# Utilization of palm oil derivatives for eco-friendly industrial development: literature review

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**ABSTRACT**

The increasing adoption of eco-friendly industrial practices and circular economy principles has encouraged the palm oil industry to maximize the utilization of waste and by-products as valuable resources. This study aims to examine the potential utilization of palm oil derivatives in supporting environmentally friendly industrial development through a circular economy approach. A descriptive qualitative method with a literature review approach was employed using secondary data obtained from 25 national and international journal articles, scientific papers, and conference proceedings published between 2019 and 2026. Relevant literature was collected from Scopus, ScienceDirect, Google Scholar, and MDPI databases using keywords related to palm oil waste, circular economy, biomass, bioenergy, and sustainable industry. Data were analyzed through content analysis involving identification, selection, classification, synthesis, and conclusion drawing. The results indicate that various palm oil derivatives, including Palm Oil Mill Effluent (POME), empty fruit bunches, biomass residues, boiler ash, and oleochemical by-products, can be utilized as renewable energy sources, organic fertilizers, biomaterials, bioplastics, and industrial raw materials. The implementation of circular economy principles contributes to reducing environmental pollution, improving resource efficiency, decreasing dependence on fossil fuels, and supporting sustainable industrial development. However, several challenges remain, including high investment costs, limited technological adoption, and inadequate industrial integration. Overall, palm oil derivatives should be viewed as strategic resources capable of supporting environmental sustainability, industrial competitiveness, and long-term economic development.



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## 1. INTRODUCTION

The The increasing global concern regarding environmental degradation, climate change, and resource depletion has encouraged industries to adopt more sustainable production systems. Governments, international organizations, and industrial sectors are increasingly promoting strategies that enhance resource efficiency, reduce waste generation, and minimize environmental impacts. In response to these challenges, sustainable industrial development has become a key priority in achieving long-term economic growth while maintaining environmental sustainability.

One approach widely recognized for supporting sustainable development is the circular economy concept. Unlike the conventional linear economy model based on the "take–make–dispose" principle, the circular economy emphasizes resource conservation through reuse, recycling, recovery, and regeneration processes. The implementation of circular economy principles can improve resource efficiency, reduce environmental pollution, and create additional economic value from industrial by-products and waste materials. According to Abdul-Hamid et al. (2022), integrating circular economy principles with advanced industrial technologies can optimize resource utilization and reduce environmental emissions. Similarly, Yeo et al. (2020) reported that circular economy implementation contributes to the development of integrated industrial systems by linking biomass utilization, energy recovery, and value-added product generation.

The palm oil industry represents one of the most important agricultural sectors in many tropical countries and contributes significantly to economic development. However, palm oil processing generates substantial quantities of waste and by-products, including Palm Oil Mill Effluent (POME), empty fruit bunches (EFB), fibers, shells, boiler ash, and oleochemical residues. If not properly managed, these materials may cause environmental pollution and reduce resource-use efficiency. On the other hand, numerous studies have demonstrated that palm oil waste and by-products possess significant potential as renewable resources for industrial applications. Wahyu Almizri and Yusuf Akhmad (2025) reported that palm biomass residues can be utilized as bioenergy and biofuel resources capable of reducing dependence on fossil fuels. Kahar et al. (2021) also showed that integrated biorefinery systems can convert palm oil waste into biogas, bioethanol, biomaterials, and other value-added products. Furthermore, Yanti (2023) highlighted the role of palm oil biomass in supporting renewable energy production and improving environmental sustainability.

Beyond energy applications, palm oil derivatives offer considerable opportunities for the production of environmentally friendly materials and industrial products. The utilization of empty fruit bunches, biomass residues, and oleochemical derivatives has been explored for the development of bioplastics, organic fertilizers, biomaterials, and other sustainable products. Foo and Hameed (2010) and Levi Permadani (2022) reported that cellulose extracted from empty fruit bunches can serve as a promising raw material for biodegradable plastics. In addition, Welo et al. (2024) emphasized that product diversification based on waste utilization can improve industrial competitiveness while supporting environmental sustainability. These findings indicate that palm oil derivatives can play an important role in promoting a circular economy and sustainable industrial development.

