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Material Flow Cost Accounting in Palm Oil: Promoting Transparency in the Use of Materials and Appropriate Scenario in Resource Saving and Waste Reduction

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Abstract. The sustainability aspect of the palm oil business strategy is a significant part of dealing with changes in the future. The rest of the processed products that have not been handled perfectly is a form of material loss that reduces income and environmental sustainability. Even though the company has reported and compiled its responsibilities, the actual productivity of the company is much lower because the amount of hidden waste has not been fully considered. This research involves companies introducing material flow cost accounting in tracing and calculating physical resources and financing. This method helps companies to determine the number of negative and positive products as a basis for evaluation for saving resources and reducing environmental impacts through reducing oil losses and increasing yields. This effort will become a competitive advantage and encourage the ability of business actors to increase revenue and reduce waste. Scenarios of improving the quality of fresh fruit bunches, optimizing the sterilization process, and increasing the amount of pulp are adaptive choices in terms of availability and resource capacity. Dissemination of efforts and successes in improving resource efficiency to stakeholders is vital to increasing the value and sustainability of the palm oil business.

Keywords: Material flow cost accounting; Palm oil; Resource-saving; Waste reduction

1. Introduction

The Indonesian palm oil industry contributes significantly to foreign exchange, promotes energy sovereignty, builds people's economy, and provides employment opportunities to face the dynamics of change (Directorate General Crop Estate, 2019). On the other hand, the Indonesian palm oil industry also contributes as a source of pollutants from agricultural land residues associated with palm oil production (fertilizers, pesticides, and other hazardous wastes). Global production and demand for palm oil and its derivatives are increasing rapidly. Expansion of the palm oil business requires investment and high awareness of environmental sustainability. Therefore, Palm Oil Mills (POM) are required to produce products with predetermined quality standards, save energy during the process, and sustainably manage natural resources (Hambali and Rivai, 2017). This condition

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encourages more effective management techniques that increase organizational output and performance (Ministry of Environment and Forestry, 2019). Palm oil companies must make improvements to milestones, identify hotspots (areas for improvement), conserve resources, and meet the requirements for sustainable adaptation (Ghadimi, Kara, and Herrmann, 2014).

In reality, many palm oil companies have not fully considered the relationship between efficiency, finance, and environmental impact as a system that shows unexpected costs (Harahap *et al.*, 2019). Conventional handling of waste and by-products has contributed to saving energy resources and reducing waste. However, this activity has not been able to balance the rate of environmental damage because of limited technology, cost allocation, and the availability of adequate land for waste disposal. This situation must be immediately followed up by increasing the scope of the hidden waste value, which is still low. Increasing resources transparency using material flow cost accounting (MFCA) is very important to illustrate the level of waste, inventory, and cost allocation, as has been done by Walz and Guenther (2021), Tran and Herzig (2020), and Kokubu and Tachikawa (2013)

Various problems, which may occur in supply chain activities, such as waste, incompatibility of processes and results, and even fraud, can be overcome by reconciling the calculated numbers, which sometimes become hidden things. The purpose of this study is to analyze the production process using a material flow cost accounting (MFCA) framework that can be used to find opportunities to reduce material use and/or material losses, increase material and energy efficiency, and reduce adverse environmental impacts. To our best knowledge, there has been no studies on transparency of the materials involved in palm oil production with the production cost approach as a form of application of material flow cost accounting. While this topic is very important to show the value of costs invested as waste that should be reduced for efficiency improvement. Therefore, this study give insight on the value of negative products waste treatment cost to encourage evaluation, improvement, and mapping of savings in the utilization of negative products for the sustainable palm oil industry.

The main contribution of this study was providing valuable insights for policymakers seeking to promote sustainable practices in the palm oil industry. By identifying opportunities for reducing waste and improving resource efficiency, policymakers can develop policies and regulations that incentivize sustainable practices and reduce the industry's environmental impact.

