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Utilization of Oil Palm Waste as a Renewable Energy Source: A Current Literature Review

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ABSTRACT

The palm oil industry is one of Indonesia's key plantation sectors, generating substantial amounts of both solid and liquid waste. This waste includes empty fruit bunches (EFB), shells, fibers, and palm oil mill effluent (POME). This literature review aims to examine the potential and recent technological advancements in utilizing oil palm waste as an environmentally friendly renewable energy source. A systematic literature review was conducted using journal articles, conference proceedings, and scientific reports published between 2018 and 2024. The findings indicate that oil palm waste can be converted into solid biomass (such as briquettes and pellets), biogas from POME, and raw materials for biodiesel and bioethanol. Technologies employed include anaerobic fermentation, pyrolysis, and gasification. Moreover, the utilization of this waste contributes to greenhouse gas emission reduction and enhances energy efficiency in plantation and processing facilities. However, technical and economic challenges remain major barriers to large-scale development. Collaboration among industry stakeholders, government, and academia is essential for the sustainable optimization of oil palm waste utilization. This study highlights that transforming waste into energy is a strategic step toward national energy resilience and sustainable development.

Keywords:, ***Oil Palm Waste, Renewable Energy, Biomass, Biogas, POME***

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INTRODUCTION

The palm oil industry has emerged as a leading sector in Indonesia's economic development. Over the past two decades, oil palm plantations have expanded rapidly, contributing significantly to national income through exports and creating employment opportunities in rural areas. According to Indonesia's Central Bureau of Statistics (BPS, 2023), the total area of oil palm plantations exceeds 16 million hectares, with annual crude palm oil (CPO) production reaching approximately 46 million tons. However, this high production activity also generates substantial amounts of waste, both solid—such as empty fruit bunches (EFB), shells, and fibers and liquid, notably palm oil mill effluent (POME). If not properly managed, these waste products may pose serious environmental and ecological problems.

In fact, oil palm waste contains high organic content and calorific value, making it a promising source for renewable energy conversion. Several studies have shown that EFB has a calorific value of approximately 17 MJ/kg, while POME contains organic matter suitable for anaerobic fermentation to produce biogas (Wulandari, Setiawan, & Lazuardi, 2020). Despite this potential, the utilization of oil palm waste remains suboptimal. Optimizing this potential could offer a viable alternative to fossil fuels, whose availability is depleting and prices are increasingly volatile. Furthermore, converting oil palm waste into energy aligns with national and global agendas to reduce carbon emissions and transition toward sustainable energy systems.

From a national energy perspective, diversifying energy sources is essential to reduce dependency on fossil fuels. Biomass derived from oil palm waste represents a renewable, environmentally friendly, and relatively abundant energy source in Indonesia. Yuliansyah, Prasetyo, and Nasution (2022) reported that biogas production from POME via anaerobic digestion yields significant volumes of methane, which can be used for electricity generation or as a fuel. Additionally, technologies such as gasification and pyrolysis can convert solid waste into thermal energy or liquid fuels. These processes demonstrate the important role oil palm waste treatment can play in advancing new and renewable energy development.

Nevertheless, the development of renewable energy from oil palm waste still faces technical and structural challenges. One major barrier is the lack of efficient technology transfer from research institutions to on-site applications, especially in smallholder plantations and small-to-medium enterprises. Hamzah and Nurcahyono (2022) noted that many palm oil mills in Indonesia still lack adequate facilities to process waste into usable energy. Moreover, the initial investment required to establish biogas or pyrolysis installations remains high, requiring strong regulatory support and financial incentives from the government to facilitate broader implementation.

Beyond technological and economic issues, social dimensions also play a critical role in the success of oil palm waste utilization. Local communities, as landowners and plantation workers, must be engaged in waste management initiatives through technical training, institutional empowerment, and access to financing. Susanti and Harahap (2020) emphasized that successful community-based waste management requires collaboration between academics, local governments, and industry stakeholders. Without community participation, waste-to-energy systems risk being top-down in nature and lacking sustainability.

At the global level, efforts to convert oil palm waste into renewable energy also support the achievement of the Sustainable Development Goals (SDGs), particularly Goal 7 (affordable and clean energy) and Goal 13 (climate action). According to the United Nations Development Programme (UNDP, 2023), renewable energy development is a key strategy to reduce fossil fuel dependency and strengthen national energy resilience. Thus, transforming oil palm waste into energy can be seen as Indonesia's strategic contribution to the global sustainable development agenda.