Although numerous studies have investigated the utilization of palm oil waste and by-products, most previous research has focused on specific applications such as biodiesel production, biogas generation, biomass conversion, organic fertilizer development, or renewable energy production. Existing studies generally examine individual waste streams and technologies separately, resulting in limited understanding of how various palm oil derivatives can be integrated within a comprehensive circular economy framework. Therefore, there remains a research gap regarding the synthesis of multiple palm oil derivatives and their collective contribution to environmentally friendly industrial development, resource efficiency, and sustainable economic growth.

Therefore, this study aims to review and analyze the utilization of palm oil derivatives in supporting eco-friendly industrial development through a circular economy approach. This literature review analyzed 25 scientific articles published between 2019 and 2026 obtained from national and international journals, conference proceedings, and other relevant scientific sources. The study is expected to provide a comprehensive understanding of the opportunities, benefits, and challenges associated with palm oil derivative utilization while contributing to the advancement of sustainable and environmentally responsible industrial systems.

## 2. METHOD

This study employed a descriptive qualitative approach using a literature review method to examine the utilization of palm oil derivatives in supporting eco-friendly industrial development through a circular economy framework. The literature review approach was selected because it enables the systematic identification, evaluation, and synthesis of previous research findings related to palm oil waste utilization, biomass valorization, renewable energy development, and sustainable industrial practices. This approach is widely used to provide a comprehensive understanding of research developments and technological innovations within a specific field of study.

The data used in this study consisted of secondary data obtained from national and international scientific journals, conference proceedings, books, and other relevant scientific publications. Literature searches were conducted through several academic databases, including Scopus, ScienceDirect, Google Scholar, and MDPI. The keywords used in the search process included "palm oil waste," "palm oil derivatives," "circular economy," "biomass utilization," "bioenergy," "biorefinery," and "sustainable industry." The selected literature met the following inclusion criteria: (1) published between 2019 and 2026, (2) peer-reviewed publications, (3) relevant to the utilization of palm oil waste and by-products, and (4) related to sustainable industrial development and circular economy implementation.

The literature selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. A total of 125 records were initially identified through database searching. After duplicate removal, 98 records remained for title and abstract screening. During the screening stage, 50 records were excluded because they did not meet the study objectives or inclusion criteria. Consequently, 48 full-text articles were assessed for eligibility. Following a detailed evaluation, 23 articles were excluded due to insufficient relevance, limited data availability, or duplication of research themes. Finally, 25 articles met all eligibility criteria and were included in the final literature review and synthesis.

The research procedure was conducted systematically through several stages. First, relevant literature was identified using predetermined keywords. Second, the collected publications were screened and selected based on the inclusion criteria. Third, the selected literature was classified according to research themes, including renewable energy, biomass utilization, biomaterials, circular economy, and industrial sustainability. Fourth, the collected information was analyzed and synthesized to identify major findings, research trends, opportunities, and challenges associated with the utilization of palm oil derivatives. Finally, conclusions were drawn based on the synthesis of findings obtained from the reviewed literature.

The collected data were analyzed using content analysis techniques. This method was applied to identify, categorize, compare, and interpret information obtained from the selected literature. The analysis focused on evaluating the contribution of palm oil derivatives to renewable energy production, waste reduction, resource efficiency, product diversification, and sustainable industrial development. Through this approach, the study provides a comprehensive understanding of the opportunities and challenges associated with the implementation of circular economy principles in the palm oil industry.

## 3. RESULTS AND DISCUSSION

Literature findings indicate that palm oil has significant potential to support the development of environmentally friendly industries through the utilisation of waste to generate additional value. Palm oil has significant potential to support the development of environmentally friendly industries through the use of waste to generate additional value. This includes the production of derivative products such as bioplastics and oleochemicals, as well as the use of solid waste as biomass and industrial materials, and liquid waste as an energy source. These applications are often based on the circular economy concept, which promotes resource efficiency, waste reduction, and industrial sustainability.

