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Implementation Of Green Economy In Palm Oil Industry Companies Through Utilizing Waste Into Biogas And Organic Fertilizer

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Abstract

The palm oil industry produces products with economic value, as well as liquid and solid residues that require sustainable management. Palm oil mill effluent (POME) contains high levels of organic matter and, if managed in open ponds without gas capture, has the potential to release methane. Meanwhile, empty oil palm bunches (EFB), decanter solids, fiber, and other biomass residues have the potential to be used as raw materials for compost and organic products. This study aims to analyze the implementation of green economy principles in palm oil industry companies through the integration of POME utilization into biogas and solid waste into organic fertilizer. The study used a structured narrative literature review approach to Indonesian scientific publications from 2021–2026 that are relevant to POME biogas, methane capture, EFB composting, clean production, the circular economy, and the sustainability of the palm oil industry. Data were analyzed through relevance selection, information extraction, theme grouping, and comparative synthesis. Literature shows that anaerobic processing of POME can produce biogas for internal energy while reducing methane release, while composting of EFB and decanter solids can produce nutrient-rich soil amendments. Integrating these two pathways has the potential to enhance resource efficiency, reduce pollution loads, and create added value. However, actual benefits depend on raw material quality, technology design, process control, investment feasibility, product quality, and environmental governance. The novelty of this study lies in the integrative framework that connects energy recovery from wastewater and nutrient recovery from solid waste as a single circular economy system at the company level. This study does not claim to measure specific company performance because it does not use primary data.

Keywords: green economy; palm oil industry; POME; biogas; empty oil palm bunches; organic fertilizer; circular economy.

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INTRODUCTION

The palm oil industry holds a strategic position in the Indonesian economy through its contributions to processing activities, trade, raw material supply, and employment opportunities. However, the characteristics of the process of processing fresh fruit bunches (FFB) into crude palm oil also generate large amounts of residues. These residues include palm oil mill effluent (POME), empty fruit bunches (EFB), fiber, shells, and separation sludge. Without proper management, these residues can become a source of pollution, waste resources, and burden environmental costs and compliance. A study of palm oil industry pollution in Indonesia highlighted the potential impacts on water, soil, and air from various types of process waste (Yoeliarniza et al., 2025).

The main problem lies not solely in the existence of waste, but rather in production patterns that do not fully return materials and energy to the economic cycle. In a linear approach, raw materials are processed into products, while residues are treated as outputs that must be disposed of or handled. In contrast, a circular economy views some residues as secondary resources that can be recovered through reuse, recycling, and energy recovery. Mesirngsih et al. (2024) used circularity indicators to assess POME governance, while Agustina et al. (2025) discussed biogas technology as a wastewater management strategy to promote a circular economy.

On the other hand, OPEFB and other solid residues contain organic matter that can be utilized through the composting process. Research by Yerizam et al. (2021), Mustangin et al. (2023), Sariah et al. (2024), and Emilia et al. (2024) demonstrates various approaches to processing OPEFB into fertilizer or compost. Sariah et al. (2024), for example, tested a combination of OPEFB and decanter solids and reported that the selected compost met the SNI 19-7030-2004 parameters tested in the study. These findings demonstrate the potential for nutrient recovery that complements energy recovery from POME.

In solid waste, OPEFB has lignocellulosic characteristics, which cause the decomposition process to require relatively controlled processing. Composting requires shredding, moisture management, aeration, carbon-to-nitrogen ratios, and microbial activity. Mustangin et al. (2023) tested variations in composting duration and inoculum of Trichoderma, Azotobacter, and POME. Sariah et al. (2024) showed that the combination of OPEFB and decanter solids can produce compost with chemical parameters that meet their standards. These studies confirm that the quality of organic fertilizer is not solely determined by the type of waste, but also by its composition and process control.