2. Methods

This research was conducted from March to April 2018 at the government-owned palm oil mills (POM) and plantations in Banten Province and in February 2020 in North Sumatra. The production system at the Banten palm oil mill is used as the initial object of the primary data measurement and the secondary data collection, starting from the seedling, cultivation, and processing of palm fruit bunches through interviews, observations, and direct calculations during the activity. Adopting the ISO 14051 standard, plant implementers are involved in identifying achievements and evaluating undocumented waste management. This activity has not been included in the determination of the costs of materials, energy, and systems involved in the quantity center. Secondary data was collected from the 2016-2018 PTPN VIII database and annual report. Supporting data for the benchmarking, including the processing of fresh fruit bunches, is also obtained, with a restricted permit and authority at the Palm Oil Mills (POM) at PTPN IV North Sumatra (POM Pasir Mandoge and POM Tinjowan) and the Ministry of Environment and Forestry Forum for discussion on sustainable topics. The four elements used to compose an MFCA are as follows:

1) Supply chain of raw materials, such as fresh fruit bunches (FFB), water, and chemicals for water treatment and laboratory consumables.
2) Process sequence flow; there are 37 stages based on the number of groups of machines and facilities installed in the factory; in this study, the processing chain was simplified into five main processes for the CPO, and one for the kernel, energy generation, and water treatment.
3) The allocation of costs related to materials (as the basis of quantity centers) is determined by limit and period.
4) A material flow model is built to visualize the relative quantity, product cost, and flow loss shown in the quantity center.

2.1. Mass and Energy Balance

All the said palm oil mills have an average installed capacity of 60 tons of FFB/hour, two work shifts, minimum production of around 2,500-3400 tons of oil, and operate in 25 working days per month with almost 80-90 percent of the employees being the residents. Most of the factory's products are marketed in the form of palm oil and palm kernel for domestic use. The mass and energy balances are prepared based on the calculated size of one ton of fresh fruit bunches (FFB) as a functional unit. The flow and inventory of materials in the palm oil mills are traced and calculated with variable *i,* the balance of materials in mill system *j,* and the energy generation for the boiler is calculated. The flow rate of the input material (fresh fruit bunches) is expressed in the variable *Fi,* and the energy (steam and electricity) from the turbine and generator is distributed to process *j,* and the flow rate is *F_ij* (Equation 1). The time of harvesting season related to fluctuations in the cost of these materials is shown as *s,* where the given input *i* will vary, and the maturity fraction (which determines the price) at The handling of raw materials in the processing system follows the methodology of previous research conducted by Foong *et al.* (2018) and Foong *et al.* (2019) (Equation 1-5).

$$\left(F_i\right)_s = \left(\sum_{j=1}^{J} B_j F_{ij}\right)_s \quad \forall\ i,\ \forall\ s \tag{1}$$

The amount of oil percentage and palm kernel from input material i (O_i) is determined by Equation 2.

$$\left(O_i\right)_s = \left(F_i OP_i\right)_s \quad \forall\ i,\ \forall s \tag{2}$$

Input material i is processed into intermediate product p with a conversion X_{ijp}. The total production rate for intermediate product p (F_p) applying technologies j is distributed to an advanced process j' to produce final product p' (including oil recovery treatment), as calculated by Equation 3.

$$\left(F_p\right)_s = \left(\sum_{i=1}^{I}\sum_{j=1}^{J} B_j F_{ij} X_{ijp}\right)_s \quad \forall p,\ \forall s \tag{3}$$

The amount of intermediate product after processing p is shown in Equation 4, where F_pe represents the flow rate of intermediate product p, which is sent to the advanced process j' with a flow rate of $F_{pj'}$.

$$\left(F_p\right)_s = \left(\sum_{j'=1}^{J'} B_j F_{pj'}\right)_s \quad \forall p,\ \ \forall s \tag{4}$$

Where B_(j^') represents the advanced process technology j′ that utilizes and manages resources to convert the intermediate product p (F_{pj}) into final product p′ with a conversion $X_{j'p'}$ in the advanced technology j′. The resulting flow rate of final product p′ is denoted as ($F_{p'}$), as calculated by Equation 5.

$$\left(F_p\right)_s = \left(\sum_{p=1}^{P}\sum_{j'=1}^{J} B_{j'} F_{pj'} X_{pj'p'}\right) \quad \forall p',\ \forall s \tag{5}$$

This formula is used repeatedly for several processing steps in this study. The value of the cost estimation system becomes the most challenging part to identify because of the lack of variation in the variations of costs allocations involved. Based on the value of the same production-consumption balance, all inputs to the process must be traced to the flow to output in physical form (weight), and the costs used are based on the plan–do-check–action (PDCA) cycle in the ISO 14051 guide (Dekamin and Barmaki, 2019; Tachikawa, 2014).