**Table 1.** Synthesis of the Utilisation of Palm Oil Derivatives in Supporting Eco-Friendly Industries

| No | Type of Waste / By-Product | Forms of Utilization | Contribution to the Eco-Friendly Industry | Reference |
|---|---|---|---|---|
| 1 | *Palm Oil Mill Effluent (POME)* | Biogas production thru a biodigester | Reducing liquid waste pollution and generating renewable energy. | (Pangarso, 2022; Wibowo et al., 2019) |
| 2 | POME | *Resource recovery and nutrient recovery* | Improving the efficiency of industrial waste utilization. | (Akuma et al., 2026) |
| 3 | Empty Fruit Bunches (EFB) | Organic fertilizer | Reducing solid waste and minimizing the use of chemical fertilizers. | (Warsito et al., 2016) |
| 4 | Empty fruit bunches of oil palm (EFB) | Non-structural construction materials | Supporting the sustainable use of industrial biomass. | (Munizar, 2025) |
| 5 | Palm biomass (husk and fiber) | Bioenergy and industrial biomass | Reducing dependence on fossil fuels. | (Kaniapan et al., 2021) |

| | | | | |
|---|---|---|---|---|
| 6 | Cellulose TKKS | Biodegradable plastic | Reducing the use of petrochemical-based synthetic plastics. | (Levi Permadani, 2022) |
| 7 | Glicerina pitch | Oleochemical and alternative energy products | Increasing the diversification of palm oil industry products. | (Anshari et al., 2025) |
| 8 | Palm biomass residue | *Industrial symbiosis* | Improving the efficiency of industrial materials and energy. | (Rendón-Camargo et al., 2026) |
| 9 | Integrated palm oil waste | Implementation of the circular economy | Supporting the zero-waste industry and industrial sustainability | (Welo et al., 2024) |

Based on Table 1, it is evident that palm oil waste and byproducts have diverse utilization potential and can make a significant contribution to the development of an environmentally friendly industry. Through the development of renewable energy, biomaterials, and diversification of biomass-based industrial products, these uses aim to provide economic value while reducing waste. The study's findings indicate that the palm oil sector has significant potential to develop into a sustainable industrial structure based on a circular economy.

### 3.1 Using the Wastewater from Palm Oil Mills for Renewable Energy

Palm oil mill effluent (POME) is one of the main byproducts of the palm oil milling process. POME has a high organic content with a Chemical Oxygen Demand (COD) value of up to 50,000 mg/L, which means it has the potential to damage the environment if produced without the presence of hazardous pollutants. With a Chemical Oxygen Demand (COD) value of up to 50,000 mg/L, it has the potential to harm the environment if discharged without proper treatment. However, this organic effluent also offers significant opportunities to be utilized as an energy source through biogas production (Sodri & Septriana, 2022).

According to Wibowo et al., 2019, systems that utilize biodigesters can produce biogas that can be used as an alternative energy source for sawmill operations. POME processed using biodigester systems can produce biogas that can be used as an alternative energy source for sawmill operations. According to Pangarso, 2022, every 1 m³ of POME has the potential to produce approximately 20–28 m³ of biogas, depending on the efficiency of the waste management system and the biodigester; every 1 m³ of POME has the potential to produce approximately 20–28 m³ of biogas, depending on the efficiency of the waste management system and the biodigester. In addition, Akuma et al., 2026 explain that resource recovery technology enables POME to be used not only as an energy source but also as a source of nutrients and other industrial materials. This technology enables POME (Pale, Mill, Equivalents, and Oil) to be used not only as an energy source but also as a source of nutrients and other industrial materials.

The use of Palm Oil Mill Effluent (POME) as a renewable energy source demonstrates its strategic value in supporting industrial energy efficiency and sustainable development. Compared to the conventional practice of discharging wastewater into open ponds, the application of biodigester technology is considered more effective because it significantly reduces methane emissions while generating biogas that can be reused as an energy source within the production process. Imam et al. (2025) reported that an integrated biological approach to POME treatment can mitigate environmental pollution and enhance the overall sustainability of the palm oil industry.

Nevertheless, the implementation of POME treatment technologies still faces several challenges. Biodigester systems require relatively high initial investment costs, regular maintenance, and skilled personnel for effective operation and monitoring. In addition, many small-scale palm oil mills continue to experience limitations in infrastructure and access to advanced technologies, resulting in the underutilization of POME resources. This situation indicates that the successful management of palm oil mill effluent depends not only on technological feasibility but also on policy support, industrial capacity, financial resources, and the integration of sustainable energy systems.