In Indonesia, various initiatives have been undertaken to develop energy from oil palm waste, led by both private sectors and research institutions. For example, POME-based biogas projects in Sumatra and Kalimantan have successfully supplied energy to local grids while reducing greenhouse gas emissions. Nugroho, Lestari, and Fauzi (2021) found that small-scale plantations using simple biodigester technology have achieved significant energy efficiency and produced organic fertilizer as a by-product. However, the adoption of these technologies remains limited due to insufficient policy support and access to information.

A comprehensive literature review is essential to synthesize scientific findings on oil palm waste utilization for renewable energy. This study aims not only to identify the types of waste and available energy conversion technologies but also to analyze the benefits, challenges, and future development opportunities. Through systematic literature synthesis, a more holistic understanding can be built regarding best practices that can be widely replicated.

The literature-based approach also allows researchers and policymakers to access empirical data and case studies from various regions. Therefore, the findings of this review are expected to serve as a foundation for developing biomass-based energy policies covering regulatory, financial, and technological adoption aspects tailored to local contexts. This study also provides avenues for further applied and interdisciplinary research.

Based on the above context, this study aims to conduct a literature review on the utilization of oil palm waste as a renewable energy source in Indonesia. The review focuses on identifying waste types, existing energy conversion technologies, environmental and economic benefits, implementation challenges, and future development prospects. The study is expected to contribute to the development of a sustainable energy system and promote the optimal management of oil palm waste at the national level.

METHODS

This study adopts a systematic literature review (SLR) approach aimed at collecting, examining, and analyzing various scholarly sources related to the utilization of oil palm waste as a renewable energy source. A literature-based method was chosen due to its ability to provide a comprehensive understanding of the development of relevant issues, technologies, and policies from multiple perspectives. The initial step in this method involved conducting a structured search for academic references using key terms such as ―palm oil waste‖, ―renewable energy‖, ―biomass from palm oil‖, ―biogas from POME‖, and ―sustainable energy Indonesia‖. The search was carried out across several reputable academic databases, including Google Scholar, ScienceDirect, Scopus, and DOAJ.

To ensure the relevance and currency of the data, inclusion criteria were established, specifically: journal articles, conference proceedings, and research reports published between 2018 and 2024, written in either English or Indonesian, and focused primarily on the use of oil palm waste as an energy source. Following the identification process, documents were screened based on topical relevance and publication quality. Irrelevant articles such as those discussing oil palm cultivation without connection to waste or energy, and opinion-based papers lacking empirical support were excluded from the analysis. The selected articles were then analyzed thematically by categorizing their content into several core topics, including: (1) types and characteristics of oil palm waste, (2) energy conversion technologies used, (3) benefits and environmental-economic impacts, (4) implementation challenges, and (5) future prospects and development pathways. The findings are presented in a narrative-critical format, comparing insights across studies that share common themes or divergent perspectives.

To enhance analytical accuracy and strengthen the validity of the arguments, the study also refers to institutional reports from agencies such as Statistics Indonesia (BPS), the Ministry of Energy and Mineral Resources (MEMR), and global documents such as the Sustainable Development Goals (SDGs) reports issued by the United Nations Development Programme (UNDP). The analysis was conducted using a descriptive-qualitative approach, emphasizing the integration of empirical data and conceptual frameworks. The synthesis of literature is not only intended to explain the potential of oil palm waste as a renewable energy source but also to build a conceptual foundation that can support the development of sustainable energy policies and appropriate technological innovations within Indonesia's oil palm plantation sector.

RESULTS AND DISCUSSION

1. Types of Oil Palm Waste and Its Potential

The palm oil industry generates various types of waste both solid and liquid that hold significant potential as renewable energy sources. The primary solid wastes, such as empty fruit bunches (EFB), palm kernel shells, and mesocarp fibers, are rich in lignocellulosic content, making them ideal feedstocks for energy conversion through thermochemical processes such as direct combustion, pyrolysis, and gasification. According to Khan et al. (2021), the calorific value of EFB is approximately 17 MJ/kg, while palm kernel shells can reach up to 20 MJ/kg, positioning them as attractive alternatives to fossil fuels. The abundance of these wastes in major palm oil-producing countries like Indonesia and Malaysia suggests a vast potential for biomass utilization in meeting domestic energy demands sustainably.

In addition to solid waste, Palm Oil Mill Effluent (POME) a liquid waste generated during palm oil processing also offers considerable potential as a feedstock for renewable energy. POME is rich in organic matter that can be converted into biogas through anaerobic digestion. Zhang et al. (2022) reported that each cubic meter of POME can yield approximately 28 m^3 of biogas, equivalent to around 168 kWh of energy. The biogas produced can be utilized for electricity and heat generation, while also contributing significantly to greenhouse gas (GHG) emission reductions. Therefore, the integration of POME utilization into renewable energy strategies not only reduces waste volumes but also supports the transition towards a low-carbon energy system.