2.2. Cost Accounting

This section is to identify the flow costs and availability of fresh fruit bunches, biomasses, intermediate products, and fossil fuels within the mill. The search and calculation (in units of mass and volume) are performed with the proportion of use and its weight to be referred to in the quantity center with the following allocation:

a) Material costs; for the materials involved (with input and output units of measurement for MFCA analysis), including fresh fruit bunches in the initial processing, intermediate products to product, chemicals for water treatment, and quality testing in the laboratory. Exposure can be used to promote transparency in material and energy flows.
b) Energy costs; the cost allocated to energy sources, such as electricity, fuel, steam, heat from biomass, and compression for process purposes, which are calculated together with the energy audit.
c) System costs; the cost allocated to material handling, employee wages and salaries, depreciation, maintenance, overhead costs, and non-material and energy allocations.
d) Waste management costs; the cost allocated to handling several aspects, including residual biomass, solid waste, palm oil mill effluent, and emissions with other particles from boilers.

These production costs are the primary budget components for the palm oil production processes (Dierkes and Siepelmeyer, 2019).

2.3. Material Flow Model

The formulation of the flow model began with determining the scope and boundaries of the process and establishing a material flow scheme (Tran and Herzig, 2020). Material flow analysis models have generally been used to track production, utilization, and materials consumption (Suh and Heijungs, 2007). Buchner *et al.* (2015) emphasized the need for a comprehensive sensitivity analysis that considers the interaction between parameters and the effect of time delays in dynamic material flow models. The identification of the model uncertainty is made by tracing the structure of the model and its parameters. The assumption used in this study is that no remaining products are used after the end of the production period, which may considerably impact the remaining amount of the inventory used. This condition will affect the model results on the production and inventory used. Fresh fruit bunches (FFB) must be processed as soon as possible to anticipate the reduction of the palm oil quality; hence, there should be no leftovers or supplies.

2.4. Formulation of Resource Saving and Waste Reduction Scenarios

The first step in this study is assessing the hotspots (areas for improvement) for the material used in crude palm oil production. In most palm oil mills, the produced non-product output is 70-75%, while the rest is CPO & kernel. Palm oil mills with relatively high FFB use require adequate facilities and infrastructure capacity to keep pace with economic growth (usually related to infrastructure investment) and regulations referring to, among others, ISPO (Indonesia Sustainable Palm Oil) and PROPER (Company Performance Rating Program).

3. Results and Discussion

3.1. Mass and Energy Balance

The amount of energy consumption for the production process is 16.78-17.53 kWh/ton FFB is obtained from the turbine generator in the palm oil mill (POM) (at an average of 14.07 – 14.92 kWh/ton FFB), and the rest is from the State Electricity Company (PLN) supply (Figure 1). Meanwhile, fiber and shell are used as fuel for water tube boilers to produce hot steam with an average efficiency of 74.5% and feeding water of 87.6°C.