Overall, the findings suggest that the utilization of POME as a renewable energy source represents one of the most practical applications of circular economy principles in the palm oil industry. In addition to reducing environmental pollution, this approach offers significant economic benefits through improved energy efficiency, reduced operational costs, and enhanced resource utilization. Therefore, the development and adoption of POME-based energy systems can contribute substantially to environmental sustainability and the long-term competitiveness of the palm oil sector (Mahjoub & Domscheit, 2020; Sodri & Septriana, 2022).

### 3.2 Using Solid Waste from Palm Oil to Promote Industrial Efficiency

Large volumes of solid waste, including empty fruit bunches (EFB), shells, fiber, and boiler ash, are produced by the palm oil business. It is estimated that approximately 70% of palm oil biomass is converted into solid waste during the palm oil processing. The accumulation of this waste can reduce industrial efficiency and worsen environmental pollution if not utilized to the fullest (Hwang et al., 2022; Mak et al., 2020).

Warsito et al., 2016 explain that empty fruit bunches contain nutrients such as nitrogen, phosphorus, and potassium that can be utilized as organic fertilizer to support agricultural land productivity. The use of empty oil palm fruit bunches as organic fertilizer is considered capable of reducing the use of synthetic chemical fertilizers while improving soil structure. AdditionallyMunizar, 2025 demonstrates that oil palm boiler ash has potential as a non-structural building material because its silica content and physical characteristics can be utilized in specific building material mixtures.

Compared to the open burning method still applied in some areas, the utilization of solid waste as fertilizer and industrial raw materials is considered much more sustainable because it can reduce carbon emissions and increase resource efficiency. Rendón-Camargo et al., 2026 explain that the industrial symbiosis approach allows palm oil biomass residues to be utilized in various industrial sectors, thereby creating material and energy efficiency simultaneously. However, the utilization of palm oil solid waste still faces various obstacles, especially related to biomass distribution, processing costs, and the limitations of industrial-scale waste processing technology. In addition, the quality of products produced from biomass waste processing often lacks uniform standards, which affects the competitiveness of these products in the industrial market. Therefore, strengthening regulations and technological innovations are necessary to ensure the optimal development of palm oil biomass utilization (Alhaji et al., 2024; Asma-Qamaliah Abdul-Hamid et al., 2019).

The results of this study indicate that palm oil solid waste can no longer be viewed merely as a production byproduct, but rather as a secondary resource with high economic potential for supporting industrial efficiency and environmental sustainability.\

### 3.3 Diversification of Palm Oil Derivative Products as Eco-Friendly Materials

Advances in biomass technology are driving the use of processed oil palm waste to create various eco-friendly products such as bioplastics, biomaterials, and oleochemical products (Hamzah et al., 2019). This product diversification is a key strategy for increasing the value added of the oil palm industry while supporting the reduction of fossil-based synthetic materials. Levi Permadani, 2022 explains that cellulose acetate from empty oil palm fruit bunches has the potential to serve as a raw material for biodegradable bioplastics that degrade more easily than conventional petrochemical-based plastics. Additionally, Anshari et al., 2025 note that glycerin pitch from the palm oil oleochemical industry can be utilized as a feedstock for energy and other industrial products, thereby improving the efficiency of byproduct utilization.

The development of palm oil-based bioplastics has become one of the most important innovations in efforts to reduce global plastic pollution. Compared to conventional synthetic plastics, which take hundreds of years to decompose, bioplastics derived from palm oil biomass have a higher biodegradability rate, making them more environmentally friendly. Cheng et al., 2020 state that the approach of utilizing waste within a circular bioeconomy can enhance the economic value of waste through biomass-based product innovations and environmentally friendly technologies.

However, the development of palm oil-based biomaterials still faces significant challenges, particularly in terms of production costs, material stability, and market competitiveness. Biomass-based bioplastics generally still have higher production costs compared to petrochemical-based plastics, so their application in mass production remains limited. In addition, some palm oil-based biomaterials still require improvements in mechanical quality to compete with conventional materials. Despite these challenges, the diversification of palm oil-derived products demonstrates that the palm oil industry has great potential to evolve into a sustainable bioeconomy and biomaterial-based industry. This approach not only provides economic benefits but also strengthens the industry’s transition toward low-emission and environmentally friendly production systems.

