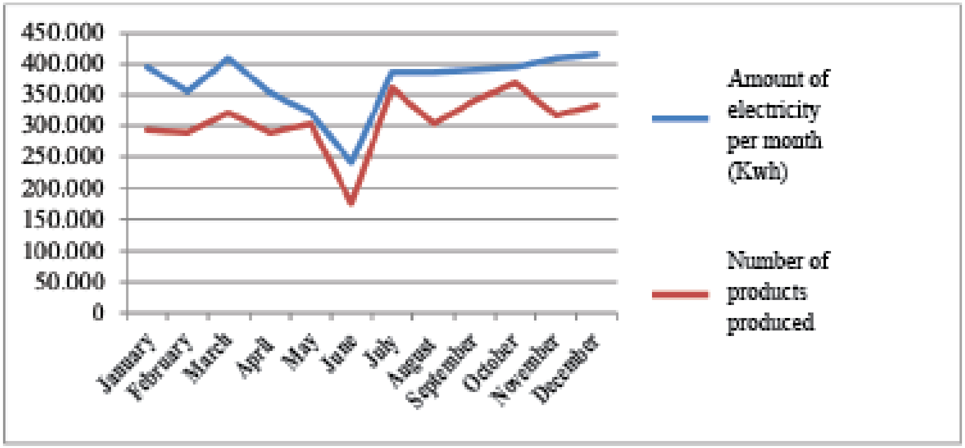

Figure 6. Electricity Usage

4. Recyclable Waste

This indicator aims to determine the total percentage of waste that can be recycled from all waste in the production of crime frames. The amount of Solid Waste and Recycling for each month varies, from 6,553 kg to 9,989 kg. Of the total waste produced throughout the year (98,657 kg), most of it was successfully recycled, namely 92,949 kg. Meanwhile, the recycling percentage: ranges from 82% to 99% every month. this indicates high recycling efficiency. In particular, March and October stand out with near-perfect recycling rates of 99% and 97% respectively. Meanwhile the average solid waste per month was 8,221.42 kg, and the average recycling per month was 7,745.75 kg , showing consistent recycling rates. On the other hand, overall effectiveness in the form of a recycling percentage of 94%, this shows that the company has succeeded in implementing effective recycling practices, reducing the amount of waste that has the potential to damage the environment. Thus the importance of recycling in industrial operations can reduce environmental impacts and demonstrate the company's commitment to sustainability[26].

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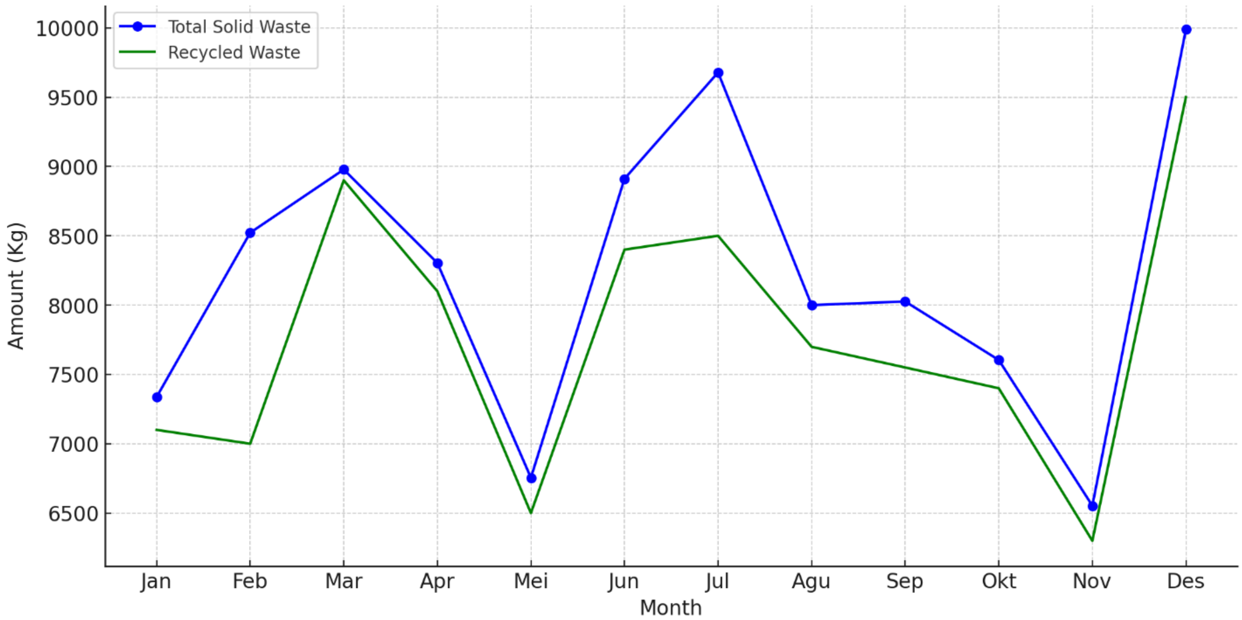