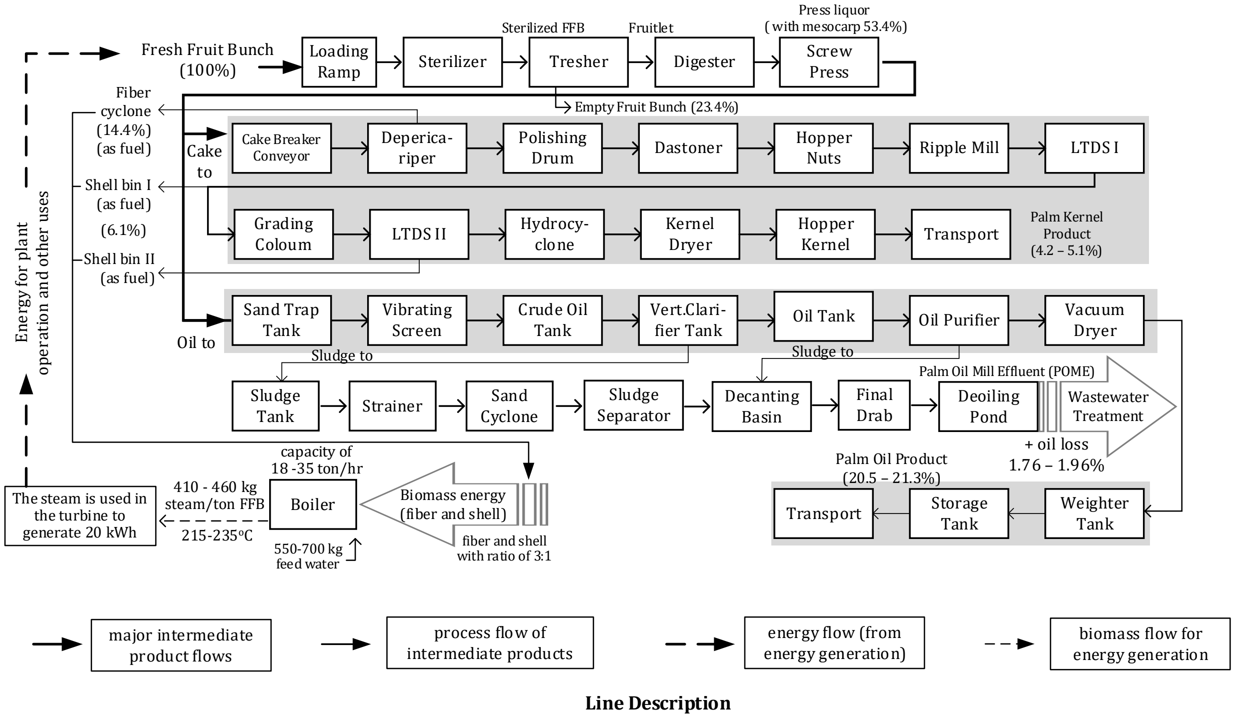

Figure 1 Material and Energy Balance of Palm Oil Processing

The average FFB processed amount is 1,574 tons per month, with a minimum operation of 30 tons/hour for an average processing capacity. However, a shortage of FFB supply occurred during the data collection; thus, 10,558 tons/month were used for calculations instead. All materials involved in the total initial input were identified as 25% product, 72% solid waste, and 84% liquid waste from supplementary usage of production water and steam. In a previous study, it was stated that recycling waste streams would reduce water consumption and the amount of palm oil mill effluent (POME) by 65-68% and 67%, respectively (Chungsiriporn, Prasertsan and Bunyakan, 2006).

3.2. Cost Accounting

Even though the yield and utilization of waste have increased, unwanted materials are still generated and require considerable energy and cost to treat. With a minimum average of 10,558 tons of the processed FFB, the product capacity that can be achieved is 2,147.5

tons of CPO (20.34% yield; 1.65% loss) and 385.37 tons of kernel (3.85% yield; oil loss of 0.5%). Therefore, the current converted average price levels are USD 686 for CPO per tonne and USD 567 for kernels per tonne. Meanwhile, the total expected revenue from sales is USD 1,691,689.79 (Tables 2 and 3). The material flow cost can be seen in Supplementary 1.

Based on the mass balance and material flow model, the negative product output consists of the following:

1. Solid waste, such as petals, leaves, insects, dirt, and other impurities in the grading area, which is in a minute amount compared to the number of fresh fruit bunches (FFB), empty fruit bunches (EFB) (including fruit and oil loss in EFB 2,470±14); fiber (760±3 tonnes); and, shells (675±64 tonnes) and light particles (±52.79 tonnes).
2. Liquid waste, such as condensate (water and oil) from the sterilization process (1,583±28 tonnes), effluent from the clarification (5384±443 tonnes), and effluent from palm kernel recovery plan (hydro-cyclone 844±147 tonnes), boiler blowdown (1,266±137 tonnes), and others (±1,055 tonnes).

Although waste management reporting and evaluation are conducted annually, there has not been much improvement in mitigating the accumulation of residual waste. Lagoon systems and solid waste final disposal are the most commonly used methods in most palm oil mills due to their suitability for use in Indonesia. These waste management methods are chosen because they require limited technology, have low maintenance costs, are energy-efficient, and have a simple design. However, these systems have some drawbacks, such as long hydraulic retention times, large lagoon areas (Hayawin *et al.*, 2018), and the potential release of significant amounts of greenhouse gases like methane.