Implementation constraints include the need for biodigester investment, land availability, continuity of waste supply, the need for skilled operators, maintenance costs, fluctuations in production load, and the certainty of biogas and compost utilization. Suganda et al. (2024) discuss the benefits of methane capture technology for palm oil

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mills, including financial and environmental dimensions. An economic study of the use of fiber and shells as boiler fuel also shows that decisions about residue utilization must be linked to the company's energy needs and operational costs (Marini et al., 2022).

Previous research in Indonesia has discussed the utilization of POME for biogas, methane capture, clean production, OPEFB composting, and waste management. However, based on the literature reviewed for this study, these discussions tend to be grouped by technology or residue type. Biogas studies have focused on energy recovery and methane reduction (Pangarso, 2022; Nisa & Wijayanti, 2023; Sagala et al., 2024), while compost studies have focused more on testing raw materials, inoculum, and product quality (Yerizam et al., 2021; Mustangin et al., 2023; Sariah et al., 2024).

The gap highlighted in the study is not a claim that integrative research has never existed, but rather the need to integrate the findings of the two streams of residue utilization into a green economy implementation framework at the company level. Specifically, an analysis is needed that links energy recovery from POME, nutrient recovery from solid waste, cost efficiency, governance, environmental risks, and measurable performance indicators. The study of the sustainability of the palm oil industry by Satriawisti and Parung (2024) positions sustainability as a multidimensional issue; this study narrows its focus to the integration of waste utilization technology as a green economy operational mechanism.

This study aims to analyze how green economy principles can be implemented in palm oil industry companies through the utilization of POME into biogas and solid waste into organic fertilizer. The specific objectives are: (1) to identify the characteristics and potential utilization of two groups of waste; (2) to explain the technical mechanisms and environmental-economic benefits of biogas and organic fertilizer; (3) to formulate supporting factors, obstacles, and implementation risks; and (4) to develop an integrative framework and evaluation indicators that can be used by companies.

The study questions are formulated as follows. First, how does the utilization of POME for biogas support energy efficiency and emission control? Second, how can OPEFB and other solid residues be processed into organic fertilizer that meets quality requirements? Third, what technical, economic, and governance conditions determine the successful integration of these two pathways? Fourth, what indicators are relevant for assessing their contribution to the green economy?

The research's novelty lies in the development of an analytical framework for two dual-stream resource recovery pathways: energy recovery through POME biodigesters and material/nutrient recovery through solid residue composting. Both pathways are positioned as part of a single corporate resource management system, rather than as stand-alone environmental projects. This framework links inputs, processes, outputs, internal/external utilization, and economic and environmental performance indicators.

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This novelty is conceptual-synthetic in nature and does not claim to be a new technological discovery.

THEORETICAL BASIS

2.1 Green Economy

A green economy can be understood as an approach to economic development that seeks to improve well-being and productive activities by reducing environmental risks and pressure on natural resources. In a corporate context, this principle translates into efficient use of raw materials and energy, pollution prevention, emissions reduction, process innovation, and value creation from residues. A green economy is not simply measured by the presence of environmentally friendly technologies; it must be seen through verifiable outcomes, such as energy intensity, waste volume utilized, avoided emissions, and management costs.

2.2 Circular Economy and Cleaner Production

A circular economy emphasizes maintaining the value of materials and energy for as long as possible through reduction, reuse, repair, recycling, and recovery. In the palm oil industry, this principle can be applied by identifying each residue stream and determining the most appropriate utilization pathway. POME can be directed towards energy recovery through anaerobic processes, while EFB and decanter solids can be directed towards composting. Fibers and shells can be utilized as energy biomass depending on process needs and technological availability. Mesirngsih et al. (2024) demonstrate the use of circularity indicators to understand POME governance.

2.3 Characteristics of Palm Oil Industry Waste

POME is a liquid waste resulting from the palm oil processing process, including boiling, clarification, and washing. The characteristics of POME are influenced by mill capacity, operating conditions, water use, and process configuration. Its high organic matter content makes it a potential substrate for anaerobic processes. However, influent quality and flow rate fluctuations need to be monitored because they affect biodigester stability and effluent quality. Research by Subekti et al. (2024) shows that residual fractions after anaerobic processing have different organic carbon contents between sludge, solid, and liquid, so further management requires attention to the characteristics of each fraction.