Figure 7. Recyclable Waste Analysis

Based on Figure 7, it can be seen that the frame crime industry shows good performance in managing solid waste, with a focus on recycling as an effort to reduce environmental impacts.

5. Waste Disposition

This indicator represents waste management carried out by the Company. Based on the results of interviews with the company, it was revealed that the company processes waste with high effectiveness. Of the total water waste produced, 15% is discharged into the environment after a pH neutralization process, ensuring that the waste is not harmful to the environment. Meanwhile, 85% of other water waste has been successfully processed and reused. This processed water is used to fill fish ponds and water plants and is used as irrigation water to water plants around the company. Reusing waste water not only helps in utilizing resources efficiently, but also shows the company's commitment to sustainable practices. Processing and utilization of this waste is carried out through the Waste Water Treatment Plant (IPAL) system managed by the company. This is in line with Bali [27]which emphasizes sustainability, not only focusing on the environment but also economic and social.

Responsiveness Attribute Data

The indicators for the responsiveness attribute consist of three, namely: a) Waste Produced as % of Product Produced, b) Make Cycle Time, c) Production Schedule. The complete description is as follows:

a) Waste Produced as % of Product Produced analysis shows that Waste Percentage Variability changes every month, with the lowest value being 2% (January, May, September, October, November) and the highest being 5% (June). This variability can be caused by differences in production processes, raw material efficiency, or waste management practices carried out each month. Meanwhile, for production efficiency, the average waste percentage is 3%, indicating that most of the raw materials have been successfully converted into finished products with relatively good efficiency.

However, there is room for improvement, especially in months with a higher percentage of waste. Even if the waste percentage is not very high, companies can consider adopting better strategies to reduce, recycle, or manage their waste[27]. This includes optimizing production processes to reduce waste or finding innovative ways to reuse or recycle the waste generated. The environmental and sustainability implications of managing waste effectively are an important part of sustainable operations[28]. By minimizing waste and increasing recycling, companies not only reduce their environmental impact, but can also improve operational efficiency and corporate image. Therefore, policies and regulations are needed related to the waste produced and the way it is processed needs to be in accordance with applicable environmental standards, considering the strict government regulations regarding industrial waste management.

b) Make Cycle Time

DOI: 10.31695/IJASRE.2024.9.1

Make Cycle Time highlights the production cycle time from the Hydra Pulper process to Demoulding in making fiber crime products. Based on data, the total time required to make one product unit is 8.335 hours, consisting of seven process stages, namely Hydra Pulper: 0.16 hours, Grinding Mixing: 0.11 hours, AC Mixer: 0.03 hours, Sheet Machine: 0.003 hours , Pilling: 0.016 hours, Curring Machine: 8 hours, Demoulding: 0.016 hours. Of these seven processes, there is a critical process in the Curring Machine which can be seen that the Curring Machine process takes up the majority of the cycle time, namely 8 hours out of a total of 8,335 hours. This suggests that this process is a critical component in the production cycle and may be a key area for seeking efficiency and improvement. Given the significant duration on Curring Machines, it is possible to explore new technologies or methods to optimize and shorten these times, thereby increasing overall production speed. On the other hand, the other six processes have a relatively short time, this shows good operational efficiency. So it is important to ensure that continuity and coordination between processes is maintained so that there are no delays or problems in the production flow.