One of the discussions in this study results in the comparison between the percentage of solid and liquid waste produced that is not much different from the output produced by the POM Agency in North Sumatra. The average value of the negative products is USD 537,718 (46.43%), and the value of the positive products is USD 723,706 (53.57%), along with the waste treatment costs (9.475%), including the allocation of the costs for handling empty fruit bunches (EFB), drying process fibers, and shells for boiler feed, and other processes for the treatment of residual solid waste. The waste treatment costs include monetary allocations for handling POME, around 27 percent from sterilization (fat-fit), 44 percent from sludge decanter, and 29 percent from hydro-cyclone. This material is used to show the value of all negative losses/products produced (Dierkes and Siepelmeyer, 2019). The most compelling finding of this study is the role of biomass in energy cost reduction. Its contribution comes from 96% energy (85% fiber and 15% shell) and 4% from diesel, with a total efficiency of 56.05%. These results can be used to control the level of target costs reached in real time and introduce prompt corrections regarding the planned costs according to external and internal changes (Burova *et al.*, 2021).

Another interesting finding is the potential for recovering trapped oil in each process phase and by-product to increase the oil extraction rate (OER). The trapped oil was found in empty fruit bunches (EFB) 0.31±0.08%, cakes 0.78±0.05%, nuts 0.10±0.05%, fruit in FFB 0.13±0.04 %, condensate (fat-fit) 0.16±0.04%, fiber cyclone (0.2%), light tenera dry separating (LTDS) 0.23±0.08%, and clay-bath ±0.07 % with a total oil loss of 1.67 – 1.96%. The types of losses that occur within the scope of the calculation affect the quality of the results, process losses, and quality degradation. Based on the material flow cost table (Table 3), every 0.5% increase in the oil extraction rate (OER) will increase USD 8,458.45 or USD 3.94 per tonne of CPO. It has revived the company to carry out improvement scenarios as an added value to the industry.

Table 1 Material Flow Cost of Palm Oil Processing

Item	QC 1 (Grading - loading ramp)	QC 2 (Sterilization)	QC 3 (Threshing)	QC (Pressing)	QC 5 (Clarification)	QC 6 (Kernel Processing)	QC 7 (Energy generation)	QC 8 (Water Treatment)
Product (total material cost in USD)	1,192,422	1,202,653	959,021	787,356	746,962	715,696	717,638	723,705
Allocation cost	99,99%	88.30%	64.60%	42.92%	21.24%	4.52%	NA	NA
Waste (from fresh fruit bunch)	0,01%	11,69%	23.40%	49.26%	71.54%	~74.23%	NA	NA
System cost	4.23	14,095	24,136	25,806	25,836	36,565	44,038	47,887
Energy cost	205	464	727	571	421	422	784	802

Table 2 Total Output and Contribution in Cost Allocation

Output	Total material (ton)	Percentage	Total cost (USD)	Percentage
Positive product	2726	24.19%*	723,706	57.37%
Negative product	7854	75.81%	537,718	42.63%

*positive product = palm oil and kernel

Efforts to increase yield/oil require additional costs for material handling, labor wages, and system maintenance have not been studied because of the limited authority of researchers. This activity requires a continuous evaluation and contribution to the system improvement. Recommendations and follow-up scenarios are decided based on a quantity center analysis that does not much change the work patterns without new technology addition, low investment, and synergies with the increase of employee capabilities (Table 3). Reducing losses and increasing oil yield are two scenario options that can improve the quality of fresh fruit bunches. This can be achieved by optimizing the sterilization of empty bunches and suppressing mesocarp. The chosen scenario aligns with previous research conducted by Gomez *et al.* (2015), Cock *et al.* (2014), Noorshamsiana *et al.* (2013), and Subramaniam *et al.* (2013). By implementing this scenario, it is expected that the value of a sustainable business will increase.