2.4 Biogas from POME

Biogas is produced through the decomposition of organic matter by microorganisms under anaerobic conditions. The main components of biogas are

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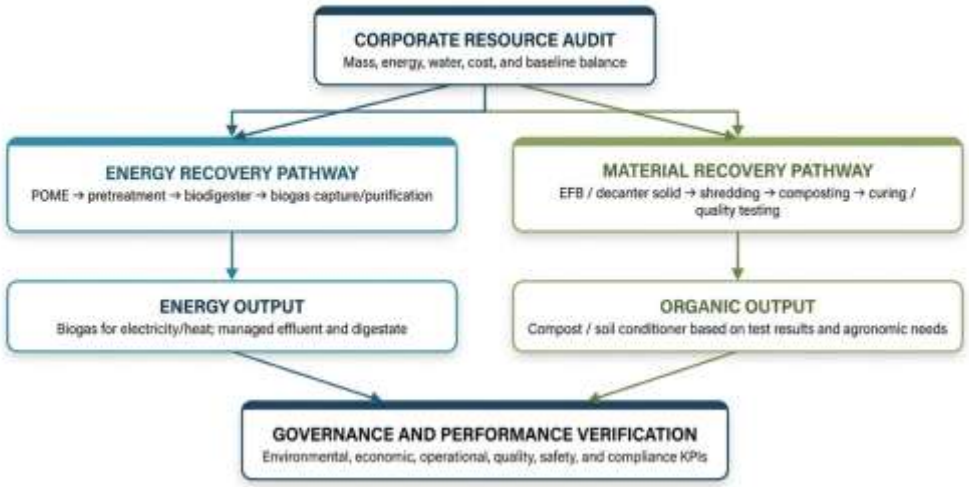
generally methane and carbon dioxide, with minor components depending on process conditions. In the context of a palm oil mill, biogas can be used for electricity generation, boiler fuel through appropriate systems, or further processed into biomethane/CBG if technical and economic requirements are met. Pangarso (2022) reviewed options for utilizing POME biogas in the context of PTPN 5, while Nisa and Wijayanti (2023) discussed methane reduction at the Tungkal Ulu Biogas Plant.

2.5 Organic Fertilizer from Solid Waste

Composting is the biological decomposition of organic matter under controlled conditions. Aerobic processes require an adequate oxygen supply, appropriate humidity, a suitable research area, and a balanced nutrient balance for microorganisms. Mature compost products can be used as a source of organic matter and nutrients, but their quality needs to be assessed based on relevant parameters, including moisture content, pH, organic carbon, nitrogen, phosphorus, potassium, C/N ratio, and contaminants

Figure 1. Conceptual model of integration of energy recovery and material recovery in palm oil industry companies.

Figure 1. Conceptual model of dual-stream resource recovery integration



The model places a resource audit as the starting point, as investment decisions and technology selection need to be based on mass, energy, and water balances, as well as output utilization requirements. The two recovery pathways operate through distinct processes but converge on a governance system and performance verification. This relationship emphasizes that success is not solely measured by biodigester capacity or the amount of compost produced, but rather by actual utilization, output quality, risk management, and demonstrable net benefits.

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The conceptual relationship is not automatic. Available technology will not necessarily yield benefits without the support of stable operation, maintenance, emissions measurement, quality control, and product markets. Therefore, supporting variables such as technical capacity, capital costs, energy prices, residual quality, regulations, and stakeholder acceptance influence the relationship between technology and green economy performance.

