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Strategy for Utilizing Liquid Waste in the Implementation of Green Productivity in the Palm Oil Industry

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Abstract

The crude palm oil industry generally faces problems in managing liquid waste. It can produce a very pungent odour, pollute river flows, damage the air ecosystems, and cause health problems for communities around the river, such as skin irritation. Therefore, there needs to be an alternative technology for processing liquid waste to create zero waste and increase company productivity. This study proposes a liquid waste processing strategy to support the implementation of Green Productivity by considering two alternative liquid waste processing methods, namely (1) processing liquid waste into biodiesel and (2) building a biogas power plant (PLTBg). One of the waste processing techniques is chosen based on the calculation of the Environment Performance Indicator (EPI) index and the Green Productivity Ratio (GPI). The GPI indicators include materials, labour, energy, maintenance and waste. The EPI indicators considered include relevance, accuracy analysis, measurability and comparability. The results of measuring these five indicators indicate that the second alternative delivers the highest total productivity value, making it feasible for implementation. Furthermore, steps to improve the company's productivity are proposed. Applying this technology will increase the industry's role in running green businesses and sustainable practices.

Keywords: Crude Palm Oil Industry; Waste Processing; Green Business; Sustainable Practics

1. Introduction

Indonesia has a wealth of tropical agro-ecosystems and marine ecosystems, including a variety of native flora and fauna, many of which are regional characteristics that are not found anywhere else in the world. The forests in Indonesia are the second-largest tropical forest area in the world after Brazil. Still, unfortunately, the area often referred to as the primary forest cover tends to continue to decline (Dwiyahreni et al. 2021). Environmental sustainability is a concept that emphasises the importance of maintaining a balance between human needs and nature's capacity to sustain life on this planet. This concept refers to responsibly using natural resources so that future generations can still enjoy the same resources without destroying the ecosystem or causing irreparable environmental damage.

The agricultural and plantation sector is among the second-highest contributors to foreign exchange for the Indonesian economy, especially oil palm plantations. According to Statistics Indonesia 2024, the area of oil palm plantations is estimated to reach 15,435,700 hectares with a total harvest of 52.76 tons of crude palm oil. Oil palm plantations also contribute to poverty alleviation efforts in rural areas through agricultural cultivation activities and

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processing industries for derivative products such as cooking oil, biodiesel, chemicals, etc. Indonesia's palm oil industry contributes almost 80% of the total export value of the plantation sector, with the main products being crude palm oil and its derivatives (Kristyantoadi et al. 2025). Seeing the increasing development of the oil palm business, the management of oil palm plantations and their derivative industries needs to be strictly controlled not to cause pollution in the surrounding environment and to continue to encourage the oil palm product business in the future (Cooper et al. 2020).

After the emergence of competition in the global market in 2015 and the implementation of the ASEAN Free Trade Area (AFTA), a company needs to increase regional competitiveness and sustainable economic growth to survive in the global market (Novendra 2021). Efforts to increase company productivity appropriately can increase competitiveness, economic development, and improve the community's quality of life. Productivity is defined as the comparison between output and input (Yadav and Marwah 2015). Output components can be in the form of sales value, profit, and consumer satisfaction, while input components are in the form of production resources, including equipment, labour, energy, and production costs.

The palm oil industry and its derivatives are encouraged to increase productivity, usually refers to the ratio of inputs to palm oil production capacity over a specific period, compared to the output produced. This measure of productivity illustrates how efficiently resources are converted into production over that period. By analysing productivity, one can gain insight into the effectiveness of using various inputs or groups (Duncan & Elwell, 1980). Production activities and their associated waste management have become an essential concern for the global community, as they can affect sustainable development in a region (Hettiarachchi et al., 2020).

The development of the palm oil-based industry continues to increase, marked by the high level of productivity of the production units owned by the palm oil industry. According to the Indonesian Palm Oil Association (GAPKI), Indonesia’s crude palm oil (CPO) and palm kernel oil (PKO) production for 2024 reached 52.76 million tons, with CPO contributing 48.16 million tons and PKO 4.60 million tons. Indonesia is the world's largest palm oil exporter, with a palm oil export value 2024 reaching $27.76 billion. Although clearing rainforests for palm oil production has caused some backlash against palm oil products from Indonesia, the fact is that palm oil production in Indonesia has continued to increase in recent years.