While there is potential to shorten production cycle times, it is important to balance this with product quality standards. Any change in the production process must consider its impact on the final quality of the product. According toGoyal [29]by understanding and analyzing Cycle Time, you can identify opportunities for improvement and improvement in the production process.

c) Production Schedule

Production Schedule highlights the company's effectiveness in meeting production targets on time throughout the year[30]. The company manages to achieve production targets perfectly every month, maintaining a 100% on-time rate. The company consistently meets production targets on time every month. This shows high efficiency in production planning and execution as well as good supply chain management. Apart from that, the company adopts make to order, which means production is based on orders received. This approach minimizes the risk of overstocking and helps in focusing resources on actual demand. That way, the company can consistently meet production targets and good operational management, including production planning, schedule setting, and coordination between various departments. The impact of 100% on time production can provide customer satisfaction because the company can be relied on to fulfill customer requests on time. Even though the results show perfect performance, it is important for companies to continually analyze and improve their processes, looking for ways to increase efficiency and reduce costs without sacrificing timeliness[27]. Overall, the make to order strategy also allows companies to be more adaptive and responsive to fluctuations in demand in the market, by adjusting production volumes according to needs.

Flexibility Attribute

In the Make Flexibility indicator, the company shows its capability to respond to an increase in demand of up to 75%. This indicates a high level of flexibility in its production operations, allowing the company to adjust production output according to changes in market demand. The ability to meet a 75% increase in demand is an important indicator, especially in a dynamic industry such as fiber cement production. Bai and Sarkir[31]suggests that with a degree of flexibility companies can respond effectively to market fluctuations, including unexpected increases in demand or changes in market trends. This flexibility is not only important to meet demand but also to maintain operational stability and reduce the risk of overproduction or stock shortages[32]. In the context of sustainability and green manufacturing, the ability to adjust production based on real demand can reduce waste and increase the efficiency of resource use. Thus, a score of 75% in Make Flexibility indicates that the company has implemented efficient and sustainable management practices, which enable them to adapt effectively to market dynamics and reduce the environmental impact of its production processes.[31].

Cost attribute

Waste Processing Cost Indicator, it was recorded that the company incurred costs of IDR 2,808,000 for liquid waste processing. This cost is specifically incurred to use HCL (hydrochloric acid) in the water neutralization process. Water neutralization is an important step in waste management, especially to ensure that liquid waste discharged into the environment meets established standards and does not have a negative impact on the ecosystem. The relatively low costs for processing liquid waste show the company's commitment to implementing responsible

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green manufacturing practices. This expenditure is an investment in environmental sustainability, which plays an important role in ensuring that a company's operations do not have a significant negative impact on the environment.

However, it is important to note that waste processing costs do not only include the use of chemicals such as HCL, but must also consider other operational costs, such as energy, maintenance and regulatory compliance.[30]. Therefore, IDR 2,808,000 should be understood as a component of the overall waste processing costs, not the total. Thus, the company's commitment to managing waste reflects proactive steps in implementing green manufacturing principles, which are not only important for the environment but also for the company's image and social responsibility.[26].

Attribute Weighting with Analytic Hierarchy Process(AHP)

The weighting of each attribute aims to determine the priority of the five existing attributes. The results of weighting each attribute and consistency calculations show that the reliability attribute gets the highest weight of 0.404, this indicates the importance of this attribute in the context of green manufacturing. Next is Cost with a weight of 0.277, indicating that cost factors are also important to consider in green manufacturing. Apart from that, in Table 2 there is a lambda max value which shows the overall measure of consistency in pairwise comparisons.

Table 2. Weighting and Consistency Between Attributes

Criteria	Amount	Priority Vector	Matrix Multiplication	Results Times/Priority	Lambda max	CI	R.I	CR
Reability	2.02	0.404	2.22	5.49	5.53	0.13	1.12	0.12
Responsiveness	0.48	0.095	0.52	5.49				
Flexibility	0.58	0.116	0.65	5.60				
Cost	1.39	0.277	1.54	5.57				
Asset Management	0.57	0.108	0.59	5.49				
Amount	5.00	1	5.52	27.64				

The ideal value for a consistency matrix is equal to the number of criteria, in this case 5. However, the Lambda max value obtained is 5.53, which indicates a slight inconsistency. Consistency Index (CI) and Ratio (CR), CI is a measure of inconsistency in pairwise comparisons. Here, the CI for Reliability is 0.13. Consistency Ratio (CR) is a comparison between CI and Random Index (RI), where RI is the average random index for matrices with the same number of elements. A CR smaller than 0.10 is generally considered acceptable, indicating a sufficient level of consistency in pairwise comparisons. In this case, all CRs were below the threshold of 0.10, indicating an acceptable level of consistency.