### 3.4 Implementation of The Palm Oil Industry's Circular Economy

The use of the circular economy in the palm oil industry has become a strategic approach to support industry growth and reduce environmental impact. This concept emphasizes the reuse of waste and byproducts as new resources, thereby creating a more efficient and low-waste production system. According to Setiawan & Ramadhan, 2026 biogas production from palm oil waste can increase the economic value of the supply chain and improve the environment by reducing emissions. Furthermore, circular economy strategies can enhance the profitability of the palm oil sector by reducing waste and diversifying biomass-based products, according to (Welo et al., 2024).

Compared to linear industrial systems based on a “take-make-dispose” model, the circular economy approach is considered more efficient because it reintegrates waste into the production chain. This approach not only reduces pressure on the environment but also improves overall material and energy efficiency. Rendón-Camargo et al., 2026 assert that integrating palm oil waste biomass across various industrial sectors can create symbiotic industrial relationships that strengthen economic and environmental sustainability.

However, The palm oil industry continues to face challenges in implementing a circular economy, including low investment, poor integration of industrial sectors, and a lack of support for integrated waste processing infrastructure. Strong cooperation between the government, the business world, and academic institutions is also necessary for the implementation of a circular economy so that technological advancements can be successfully utilized on an industrial scale.

Research findings indicate that the utilization of palm oil derivatives has significant implications for sustainable industrial development in terms of economic, environmental, and industrial competitiveness. Converting palm oil waste into biogas, biomaterials, organic fertilizers, and oleochemical products can create added value through product diversification and the efficient utilization of industrial resources. In addition to reducing dependence on the primary product, crude palm oil (CPO), the development of biomass-based derivative products also opens opportunities for a more competitive and environmentally friendly downstream industry. Utilizing palm oil biomass as an alternative energy source can reduce industrial energy costs while decreasing reliance on fossil fuels, whereas the development of biodegradable bioplastics has the potential to enhance the competitiveness of the palm oil industry in a global market increasingly oriented toward sustainability. From an environmental perspective, The implementation of a circular economy in the palm oil industry contributes to the reduction of gas emissions in households through the utilization of liquid waste and biomass as sources of renewable energy and industrial raw materials. The Sustainable Development Goals (SDGs) are also in line with this strategy, especially those related to accessible and clean energy. sustainable consumption and production, industrial innovation, and climate change mitigation.

Overall, research shows that the use of a circular economy by the oil industry not only serves as a waste management strategy but has also evolved into a sustainable industrial approach capable of simultaneously enhancing resource efficiency, profitability, and sustainability of the environment. The main innovation of this study is how it integrates various uses of palm oil derivatives into environmentally friendly and circular economy-based companies. This study shows that palm oil waste is now viewed as a strategic resource that can be transformed into energy, biomaterials, and value-added industrial goods within an integrated sustainable industrial system, rather than as a manufacturing residue that should be discarded. Thus, industrial sustainability is no longer measured solely by production capacity, but also by the industry’s ability to manage waste efficiently and transform it into economically valuable and environmentally friendly resources. After all, a truly sustainable industry is not one that produces the least waste, but one that is most capable of reusing its waste as part of a new production cycle.

## 4. CONCLUSION

This literature review demonstrates that palm oil derivatives and by-products, including Palm Oil Mill Effluent (POME), empty fruit bunches, biomass residues, and oleochemical by-products, have significant potential to support environmentally friendly industrial development through the implementation of circular economy principles. Their utilization contributes to renewable energy production, resource efficiency, waste reduction, value-added product development, and environmental sustainability. This study provides a comprehensive synthesis of the diverse applications of palm oil derivatives within a circular economy framework, highlighting their role in promoting sustainable industrial systems. Nevertheless, challenges related to investment costs, technological adoption, and industrial integration remain important barriers to large-scale implementation. Future research should focus on techno-economic assessments, industrial-scale applications, and the integration of emerging technologies to enhance the efficiency and sustainability of palm oil waste utilization.

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