Dimensions	Recommended operational indicators	Evidence/data required
Material efficiency	Percentage of TKKS/decanter solid utilized; residue discarded	Monthly mass balance; weighing records
Energy efficiency	Biogas volume; electrical/thermal energy produced; conventional energy substitution	Gas flow meter; heat data; electricity meter
Climate performance	Methane capture; leakage; avoided emissions based on selected methodology	Gas flow and composition data; emission factors; flare records
Water performance	Effluent discharge and quality before/after treatment	Laboratory test results and routine monitoring
Fertilizer quality	C-organic, N, P, K, pH, water content, C/N, contaminants	Laboratory test results against applicable standards
Economic performance	Operating costs, energy/fertilizer savings, product revenue, payback period	Project financial reports and operating costs
Governance	SOP, operator competency, audit, compliance, reporting	Company documents, training, audits

This framework avoids using a single indicator to represent a green economy. Emission reductions, for example, need to be calculated using transparent system boundaries and emission factors. Similarly, claims of cost savings need to be based on a comparison of actual pre- and post-project costs, including investment, maintenance, and residue treatment costs.

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RESEARCH METHODS

3.1 Design and Approach

This research uses a qualitative approach through a structured narrative literature review. This approach was chosen because the research objective was to synthesize published knowledge regarding the application of a green economy in the palm oil industry through two waste utilization pathways. The article does not utilize surveys, interviews, field observations, or laboratory measurements. Therefore, the unit of analysis is scientific publications, not specific companies or factories.

3.2 Literature Search Strategy

The search was conducted using keywords in Indonesian and English, including "palm oil palm liquid waste," "POME," "biogas," "methane capture," "palm oil empty fruit bunches," "organic fertilizer," "compost," "green economy," "circular economy," "clean production," and "sustainability of the palm oil industry." Prioritized sources were national journal research that had bibliographic identification, year of publication, author name, journal name, and searchable DOI or publisher page.

The publications found were not treated as equivalent evidence. Experimental composting studies were used primarily to explain the influence of materials and process conditions on compost quality; biogas case studies were used to describe technology applications and energy utilization contexts; while conceptual or review research was used to develop green economy, circular economy, and governance frameworks. This distinction in the function of evidence prevents results from a single location or scale of testing from being directly translated into general claims for all palm oil companies.

To maintain traceability, searches were conducted using a combination of Indonesian and English terms, including "palm oil mill liquid waste," "POME," "biogas," "methane capture," "palm oil empty fruit bunches," "compost," "organic fertilizer," "green economy," "circular economy," and "cleaner production." These terms were used either singly or in combination with the words "palm oil mill" or "palm oil industry." Searches were directed at national journal research and publisher portals or scientific repositories that allow for examination of metadata and research substance. The primary publication range was set from 2021 to 2026 so that the synthesis represents developments over the past five years at the time of manuscript preparation.

The primary publication window was set for 2021–2026 to reflect the research developments of the past five years. Articles directly addressing POME technology, OPEFB compost, cleaner production, circularity, and sustainability were prioritized. Documents that only discussed palm oil in general without any relevance to waste or sustainability were not included in the primary synthesis.

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3.3 Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Year	2021–2026	Out of range, unless absolutely necessary context source
Document type	Scientific journal articles/academic proceedings with bibliographic identity	Blogs, news, opinions, promotional materials
Topics	POME, biogas, methane capture, EFB, compost, organic fertilizer, clean production, circular economy, palm oil sustainability	Not relevant to the focus of utilizing palm oil industry waste
Availability of information	Abstract/content and metadata can be checked	Metadata is insufficient or claim cannot be verified
Language	Primarily Indonesian publications; English titles/abstracts are acceptable if the study is Indonesian.	Sources without relevance to the Indonesian context

3.4 Analysis Procedure

The analysis was conducted in four stages. First, source identification and examination of the relevance of titles, abstracts, and metadata. Second, information was extracted regarding waste types, technologies, research objectives, key findings, and stated limitations. Third, grouping into themes: POME biogas, composting and organic fertilizers, cleaner production and circularity, economic-environmental benefits, and implementation factors. Fourth, a comparative synthesis was conducted to identify patterns of findings, relationships between themes, and research gaps.