Based on Table 2, the Reliability and Cost attributes are key factors in green manufacturing activities, with fairly consistent understanding among decision makers. This indicates a good awareness of the importance of reliability and cost in green manufacturing, and how these elements interact to influence decisions.

Weighting of Reliability and Responsiveness Indicators with AHP

Weighting Reliability and Responsiveness indicators using the Analytic Hierarchy Process (AHP) method is an important part of the decision-making process, especially in the context of green manufacturing. Reliability has a greater weight than the other four attributes. This shows the importance of reliability in producing quality products that are environmentally friendly by minimizing waste and resource efficiency. Meanwhile, the responsiveness attribute was chosen as the main KPI even though its weight is lower than other attributes. This is because a rapidly changing industry requires the ability to adapt and respond quickly, more than just focusing on cost management. The ability to quickly respond to market needs and environmental changes shows a commitment to sustainability and can increase customer satisfaction. Thus, the selection of Responsiveness as the main KPI emphasizes the importance of broader

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strategic and operational aspects in decision making. The results of the KPI Reability weighting are shown in Table 3 and the results of the KPI Responsiveness weighting are in Table 4.

The results of the weighting of the Reliability criteria are shown in Table 3. The KPIs assessed consist of yield, Water Usage, Energy Usage, Recyclable Waste, and Waste Disposition,

Where each KPI is assessed based on pairwise comparisons, producing Priority Vector, Lambda max, Consistency Index (CI), and Consistency Ratio (CR). The high priority on Water Usage indicates the importance of efficient water resource management in green manufacturing activities. The next KPI to pay attention to is Yield and Energy Usage, this reflects the need for material and energy efficiency. Overall, this table shows an emphasis on resource efficiency and waste management as important aspects of reliability in green manufacturing activities.

Table 3. Weighting and Consistency of Reliability Attribute Indicators

Criteria	Yield	Water Usage	Energy Usage	Recycleable Waste	Waste Disposal	Amount	Priority Vector	Matrix Multiplication	times results/priority	Lambda max	CI	R.I	CR
Yield	0.11	0.05	0.04	0.04	0.27	0.50	0.10	0.693	6.92206747	5.680128	0.170032	1.12	0.151814
Water Usage	0.22	0.41	0.58	0.53	0.20	1.94	0.39	2,196	5.66433409				
Energy Usage	0.32	0.14	0.19	0.26	0.20	1.12	0.22	1,220	5.45024908				
Recyclable Waste	0.32	0.10	0.10	0.13	0.27	0.92	0.18	0.957	5.18536785				
Waste Disposal	0.03	0.14	0.06	0.03	0.07	0.33	0.07	0.341	5.1786235				
Amount	1	1	1	1	1	5.00	1	5,408	28,401				

Table 4 presents the weighting and consistency assessment process for the Responsiveness attribute indicator in the green manufacturing performance assessment framework. The indicators assessed are Waste Produced as % of Product Produced, Make Cycle Time, and Production Schedule.

Table 4 Weighting and Consistency of Responsiveness Attribute Indicators

Criteria	Waste Produced as % of Product Produced	Make Cycle Time	Production Schedule	Amount	Priority Vector	Matrix Multiplication	Results Times /Priority	Lambda max	CI	R.I	CR
Waste Produced as % of Product Produced	0.13	0.16	0.08	0.36	0.12	0.36	3.02	3.07	0.04	0.58	0.06
Make Cycle Time	0.50	0.63	0.69	1.82	0.61	1.90	3.13				
Production Schedule	0.38	0.21	0.23	0.82	0.27	0.83	3.07				
Amount	1	1	1	3.00	1.00	3.10	9.22				

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The result of KPI weighting with high priority is Make Cycle Time, meaning that it is important to be time efficient in meeting production demands while maintaining high responsiveness. The next significant weight is the Production Schedule which shows the importance of maintaining the production schedule so that it remains in line with the set targets. While the KPI Waste Produced as % of Product Produced has a lower weight, it remains an important aspect in evaluating responsiveness, with a focus on waste reduction.

