Palm Oil Waste Management with Local Wisdom as an Approach to Achieve Sustainable Development in Independent Smallholder Palm Plantations

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Palm Oil Waste Management with Local Wisdom as an Approach to Achieve Sustainable Development in Independent Smallholder Palm Plantations

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Abstract: The Indonesian palm oil industry has significantly boosted the nation's GDP and foreign exchange earnings, driven by the rise of Independent Smallholders (ISH). Despite this, environmental issues like deforestation and low land productivity persist. The government supports smallholders, but sustainable waste management remains a challenge. This research uses literature reviews, Expert Data Triangulation, and qualitative analysis to examine palm oil waste management, focusing on innovative waste use in handicrafts in Tanjung Leban Village. The research findings indicate that less than 16% of ISH farmers actively engage in palm oil waste management practices that incorporate local wisdom as a source of livelihood. These results suggest that integrating local knowledge and traditional practices could be an instrument to promote the downstream utilization of palm oil waste, thereby generating income and enhancing sustainability. Effective waste management provides economic benefits and contributes to environmental sustainability, offering potential advantages in renewable energy development, advancing rural communities, and conserving natural resources.

Keywords: biomass energy; palm oil; renewable energy; smallholders; waste management; waste utilization

1. Introduction

The Indonesian palm oil industry has experienced significant growth, particularly since around 2004, when the international palm oil commodity price rose from USD 295.36 per metric ton in 2000 to USD 448.70 per metric ton in 2004 in the Malaysian palm oil market.

Palm oil production in Indonesia increased from 5.39 million tons of crude palm oil (CPO) in 1998 to 48.42 million tons in 2019, marking an impressive 8.16-fold growth in production. This increase has substantially contributed to the country's GDP and employment. Additionally, CPO exports surged from 1.47 million tons in 1998 to 28.28 million tons in 2019, significantly boosting foreign exchange earnings from palm oil exports (including palm kernel), which increased from USD 940 million in 1998 to USD 15.98 billion in 2019[1)].

However, this significant growth has been accompanied by challenges such as environmental problems, deforestation, and peatland degradation. Another issue is the lower productivity of palm oil plantations in Indonesia compared to those in Malaysia. Additionally, despite the increase in CPO exports, there has been limited progress in downstream processing, which has long been anticipated.

The proposed solution to address these issues involves vertically enhancing the palm oil industry by improving land productivity through intensified planting and promoting downstream processing in industrial operations. The solution we propose is also based on factual data calculations. Indonesia's palm oil production has seen significant growth, with an annual production growth of 4.43% from 1998 to 2019[1)]. During this period, there was an increase in production in the Smallholder Plantation sector by 5.28%[2)] and the Private Plantation sector by 4.48%[3)]. Much of this production growth can be attributed to the expansion of oil palm plantations. The expansion of productive oil palm land increased by 2.96%[4)], consisting of an expansion of smallholder oil palm plantations by 4.03%[5)], while private plantations increased by 2.77%[6)]. On the other hand, the increase in land productivity (palm oil production per 1 ha of oil palm land) was only 1.43% from 1998 to 2019[7)]. The increase in land productivity for smallholder oil palm plantations was also only 1.20%[8)], while the increase in productivity for private plantations was 1.99%[9)].

From this data, it can be inferred that the increase in palm oil production has largely been achieved through horizontal development, specifically by changing land usage through expanding plantation areas. However, there is a need to shift focus towards vertical development by increasing productivity. Vertical development entails growing downstream activities, meaning that instead of primarily exporting CPO, there should be a greater emphasis on developing downstream industries to produce and export manufactured palm oil products[10]. This shift will increase added value to the downstream products and enhance the technology and human resources involved in the downstream palm oil industry[11].