In the synthesis stage, each source was read with attention to the research objectives, data types, objects or locations of the study, technologies discussed, outcome indicators, and limitations stated by the authors. The findings were then grouped into five themes: energy recovery from POME, material recovery from solid residues, environmental performance, economic-operational feasibility, and implementation governance. Comparisons were conducted qualitatively because the parameters, scales, and research designs across studies were not uniform. Therefore, this study did not

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calculate averages across studies or combine figures with different units and measurement bases.

The synthesis is narrative in nature and does not aggregate effect sizes or calculate averages across studies due to the wide variety of designs, subjects, variables, and measurement methods used by the sources. Quantitative figures cited in the studies are used only when explicitly reported by the relevant sources and their context is explained. The study results are not intended to estimate the average performance of all palm oil mills in Indonesia.

3.5 Methodological Limitations

This study has limitations. First, the scope of the literature depends on the publications that can be found and accessed at the time of the search. Second, the methodological quality of each scientific publication was not assessed using a formal systematic review instrument. Third, this study does not claim to adhere to PRISMA because it does not present a complete systematic review protocol, number of records identified, duplications, and reasons for exclusion. Fourth, the synthesis cannot replace technical audits and feasibility studies of specific companies.

RESULTS AND DISCUSSION

4.1 Map of Reviewed Literature

The reviewed literature reveals four groups of studies. The first group focuses on biogas production from POME and its utilization for energy. The second group discusses methane reduction and the benefits of methane capture technology. The third group examines the composting of OPEFB, decanter solids, and other organic residues. The fourth group addresses waste management, clean production, the circular economy, and the sustainability of the palm oil industry. These four groups complement each other but differ in their focus and performance metrics.

Table 4. Evidence synthesis matrix and interpretation limits

Evidence group	Examples of sources in the corpus	Findings that can be used	Limits of interpretation
POME and biogas	Pangarso (2022); Nisa and Wijayanti (2023); Sagala et al. (2024); Agustina et al. (2025)	Describes anaerobic pathways, biogas utilization, and potential for methane control.	It cannot be assumed that identical performance will be achieved across all plants; data on

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Evidence group	Examples of sources in the corpus	Findings that can be used	Limits of interpretation
			flowrate, COD, gas composition, and utilization are required.
Methane capture and post-process residue	Suganda et al. (2024); Subekti et al. (2024)	Demonstrates the importance of gas capture benefits as well as characterization of residual fractions after anaerobic processes.	Climate benefits and digestate utilization require leakage measurements, effluent quality, and residue testing.
TKKS and compost	Yerizam et al. (2021); Mustangin et al. (2023); Sariah et al. (2024); Emilia et al. (2024)	Supporting the utilization of solid residues through composting and quality testing.	Results are influenced by the material, inoculum, processing time, and test method; the standard tested should be stated.
Clean production and circular economy	Azzahro et al. (2022); Greecengsih et al. (2024); Widodo et al. (2024)	Provides a basis for linking process efficiency, POME governance, and waste prevention.	Not always providing integrated techno-economic data for both recovery paths.
Sustainability and pollution risks	Satriawisti and Parung (2024); Yoeliarniza et al. (2025); Tsiwiyati (2024)	Placing residue management as part of the industry's sustainability agenda.	Review or conceptual sources do not replace verification of the company's operational data.