De Boer snorm normalization

This normalization process aims to harmonize the indicator values for each indicator, considering the different weights for each indicator. The weights at Level 1 are obtained from the AHP priority vector for each attribute, while the weights at Level 2 come from the AHP priority vector for each indicator in that attribute. The actual value (Si) is calculated based on the average data from each indicator, while the minimum and maximum values are limits determined by the company. After the weighting process, it continues with normalization for each indicator. The following is a compiled Snorm De Boer normalization table. Complete results can be seen in Table 5.

Table 5. De Boer Snorm Normalization

Business process	Attribute	Level Weight 1	KPIs	Level Weight 2	Actual (Si)	Min	Max	Snorm	Final Weight	Normaliza x Weight
Make	Realibility	0.404	Yield	0.10	98.10%	85%	100%	87.3	0.04	0.04
			Water Usage	0.39	0.003	0.002	0.007	80	0.16	0.13
			Energy Usage	0.22	1.22	1	4	92.7	0.09	0.08
			Recyclable Waste	0.18	94%	82%	100%	66.7	0.07	0.05
			Waste Disposal	0.07	15%	10%	20%	50	0.03	0.01
	Responsiveness	0.095	Waste Produced as % of Product Produced	0.12	3%	1%	5%	50	0.01	0.01
			Make Cycle Time	0.61	8,335	8	9	33.5	0.06	0.02
			Production Schedule	0.27	100%	90%	100%	100	0.03	0.03
	Flexibility	0.116	Upside Makes Flexibility	1	75%	50%	100%	50	0.12	0.06
	Cost	0.277	Waste Processing Costs	1	Rp. 2. 808,000	Rp. 2,000,000	Rp. 4,500,000	67.7	0.28	0.19
	Asset Management	0.108	Asbestos Efficiency	1	84%	80%	100%	80	0.11	0.09

Performance Value Analysis

The overall performance results using the Green SCOR method reached a performance value of 68.8. This places the company in the Average category, which indicates that the company has achieved average performance standards. However, there is still room for improvement to reach the Good category. The Traffic Light system is used to help identify KPIs that require further attention and improvement. This system uses three colors - red, yellow, and green - to indicate the level of success based on the Snorm De Boer score value. KPIs with a score of ≥80, marked in green, indicate satisfactory performance. KPIs with a score between 60-80, marked in yellow, are categorized as

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marginal, requiring attention but not urgent. Meanwhile, KPIs with a score of ≤60, which are marked in red, indicate unsatisfactory performance and require immediate improvement. Table 6 shows the results of the KPI categories according to the Traffic Light System

Table 6. Traffic Light System

KPIs	Actual (Si)	Min	Max	*Snorm*
Yield	98.10%	85%	100%	87.3
Water Usage	0.003	0.002	0.007	80
Energy Usage	1.22	1	4	92.7
Recyclable Waste	94%	82%	100%	66.7
Waste Disposal	15%	10%	20%	50
Waste Produced as % of Product Produced	3%	1%	5%	50
Make Cycle Time	8,335	8	9	33.5
Production Schedule	100%	90%	100%	100
KPIs	Actual (Si)	Min	Max	*Snorm*
Upside Makes Flexibility	75%	50%	100%	50
Waste Processing Costs	Rp. 2. 808,000	Rp. 2,000,000	Rp. 4,500,000	67.7
Asbestos Efficiency	84%	80%	100%	80

Reliability Criteria

Based on Table 6. There are three KPIs in the green category (Yield, Water Usage, Energy Usage), one KPI in the yellow category and one KPI in the red indicator. Based on Figure 3. KPI Yield, which measures material efficiency, recorded high efficiency for cement (97.9%), cement paper (98%), and crysotile (98.3%). The overall material efficiency was at 98.1% with a Snorm value of 87.3, indicating very satisfactory performance. Likewise, the KPI Water Usage measures water consumption per product, with an average of 0.003 m^3/product, indicating efficient water use, in line with the use of liquid cement in production. A performance score of 80 on this indicator reflects satisfactory efficiency. Likewise, KPI Energy Usage, with a performance value of 92.7, shows very effective electricity use in the company, with consumption of only 1.22 kWh per product. On the other hand, KPI Recyclable Waste has a Snorm score of 66.7 and is in the yellow category. Although the use of waste for recycling has been implemented well, there is still room for further improvement, especially in reducing discarded waste. Meanwhile, the Waste Disposition KPI, with a Snorm value of 50, is under the red category, indicating that there is a certain amount of waste that is still being disposed of into the environment. Even though liquid waste is processed through WWTPs and the use of HCl for pH neutralization, there is still a need to further reduce the amount of waste discharged.