Table 3 Potential Scenario for Oil Losses Reduction

Potential Scenario	Main activities	Achievement
To recover trapped oil in mesocarp (residual oil recovery system)	(a) Using a washing technique at a particular temperature, followed by pressing in the digester and screw press to recover oil (b) Utilizing ± 7.8% of biomass (shell and fiber); and (c) Reallocating resources and schedule to conduct these activities.	(a) Increased potential oil recovery/reduced oil loss (b) more solid waste is utilized as biomass energy (c) Determination of method, quality, and quantity of palm oil standard
To recover oil from the empty fruit bunch	(a) Re-sterilization of poorly recovered un-stripped bunches. (b) Using aqueous extraction (water and steam) to increase the oil extraction rate (using hydro solvent) (c) Performing the setup and installation to improve the lab-scale capacity to the pilot plant	(a) Report of a feasibility study for remaining shell and fiber utilization as biomass energy (b) Improved combustion efficiency of EFB after this treatment (c) Collaboration with academics to conduct further studies on oil-water emulsion using micro-separation technologies, such as column flotation
To ensure the maturity level & good handling practices on harvesting for audit data assessment enhancement	(a) Enhancing harvesting strategy for bunch analysis of the minimum number of detached fruits per bunch (b) Strictly maintaining audit data with harvesting round to estimate oil content before the delivery to the mill. (c) Cutting only ripe bunches and ensuring no ripe is left behind (d) Disseminating best practices and supervision to picking up all loose fruits	(a) Mitigation of insufficient harvesters by estimating potential product contents of individual FFB deliveries (b) Reliable assessment and supervision system for oil recovery efficiency (ORE) from the plantation until the mill (c) Provision of an accurate account and information to improve crop recovery plantation (d) Reduced unstandardized FFB in POM
To combine three potential scenarios	(a) Developing standard operations and procedures to drive the roles of line managers and human resources of palm oil mills and plantation (b) Developing appropriate skills and awareness of employees and upgrading them to required levels. (c) Synergizing with academics, the government, and industry to enhance capacity building for farmer	(a) Adjustments to some working operations and resources based on improvement results (b) Assessment and monitoring conducted in the factual working situation without less investment (c) Requirement of assessment and policies in a coherent approach and supported by an IT-based environment for integrated resource efficiency analysis

Scenario formulations for oil loss are available by gradually expanding the scope of material flow analysis (MFA) to material flow cost accounting (MFCA) following the given authority. The identified 'Hotspots' will later be used to assess the success of these efforts. Documentation of the production stage to waste handling plays a significant role in material efficiency and waste management as the innovative potential of alternative energy at the level of an economic entity in the context of increasing the global significance of the transition to the circular economy (Zaytsev *et al.*, 2021).

3.3. Material Flow Model

The material flow model is in line with the use of the processing costs usage model that involved materials, labor, energy, utilities, depreciation, and other usage costs. The amount of each use is still hard to identify because the production process runs continuously (Let, Weng, and Wahid, 2010). Improvement scenarios require the approval and involvement of all stakeholders for the amount of material and costs spent. To address several limitations, such as those related to authority, documentation, and reporting capabilities, the flow scheme is presented in a simple manner by comparing inputs and outputs, as illustrated in Supplementary 2. This scheme provides a comprehensive assessment of the proportion of each material and energy use, products, by-products, waste, and losses to assess the achievement and justification of the applied instruments, as noted by Egorova *et al.* (2021).

Standardization of improvement and calculation of resource use with sensitivity requires technology to actualize transparency, especially regarding the price, traceability of fresh fruit bunches, quality, process, and waste treatment as a monitoring system for the palm oil industry and policymakers (Heryani *et al.*, 2022). The standardization is vital in increasing the transparency of the resources used as these activities sometimes interfere with the processing at the factory, and there is limited reporting authority. Therefore, these results are needed to stimulate the integration of the analysis of each scenario using life cycle assessments for the feasibility of a sustainable palm oil industry.

4. Conclusions

The calculation of the production process data using information obtained from a POM in Banten showed a high percentage of negative products (±75.81%), with a waste treatment cost of 42.63% of the expenditure. MFCA also illustrates that the allocation of financing for materials is a hidden waste so that the flow of supporting resources transparency becomes the basis for evaluation, improvement, and mapping of savings in a more detailed supply chain. Investing in research and development to improve oil recovery and material efficiency and to identify new opportunities for resource optimization play important role in complying with sustainability standards such as the Indonesian Sustainable Palm Oil and Roundtable on Sustainable Palm Oil (RSPO), which require companies to minimize their environmental impact and promote sustainable practices. By implementing MFCA, palm oil companies can demonstrate their commitment to sustainability, differentiate themselves from competitors who may not be taking similar steps, and enhancing a company's reputation among consumers and stakeholders.

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