The mapping reveals that the available evidence is diverse. The biogas literature provides a basis for explaining POME utilization and methane capture, but not all scientific publications present comparable economic indicators. The composting

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literature more often examines material composition, inoculum, and product quality parameters, so its contributions are primarily focused on technical and agronomic aspects. Meanwhile, cleaner production and circularity studies provide governance context but do not always link environmental indicators to financial costs and benefits within a single framework. These differing focuses underscore the need for a cross-theme synthesis.

study group	Example sources	Main focus	Contribution to research
POME Biogas	Pangarso (2022); Nisa & Wijayanti (2023); Sagala et al. (2024); Agustina et al. (2025)	Energy recovery and methane reduction	The basis of the energy recovery path
Methane capture and benefit value	Suganda et al. (2024); Subekti et al. (2024)	Benefits of technology and characteristics of post-anaerobic residues	Basis for environmental and residue evaluation
Compost and organic fertilizer	Yerizam et al. (2021); Mustangin et al. (2023); Sariah et al. (2024); Emilia et al. (2024)	Composting process and compost quality	Basic nutrient recovery pathways
Clean production and circularity	Azzahro et al. (2022); Greecengsih et al. (2024); Widodo et al. (2024)	Process efficiency and residue management	Basics of system integration
Sustainability and governance	Satriawisti & Parung (2024); Yoeliarniza et al. (2025); Tsiwiyati (2024)	Dimensions of sustainability and pollution risks	Basic context and governance

The map shows that technical evidence for each pathway is available, but assessing implementation success requires combining technical results with organizational and economic context. Companies need to measure not only how much

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biogas or compost is produced, but also how much is actually utilized, what the lifecycle costs are, what the effluent and product quality are, and whether environmental impacts are reduced.

4.2 Utilization of POME into Biogas

POME contains organic matter that can be decomposed through anaerobic processes. In well-designed systems, this process produces biogas and reduces the organic matter content of waste. Gas capture is crucial because uncontrolled methane formation and release can contribute to greenhouse gas emissions. Nisa and Wijayanti (2023) studied methane reduction through the Tungkal Ulu Biogas Power Plant, while Sagala et al. (2024) assessed the renewable energy potential of POME biogas utilization in Jambi.

4.3 Utilization of Solid Waste as Organic Fertilizer

Palm oil mill solid waste can be used as raw material for organic fertilizer through a composting process. The EFB contains fiber and organic matter that can be returned to the soil after decomposition. Decanter solids can be used as a mixing material, while boiler ash or other organic materials can be considered depending on their characteristics and process requirements. Utilization must consider the material balance, as some biomass may have been allocated for energy use.

4.4 Integration of Biogas and Organic Fertilizer as a Circular Economic System

Integration can improve efficiency when there is coordination between production, utilities, environment, farm, and finance units. The factory unit supplies POME discharge data and solid residue amounts; the utilities unit records biogas production and usage; the farm unit plans compost needs; the environment unit monitors effluent and emissions; and the finance unit assesses costs and benefits. This coordination prevents unused biogas production or compost accumulation due to lack of an application plan.

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Figure 2. Comparison of annual biogas production at LDA and TAN plants in Riau Province

Source: Processed from data from Agustina et al. (2025).

CONCLUSION

Based on a literature review, the implementation of a green economy in the palm oil industry can be developed through the integration of liquid waste into biogas and solid waste into organic fertilizer. POME has the potential to act as a substrate for anaerobic processes to produce biogas, which can be used for internal energy or converted through appropriate technology. Biogas capture and utilization also have the potential to reduce uncontrolled methane release. However, these benefits depend on the effectiveness of gas capture, process stability, leak control, energy utilization, and subsequent effluent treatment.

Solid waste such as OPEFB (TKKS) and decanter solids can be utilized through composting to produce organic fertilizer or soil conditioner. Literature shows that material composition, inoculum type, composting time, moisture, aeration, and maturation affect product quality. Compost utilization can support organic matter recovery and potentially reduce some organic input requirements, but its use should be based on quality test results and agronomic needs.

The study's primary contribution is a dual-stream resource recovery framework that positions energy recovery from POME and nutrient recovery from solid residues as a single enterprise circular economy system. The framework connects resource audits, technology selection, process integration, output utilization, and evaluation of

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environmental and economic indicators. With this approach, the green economy is not judged solely by the existence of facilities, but by tangible, measurable and verifiable outcomes.

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