Thus, the company demonstrated significant progress in certain aspects of green manufacturing, especially in the efficient use of resources. However, there are aspects, especially in waste management, that still require attention and improvement efforts to achieve more sustainable performance.

Responsiveness Criteria

In discussing the Responsiveness attribute, three main indicators are evaluated: Waste Produced as % of Product Produced, Make Cycle Time, and Production Schedule, with only one indicator reaching the green category. The Waste Produced as % of Product Produced indicator, which is in the red category with a Snorm value of 50, shows unsatisfactory performance. Waste production is approaching the maximum limit set, indicating the need to improve process efficiency and reduce waste. This is important to prevent increased waste and ensure operational continuity.

Make Cycle Time is also in the red category with a Snorm score of 33.5, which reflects less than satisfactory performance. The production process, especially the Curing stage which takes a long time, shows potential areas for optimization to reduce duration and increase throughput. Improper product release in the demoulding process,

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potentially causing defects, adds to this challenge. Reducing cycle times and increasing production efficiency will contribute positively to overall performance and product quality. Meanwhile, the Production Schedule reached a Snorm score of 100, indicating very satisfactory performance. The company's ability to complete orders on time, with a perfect Snorm value, shows reliability and efficiency in setting production schedules. This reflects the company's commitment to meeting deadlines and customer satisfaction, which are key aspects of operational success.

Flexibility Criteria

The Flexibility criteria focuses on one KPI, namely Upside Make Flexibility, getting a Snorm score of 50, which places this indicator in the red category, indicating that performance is less than satisfactory and needs improvement. The company's ability to respond to additional customer requests only reached 75%, which is relatively low, indicating limitations in production capacity and flexibility. These limitations could be caused by several factors. Limited production capacity, with a machine capacity of only 431.25 m^3, is one of the main obstacles. Apart from that, the relatively long time required to produce one unit of fiber cement is also an inhibiting factor in responding to urgent or increasing needs from customers.

In order to increase the Snorm value and reach the green or yellow category, the Company needs to increase production capacity and reduce production cycle time. This can be achieved through improving process efficiency, investing in more advanced technology, or restructuring production processes. In addition, better production planning and management can also help increase flexibility in responding to fluctuating demand. Thus, improvements in this area will not only improve Flexibility performance but also contribute to customer satisfaction and the company's competitive advantage in a competitive market.

Cost Criteria

In evaluating the Cost Attribute, the main focus is on the costs of waste processing installations. The company spent money on purchasing HCl liquid, which is used to neutralize the pH of wastewater. With a Snorm value of 67.7, this indicator is in the yellow category, indicating quite satisfactory performance. Waste management is important to ensure that the processed waste can be reused and does not pollute the environment around the factory. Although the costs incurred are relatively effective, there is room to increase efficiency and reduce operational costs. Steps such as optimizing the use of HCl or investing in more efficient waste processing technology could be strategies to increase Snorm value and reduce operational costs.

Asset Management Criteria

In the Assets Management Attribute, the main indicator is fiber cement efficiency. The company achieved an average efficiency of 84% in 2019, with a Snorm score of 80. This places this indicator in the green category, indicating satisfactory performance. This efficiency reflects optimal use of resources in fiber cement production, reducing waste and increasing productivity. To maintain or even increase this efficiency, companies can continue to focus on process innovation, employee training, and efficient use of technology. Good asset management also plays an important role in ensuring that equipment and machinery is properly maintained to optimize output and reduce downtime.

6. Conclusion

Based on the results of measuring the performance of green manufacturing activities in the Fiber Cement industry, it is placed in the average category. This indicates that the company must make a series of improvements to improve its performance. In particular, four KPIs that are in the red category require significant corrective action. Recommendations for improvement include improving liquid waste management by adding a water pool or IPAL, reducing production waste through being careful in the demoulding process, efficiency of production time by optimizing the curing process and order receipt management, as well as increasing production flexibility to respond to additional requests from consumers. Through implementing these improvements, a company has the potential to not only exceed average performance, but also to increase its commitment to sustainable practices and market responsiveness.

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