Unfortunately, increased palm oil caused environmental problems as a follow-up effect of the provision and utilisation of production resources. Many issues are produced by waste from material, gas emissions from the fuel used, and chemical solutions from production waste that will burden the environment. The concept of a good production process must pay attention to environmental safety, minimise the side effects of its waste, and reduce the waste produced (Tenaw 2025). Therefore, a sustainable waste management strategy is needed that considers efforts to minimise the waste produced (Anwar et al. 2025). As global environmental issues become increasingly urgent in facing the challenges of climate change, energy, and pollution, environmental governance is needed to implement green environmental development, although its implementation still requires high supervision. (Lu and Yi 2025).

The issue of industrial waste in Indonesia is an environmental problem that urgently needs to be addressed. Along with the increasing palm oil processing industry, the amount of waste produced is also increasing. The solid waste is in the form of empty bunches, shells, and fibres. Liquid waste as a by-product of palm oil processing contains high levels of organic pollutants, such as Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD). Direct disposal of liquid waste without prior treatment will pollute rivers, lakes, and seas, damage aquatic ecosystems, and threaten clean water sources. The impact of palm oil waste can cause a very sharp odour due to the damage to the organic materials it contains and pollution in the air, and can damage the air ecosystem. Liquid waste is hazardous for the surrounding community, causing itching and polluting water sources commonly used by the community. Therefore, more environmentally friendly, economical, and sustainable waste management and processing is needed.

The application of Green Productivity can be used to overcome the problem of industrial environmental damage (Bai et al. 2024). Green Productivity is a strategy that simultaneously integrates increased productivity and environmental performance by providing alternative solutions for improvement (Li and Ouyang 2020). Green Productivity has four main objectives: waste reduction, pollution prevention, material management, and product

improvement (Asian Productivity Organization 2006). Productivity is essential for companies as one of the guidelines for continuous improvement. Along with the increasing issue of environmentally friendly productivity, companies need to review the waste that arises during the production process so that it meets green standards.

Green Productivity is very interesting to implement because it combines efforts to increase productivity and mitigate environmental impacts to achieve sustainable profits. This study aims to identify waste utilisation that can increase productivity and reduce environmental pollution with a green productivity approach. The EPI indicators measure how countries achieve environmental policy targets for ecological health and ecosystem vitality. The EPI also provides performance scores to identify leading and lagging countries and offers practical guidance towards sustainability. EPI also supports the achievement of the Sustainable Development Goals (SDGs) and provides insights for policymakers to refine their environmental strategies effectively.

2. Methodology

All determine the real conditions of the company, especially in processes that produce a lot of waste. After obtaining a picture from the initial survey and knowing the obstacles faced by the company, a literature study was conducted to support the research to be carried out, so that the research has a focused theoretical basis and provides optimal solution results. The research began with a comprehensive review and observation of a palm oil processing facility focused on producing crude palm oil, aiming to identify and understand existing challenges within the industry. The research was conducted in five distinct stages: the preliminary phase, data collection phase, data processing phase, data analysis phase, and conclusion-drawing phase.

The research began with reviewing and observing the palm oil processing industry to produce crude palm oil to obtain a detailed picture of the existing problems. This research was conducted through five stages: the preliminary stage, data collection stage, data processing stage, data analysis stage, and conclusion drawing stage. Field studies and literature studies were conducted in the preliminary stage, which is the initial step of the research. The field study aims to

The data collection stage includes interviews and direct observation. The data consists of an industry overview, production process, input and output of production results, chemical content analysis data, and questionnaire distribution. The questionnaire is intended to determine the weight value of each chemical substance's danger level to the parameters of environmental balance and human health. The research respondents are employees who understand waste in the palm oil industry.

The data processing stage is processing the collected data to obtain results according to the objectives set. Data processing includes measuring the level of productivity, calculating the Environmental Performance Indicator (EPI) index, identifying factors that affect the level of productivity and environmental performance and compiling alternative improvements, selecting alternative enhancements based on the highest Benefit Cost Ratio (BCR) index value, estimating the contribution of selected alternatives to productivity and environmental performance in the utilization of liquid waste, and compiling an implementation plan.