Developing vertically integrated and sustainable oil palm plantations is necessary for smallholder plantations, which account for 40% of the total national oil palm plantation area. Intensifying production on smallholder oil palm plantations in Indonesia has the potential to increase output by 26%, equivalent to the production from 1.75 million hectares of land[12]. Vertical oil palm development creates an integrated system that connects producers to consumers, including marketing channels. By intensifying downstream development within this vertical approach, the need to expand oil palm plantations into forest areas or regions unsuitable for cultivation can be minimized. Given Indonesia's current suboptimal productivity, the country has a significant opportunity in these efforts. Therefore, appropriate strategies tailored to the specific characteristics of each plantation type and location are essential.

One of the methods to develop palm oil waste downstream processes is implementing the Organic Rankine Cycle (ORC) system. The ORC system is an efficient method for converting low-grade heat into electricity[101]. The following are the key components and operational parameters of the system:

a. Evaporator. This component heats the working fluid, causing it to vaporize. Operational parameters include the temperature and pressure at which the fluid is heated.
b. Turbine. The vaporized working fluid expands through the turbine, generating electricity. Key parameters include the turbine's efficiency, rotational speed, and the pressure drop across the turbine.
c. Condenser. This component cools the working fluid, causing it to condense back into a liquid. Operational parameters include the cooling temperature and the effectiveness of heat exchange.
d. Pump. The pump increases the pressure of the condensed working fluid before it returns to the evaporator. Key parameters include the pump's efficiency and the pressure boost it provides.

The ORC system has been successfully implemented in a biomass power plant in South Sumatra, where ORC technology was successfully integrated to convert palm oil waste into electricity. Key takeaways from this project highlight the importance of optimizing the feedstock and maintaining high operational efficiency. Additionally, in East Kalimantan, a biogas power generation project utilized Palm Oil Mill Effluent (POME) for biogas production. This approach significantly reduced greenhouse gas emissions and offered economic benefits, including a favorable payback period. Another example is Java's Integrated Waste Management System, which combines composting, anaerobic digestion, and thermal conversion. This initiative showcased a holistic approach to managing palm oil waste, leading to improved soil fertility, energy production, and reduced environmental impact.

2. Methodology

This qualitative research comprises a literature review and data collection. The literature review phase consisted of a systematic search and collection of relevant scholarly articles, research papers, reports, and publications from various databases such as PubMed, Scopus, Google Scholar, Elsevier ScienceDirect, JSTOR, ResearchGate, Web of Science, and SpringerLink. The search strategy utilized keywords like "palm oil waste management," "local wisdom," "sustainable development," and "smallholder palm plantations." The collected literature were then organized, analyzed, and synthesized to identify prevailing trends, challenges, and existing practices related to waste management in the palm oil industry[13], with a particular focus on the role of local wisdom in sustainable development[14].

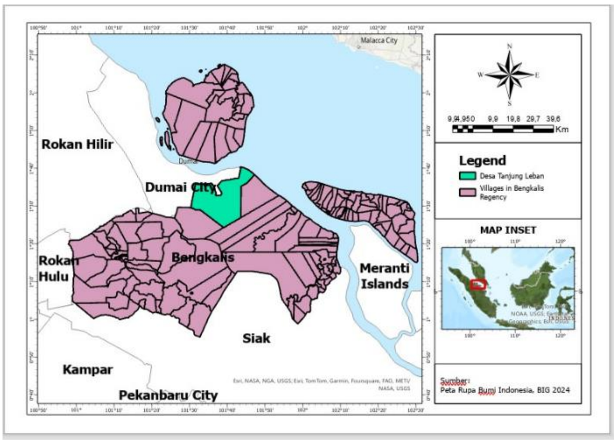

Fig. 1: Tanjung Leban Village, Riau Province.

Primary data on palm oil waste management was collected through a survey of 94 ISH community members in Tanjung Leban Village, Bengkalis Regency, Riau Province, from February to April 2023. The research location is shown in Fig. 1.