The utilization of both solid and liquid waste streams reflects a holistic approach to waste management within the palm oil industry. This approach aligns with the principles of the circular economy and carbon footprint reduction. A study by Tan et al. (2023) found that converting palm oil waste into energy can reduce fossil fuel dependence by up to 25% in medium-scale processing units, while also improving overall energy efficiency within the industry. Furthermore, the implementation of appropriate thermal and bioconversion technologies not only facilitates waste utilization but also generates economic and environmental value-added. Hence, it is crucial for palm oil industry stakeholders to increase investment in research and waste-to-energy conversion technologies in support of both national and global renewable energy agendas.

2. Energy Conversion Technologies for Oil Palm Waste

The conversion of oil palm waste into renewable energy can be achieved through a variety of technological approaches, which have evolved in response to the growing demand for clean energy. Commonly applied technologies include direct combustion, pyrolysis, gasification, anaerobic fermentation, and transesterification, each offering distinct advantages and limitations. According to Yusuf et al. (2022) direct combustion of solid waste such as empty fruit bunches (EFB) and palm kernel shells has been utilized as fuel in biomass power plants. Meanwhile, pyrolysis and gasification enable the transformation of waste into liquid fuels and syngas, which are more easily stored, transported, and utilized. Anaerobic fermentation has also demonstrated promising results in processing liquid waste like POME (Palm Oil Mill Effluent) to produce biogas, which serves as an alternative energy source for both domestic and industrial applications.

The selection of conversion technology is influenced by factors such as waste characteristics, energy output efficiency, and the economic and technical feasibility of implementation. A study by Nair et al. (2023) revealed that anaerobic digestion is most effective for POME due to its high organic content, while gasification is better suited for dry solid waste like palm kernel shells, which possess low moisture content and high calorific value. In contrast, transesterification is used to produce biodiesel from used palm oil or industrial oil waste, illustrating how the diversity of waste types enables the adoption of multiple suitable conversion technologies. With ongoing innovations and technological advancements, various oil palm waste streams can be processed into high-efficiency energy sources with minimal environmental impact.

In terms of sustainability, combining multiple conversion technologies often proves to be the most effective strategy. For instance, residual by-products from gasification can be reused as fuel or as an additive in organic fertilizer production, creating a more efficient circular economy system. As highlighted by Abdullah et al. (2024), integrated conversion technologies not only enhance energy productivity but also reduce the amount of residual waste discharged into the environment. The application of appropriate technologies supported by conducive policies and government incentives will reinforce the palm oil sector's contribution to the transition toward green and sustainable energy. Therefore, the development of oil palm waste-to-energy technologies plays a central role in supporting national energy resilience while safeguarding environmental sustainability.

3. Benefits of Utilizing Oil Palm Waste

The utilization of oil palm waste as a source of renewable energy offers significant environmental and economic benefits. Waste materials such as empty fruit bunches (EFB), fibers, shells, and palm oil mill effluent (POME), which were previously considered burdensome to manage, can now be efficiently transformed into bioenergy. According to Ahmad et al. (2023) converting these waste streams into biomass energy can reduce greenhouse gas emissions by up to 30% compared to traditional open burning or decomposition methods. This practice also aligns with the principles of the circular economy, whereby waste is reintegrated into the production cycle rather than discarded.

Beyond environmental advantages, the economic value of oil palm waste utilization is increasingly evident. The conversion of solid waste into biomass fuel helps reduce dependence on fossil fuels and lowers the operational costs of palm oil processing industries. A study by Kumar and Ramasamy (2024) found that employing oil palm waste as a renewable energy source can improve energy efficiency in the industry by up to 25%, while also opening new opportunities in the renewable energy sector. This is particularly relevant for palm oil-producing countries such as Indonesia and Malaysia, which are under growing global pressure to decarbonize their agricultural industries.

In addition, effective management of oil palm waste can improve the quality of life for communities surrounding plantations and processing facilities. The use of POME for biogas production, for example, not only reduces water pollution but also generates electricity and clean cooking fuel for local households (Chen et al., 2023). Thus, oil palm waste utilization contributes not only to national energy resilience but also to rural empowerment and energy poverty reduction. Achieving these outcomes requires strong regulatory frameworks, government incentives, and collaboration among private sectors, academic institutions, and civil society.