Estimation of the contribution of selected alternatives to productivity and environmental performance. The productivity increase figure and EPI index are estimated after finding the best alternative and conducting its technical analysis. One of the main objectives of the Green Productivity concept is to increase productivity while still considering environmental performance. Furthermore, the preparation of the implementation plan is a continuation of the technical feasibility analysis and will involve the creation of an implementation plan schedule. Analysis and discussion of data processing results are carried out at the analysis stage. At the final stage, conclusions will be drawn from the research results

3. Results

3.1. Field Study

PT. ABC's palm oil mill utilizes palm oil to produce Crude Palm Oil (CPO), palm kernels, and some residual liquid waste. The liquid waste originates from areas of the factory where fruit is steamed, oil is separated, and kernels are processed. PT. ABC's waste treatment system uses ponding, which means the waste is held in special ponds where it breaks down with and without air. This type of treatment cannot be used directly on land because the waste still does not meet safety standards.

3.2. Calculating Productivity Level

Producticity is obtained by comparing total output with total input. Input factors include primary material input and production input, while output factors represent the output of production results (in rupiah). The company's total productivity level is calculated using the following equation:

$$\text{Total Productivity Index} = \frac{\text{Total Output}}{\text{Total Input}} \times 100\% \quad (1)$$

The results of the productivity index calculation for PT. ABC can be seen in Figure 1.

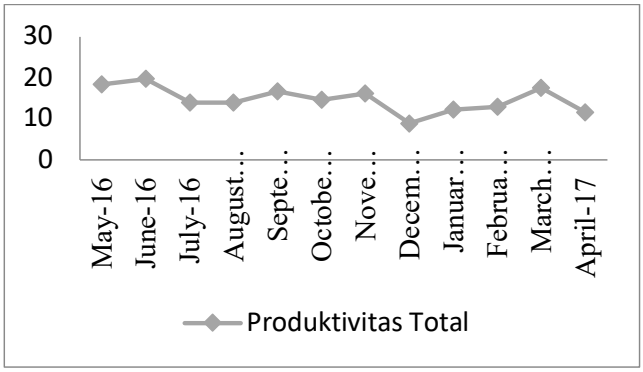

Figure 1. Productivity Level PT. ABC

From the image above, it can be seen that PT. ABC's total productivity experienced a decline in productivity in December 2016 and April 2017. The productivity level is greatly influenced by raw materials.

3.3. Calculation of the Environmental Performance Indicator (EPI) Index

There is no fixed (consistent) basis for selecting indicators, the number of indicators, measurement techniques, or standard requirements. The EPI reflects the environmental efficiency of a production process involving a number of inputs and outputs. The characteristics of the EPI are (a) relevance, (b) analytical accuracy, (c) measurability, and (d) comparability.

The EPI index is calculated by multiplying the deviation value between the BAPEDAL standard and the company's analysis results by the weight of each waste criterion obtained through questionnaire distribution. The EPI index is calculated using the following formula:

$$\text{EPI Index} = \sum_{i=1}^{k} \text{Wi.Pi} \quad (2)$$

The Wi is the weight of the i-th variable obtained from the questionnaire, while the Pi value is the percentage deviation between the BAPEDAL standard and PT. ABC, with the formula:

$$Pi = \frac{\text{Standar - Analisis}}{\text{Standar}} \times 100\% \quad (3)$$

To obtain a weighted value for the hazard level of the environmental indicators used as measurements in the EPI index, the scale used ranges from 1 to 5, with higher values indicating greater hazard levels. The distributed questionnaire was divided into two sections: one based on human health parameters and one based on fauna health parameters. The questionnaire was distributed to eight workers.

The total EPI index calculated for human health (Table 1) was -3,467.71, and for flora and fauna health (Table 2) was -7,993.81. This indicates that the RPA's environmental performance is still below the quality standard. A negative EPI value indicates that environmental pollution could endanger the environment at PT. ABC.