The survey focused on capturing the innovative use of palm oil waste materials, such as shells, fibers, fronds, and leaves, in creating handicrafts within the smallholder community. This initiative aims to document the process and outcomes of transforming these often-discarded palm oil byproducts into valuable and sustainable products. The findings are presented in a photo collage that highlights the importance of local wisdom in repurposing palm oil waste for economic and ecological sustainability. This qualitative data collection effort seeks to offer an insightful portrayal of how waste materials are creatively repurposed into handicrafts, showcasing the community's commitment to sustainable practices and the preservation of traditional knowledge in Tanjung Leban Village.

Next, the Expert Data Triangulation method was employed to enhance the credibility and validity of the research findings. This process involved comparing the data with insights from experts in the palm oil industry, waste management specialists, academics from relevant institutions, and policymakers. By integrating multiple types of information from different sources, we enhanced the validity and reliability of the research findings.

The final step was conducting the qualitative analysis, which involved fieldwork and interviews with multiple stakeholders, including smallholder farmers, local communities, experts from the agricultural sector, academics, and policymakers involved in palm oil agribusiness. The data collected aimed to explore the perspectives, experiences, and insights of these stakeholders from six sectors regarding the integration of local wisdom into palm oil waste management practices. The findings from the literature review, expert data triangulation, and qualitative analysis were then combined to propose recommendations and strategies for enhancing sustainable waste management practices in smallholder palm plantations, with an emphasis on integrating local knowledge and practices to achieve sustainable development goals (SDGs).

Table 1. Research Sample.

Category / Sector	No. of Informants (person)
ISH	58
Local community	36
Palm business experts	2
Waste management experts	4
Academic / Institution	4
Policymaker	1
TOTAL	105

Table 1 shows the research sample, which is the number of interviewees from whom the data was collected through semi-structured interviews. At the final stage, we also conducted a comprehensive review of over 80 articles to analyze the qualitative findings from this research.

3. Results and Discussion

3.1 The potential of palm oil waste management from palm plantations in Indonesia

Waste management is a pressing concern within the palm oil industry. Field data indicate that the production yield of CPO from 1 ton of fresh fruit bunches (FFB) is only approximately 20-25%, with the remainder classified as waste[22]. The volume of this waste is considerable, and failing to utilize it would result in significant inefficiencies. Therefore, a key opportunity for vertical development within oil palm plantations is the downstream processing of this production waste. Figure 2 provides an overview of the different types of waste generated in the palm oil industry.

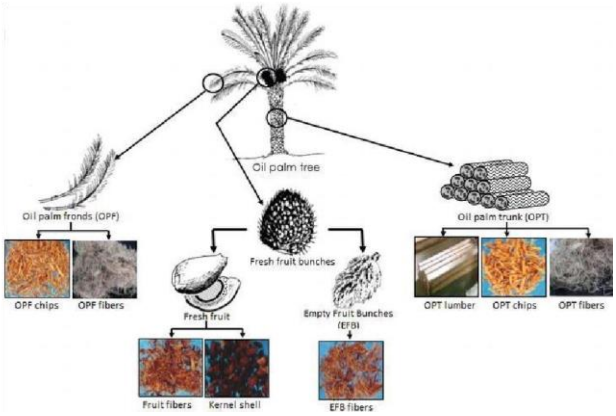

Fig. 2: Types of Palm Oil Industry Waste and Their Derivatives[18].

The waste generated by the palm oil industry is categorized into several types: Empty Fruit Bunches (EFBs), palm fiber, palm shells, and POME. Among these, EFB constitutes the largest portion of palm oil waste, followed by palm fiber, palm shells, and POME[15].

Table 2. Percentage of Potential Palm Oil Waste from Processing 1 Ton of FFB[17].