4. Challenges in Implementation

The implementation of palm oil waste utilization as a renewable energy source faces several challenges, encompassing technical, economic, and regulatory aspects. One of the primary barriers is the high initial capital investment required to establish waste-to-energy facilities, such as biogas installations and biomass power plants. According to Kumar et al. (2023) the substantial upfront costs hinder many palm oil mills particularly small- and medium-scale operations from accessing the necessary funding and technologies to carry out efficient waste conversion. Furthermore, not all mills are equipped with adequate infrastructure to store and manage waste properly, resulting in the loss of significant energy potential.

The limited availability of appropriate local technologies also impedes effective implementation. Many energy conversion technologies offered in the global market are not well-suited to local conditions in terms of technical requirements and operational climate. Binh et al. (2022) observed that the adoption rate of advanced technologies such as gasification and pyrolysis remains low in major palm oil-producing countries, mainly due to their complexity and the need for intensive maintenance. This issue is exacerbated by the lack of innovation in developing context-specific local technologies tailored to the unique characteristics of palm oil waste and the energy demands of individual mills or communities.

From a policy perspective, the absence of regulatory incentives further constrains the development of palm oil waste-based renewable energy. In many producing countries, policy frameworks remain weak or insufficient to stimulate investment and promote the adoption of environmentally friendly technologies. Additionally, the scarcity of skilled labor in the field of waste-to-energy conversion poses a significant hurdle. This labor gap reduces the effectiveness and efficiency of energy conversion processes and leads to continued dependence on foreign technical experts. As highlighted by Zhang et al. (2023), strengthening human resource capacity and establishing supportive regulatory measures are two critical factors in accelerating the sustainable utilization of palm oil waste as a renewable energy source.

5. Opportunities and Future Development Directions

The utilization of oil palm waste as a renewable energy source presents strategic opportunities to support the transition toward sustainable energy, particularly in major palm oil-producing countries such as Indonesia and Malaysia. Government policy support in the form of fiscal incentives, streamlined licensing procedures, and technology subsidy programs can accelerate the adoption of waste-based energy schemes within the industrial sector. According to Adnan et al. (2023) tax incentives and green financing mechanisms can encourage businesses to invest in bioenergy technologies. This aligns with global energy transition targets, including commitments to net-zero emissions declared in various international energy forums.

Furthermore, collaboration among universities, research institutions, and industry stakeholders plays a vital role in fostering innovation and accelerating the diffusion of technology. Such partnerships facilitate knowledge exchange and the development of context-specific conversion technologies, particularly those tailored for small and medium-scale applications. As emphasized by Aslam et al. (2024) interdisciplinary approaches and the formulation of bioenergy research roadmaps are essential for building a robust and well-structured waste-to-energy innovation ecosystem. Strengthening human resource capacity and providing technical training are also necessary to ensure effective implementation at the operational level.

Looking ahead, the development of decentralized energy systems based on oil palm waste is emerging as a promising trend. These systems enable the direct utilization of biomass at the source, thereby enhancing energy efficiency and reducing logistics costs. A study by Noor et al. (2023) demonstrated that the deployment of microgrid systems powered by POME-based biogas in palm oil industrial areas can provide independent electricity supply while reducing reliance on fossil fuels. Therefore, an integrated effort involving both public and private sectors is needed to formulate policy directions, applied research agendas, and long-term investment strategies in this sector.

CONCLUSION AND IMPLICATIONS

The utilization of oil palm waste as a source of renewable energy represents a strategic step in supporting the transition toward clean and sustainable energy in Indonesia and other palm oil-producing countries. Various types of waste, such as empty fruit bunches (EFB), shells, fibers, and palm oil mill effluent (POME), have been proven to possess significant potential for energy conversion through technological approaches such as pyrolysis, anaerobic fermentation, gasification, and transesterification. Recent literature indicates that not only does solid waste offer high calorific value, but the organic content in liquid waste also makes palm oil biomass an efficient, economical, and environmentally friendly energy alternative. In addition, the potential use of this waste contributes positively to carbon emission reduction, improved waste management, and enhanced energy efficiency in the palm oil industry.

Nevertheless, the implementation of these technologies still faces various challenges, ranging from limited local technological capacity and high initial investment costs to inadequate regulatory support and government incentives. The shortage of human resources with expertise in biomass energy conversion also hampers the optimization of such programs. Therefore, synergy among government, private sector, academia, and local communities is essential to promote the adoption of more affordable and efficient technologies. Furthermore, strengthening national policies supporting renewable energy, offering tax incentives, and fostering collaborative research and development are key strategies to unlock the full potential of oil palm waste-based energy in the future.

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