Table 1. EPI Index for Human Health Parameters.

Indicators	Bobot (Wi)	Liquid Waste Standards	Analysis Results	Devitation (Pi)	EPI Index
BOD	4,8	100 mg/l	25.500 mg/l	-254	-1.219,2
COD	6	350 mg/l	48.000 mg/l	-136,143	-816,857
TSS	5,2	250 mg/l	29.000 mg/l	-115	-598
Ph	4,4	6,0-9,0	4,6	0,488	2,151
Minyak	4,2	25 mg/l	5.000 mg/l	-199	-835,8
		Total			-3.467,71

Table 2. EPI Index for Flora and Fauna Health Parameters.

Indicators	Bobot (Wi)	Liquid Waste Standards	Analysis Results	Devitation (Pi)	EPI Index
BOD	5,6	100 mg/l	25.500 mg/l	-254	-1.422,4
COD	6,4	350 mg/l	48.000 mg/l	-136,143	-871,31
TSS	6	250 mg/l	29.000 mg/l	-115	-690
pH	5,2	6,0-9,0	4,6	0,488	4,71
Minyak	6	25 mg/l	5.000 mg/l	-199	-5.014,8
		Total			-7.993,81

3.4. Problem Identification and Causes

The steps taken to identify the problem included gathering information on palm oil processing and the environmental impact of liquid waste management using an Ishikawa diagram. Based on observations and interviews, it was found that the liquid waste management involves treatment, such as constructing holding ponds and using aeration technology to reduce the BOD and COD values. Once the specified threshold is reached, the waste is returned to the environment.

The Ishikawa diagram was used to identify the root cause of the problem. The results of the Ishikawa diagram analysis were obtained based on interviews conducted in the field. The Ishikawa diagram can be seen in Figure 2.

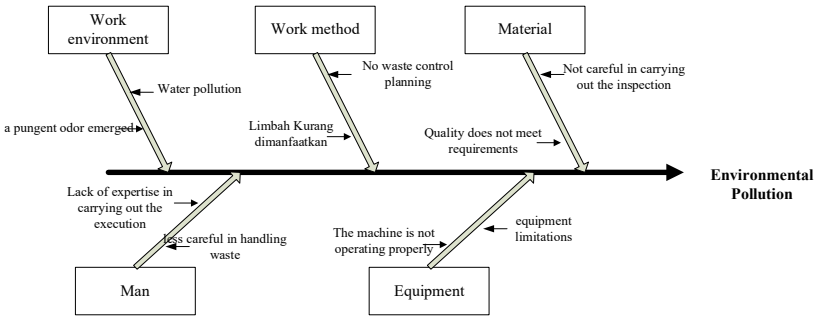

Figure 2. Ishikawa Diagram

Based on Figure 2, the liquid waste produced from oil processing requires action to address the negative impacts of waste on the environment. Waste management is a serious issue that must be considered to maintain environmental sustainability and prevent negative impacts on surrounding communities.

3.5. Developing Alternative Solutions

The researchers' proposed alternative solutions are as follows:

a. Based on the hierarchy of pollution prevention, according to the order of reduce, reuse, and recycle, reduction is achieved by using liquid waste as biodiesel fuel, which can replace diesel fuel. Therefore, alternative 1 is proposed to solve this problem.
b. Based on this hierarchy, reuse and recycling are still feasible. Therefore, liquid waste can be processed into biogas (PLTBg), which can be used as a substitute for the electricity needed by the factory. This can help increase productivity and save electricity costs; therefore, alternative 2 is proposed.

3.6. Selection of Improvement Alternatives Based on the Benefit-Cost Ratio

The benefit-cost ratio analysis is estimated for the next 5 years and an interest rate of 8%. The results of the benefit-cost ratio index calculation for each proposed alternative are as follows:

$$\text{Index BCR Alternative 1} = \frac{\text{Benefit}}{\text{Cost}}$$

$$= \frac{\text{Rp.70.726.626.864}}{\text{Rp.12.270.237.829}} = 5{,}764 \quad (4)$$

And,

$$\text{Index BCR Alternative 2} = \frac{\text{Benefit}}{\text{Cost}}$$

$$= \frac{\text{Rp.275.378.439.835}}{\text{Rp.9.906.690.835}} = 27{,}797 \quad (5)$$

Based on the BCR index calculation results, it can be seen that alternative 1 has a BCR index of 5.764 and alternative 2 has a BCR index of 27.797. Therefore, alternative 2 was chosen as the alternative solution, namely PLTBg processing.

3.7. Estimating Alternative Solutions

Estimating alternative solutions is done to determine the productivity level of each alternative. The formula for calculating the estimated productivity is:

$$\text{Estimated Productivity} = \frac{\text{Total Output}}{\text{Total Input}} \quad (6)$$

A summary of the results from calculating five green productivity indicators for the two alternative actions on waste utilisation in palm oil mills is presented in Table 3.

Table 3. Summary of Productivity Increase Calculations.

Factors	Real Condition	Alternative 1	Alternative 2
Penjualan Minyak dan Inti Sawit	13.304.765.849	17.712.653.860	68.965.299.233
Input Material	124.115.784	260.009.934	1.550.283.143
Input Tenaga Kerja	329.264.521	41.284.521	41.284.521
Input Energi	239.224.324	137.008.736	136.823.525
Input maintance	242.646.633	506.025.318	407.999.286
Total Productivity	14,22	18,75	32,28

The average total productivity value obtained for the period May 2016-April 2017 was 14.22 and the total productivity estimate for alternative 2 was 32.28, which means there was an estimated increase in productivity of 18.05%.

4. Analisys

This research aims to address the issue of liquid waste processing methods that do not support the principles of recycling, reuse, or reduction. Therefore, companies must develop liquid waste processing technologies. There are two alternatives to address this waste problem: Alternative 1, utilising liquid waste processing technology to produce biodiesel, and Alternative 2, converting liquid waste into a biogas power plant (PLTBg). Waste is used as biodiesel fuel to replace the use of diesel fuel. Meanwhile, the selection of waste technology as a Biogas Power Plant (PLTBg) can reduce electricity costs in the factory. The selected technologies are expected to increase green productivity and create an environmentally friendly industry. The selection of the best alternative between the two is done by comparing the green productivity ratio (GPR) index, Green Productivity Index (GPI), benefit cost ratio and productivity calculations.

Implementing the chosen alternative or proposal, a work strategy is required so that it can be implemented well, namely:

a. Trial and small scale implementation to minimise and assess the potential impact on the existing system, it is recommended to conduct trials and implementations on a small scale first.
b. Regular meetings and trouble shotting session to ensure good communication between departments, the team meets weekly to review and compile any problems encountered during implementation and discuss any necessary corrective actions, all while maintaining the objectives of the alternative selection.
c. Follow-up and accountability. Each section understands its duties and responsibilities in implementing the alternative. This was done before the implementation trial. During the session, employee duties and responsibilities were clearly explained.
d. Allocating resources ensures that the necessary resources are available when needed, thereby maximising time efficiency.
e. Management support is essential to ensure that the workforce provides the necessary support for successful implementation.

5. Conclusion

The green productivity approach yielded these conclusions from the productivity and processing measurement research:

a. The productivity index value from May 2016 to April 2017 was lowest in December 2016, at 8.918, and highest in June 2016, at 19.706.
b. The company investigated liquid waste, which negatively impacts human health, flora, and fauna. The EPI index was -3,467.71 for human health and -7,993.81 for flora and fauna.
c. Proposed alternatives: establish a biodiesel process using liquid waste (alternative 1) or convert liquid waste into fuel for a biogas power plant (PLTBg) (alternative 2).
d. Benefit-cost ratio analysis over five years showed a BCR of 5.764 for alternative 1 and 27.797 for alternative 2. Calculations favored alternative 2.
e. The average total productivity obtained from May 2016 to April 2017 was 14.22, and after estimation, the total productivity for alternative 2 was 32.28, representing an 18.05% increase in productivity.

In implementing green productivity, the PT. ABC palm oil mill is expected to implement various strategies proposed to utilise the liquid waste produced as biodiesel fuel; however, this effort requires technological readiness and investment capital.

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