Type of Waste	Percentage
Empty Fruit Bunches (EFBs)	21-23%
Shell	5.75-6.5%
Palm Kernel Expeller (PKE)	4-5%
Fiber	12.5-13%
Palm Oil Mill Effluent (POME)	50-55%
TOTAL	100%

Table 2 outlines the potential waste generated from processing 1 ton of Fresh Fruit Bunches (FFB). According to this table, a palm oil mill with a processing capacity of 50 tons per hour is estimated to produce approximately 23.25 tons of solid waste per day[19]. Data from the Indonesian Palm Oil Entrepreneurs Association (GAPKI) reported Indonesia’s CPO production at 46.73 million tons in 2022[1]. Based on this data, it can be interpolated that in 2022, Indonesia generated approximately 47.62 million tons of EFBs waste, 28.34

million tons of palm fiber waste, 13.04 million tons of palm kernel shell waste, and 116,000 megaliters of POME. The substantial volume of untreated solid waste presents significant environmental challenges for the palm oil industry, which can ultimately impact its competitiveness and productivity in Indonesia.

Quantifying the palm oil waste generated in Indonesia is crucial for understanding the scope of the issue. Several studies have been conducted to estimate the volume of palm oil waste produced in Indonesia. These studies involved collecting samples from various palm oil mills and aggregating the data to provide a more precise estimate of waste generation[20].

Furthermore, each type of waste generated by the palm oil industry has distinct characteristics regarding moisture content, acidity, and chemical composition[16]. Understanding the chemical composition of palm oil waste is crucial for assessing its energy potential. Palm oil waste contains various organic materials, including cellulose, hemicellulose, and lignin. These components possess high energy potential and can be harnessed to generate bioenergy[21].

3.2 The development of sustainable palm waste management in Indonesia

In Indonesia, palm oil waste is typically disposed of using conventional methods like open burning, which leads to significant air pollution. Burning palm oil waste produces harmful emissions such as particulate matter, carbon monoxide, and polycyclic aromatic hydrocarbons[23], contributing to air quality problems that adversely affect human health and the environment[24].

Inadequate management of palm oil waste can also result in water pollution and soil degradation. When waste is disposed of in rivers or water channels, it introduces oil, chemicals, and excessive nutrients[22] into the water, harming aquatic ecosystems[24] and threatening water sustainability. Direct deposition of waste into the soil can degrade soil fertility[25] and agricultural productivity[26].

Improper palm oil waste management not only damages the environment[27] but also poses risks to human health, as hazardous emissions from burning can cause respiratory issues for nearby communities[28]. Additionally, pollution from waste disposal can harm biodiversity[29] and disrupt natural ecosystems[30], which are vital for maintaining environmental balance.

Therefore, it is vital to implement a sustainable and environmentally friendly palm oil waste management system to address these challenges. Employing a life cycle analysis (LCA) approach— which assesses the environmental impacts of waste management practices throughout their entire life cycle, from resource extraction to disposal— provides a comprehensive evaluation of their sustainability. This approach suggests that using palm oil waste for energy production can reduce greenhouse gas emissions and offer significant environmental benefits[31]. Utilizing palm oil waste as a renewable energy source can also decrease reliance on fossil fuels and lower the overall carbon footprint[32].

In the context of sustainable development, utilizing palm oil waste aligns with several SDGs. Specifically, using palm oil waste for energy production can contribute positively to goals such as poverty alleviation, job creation, and reducing greenhouse gas emissions[32].

Furthermore, supportive policies and regulations in Indonesia are essential for advancing sustainable palm oil waste management. Clear and stringent policies are needed to ensure that palm oil waste management practices adhere to environmental standards. Effective management at the community level requires the involvement of various stakeholders, including the government, private sector, technology providers, researchers, press, and social media media[33]. An example of such a policy is Government Regulation No. 18 of 2016 on Community-Based Waste Management, which promotes integrated and sustainable waste management practices. These joint efforts can address environmental challenges and harness the potential of palm oil waste more effectively. This collaborative approach can also substantially benefit Indonesia's environment, economy, and society.

Additionally, implementing supportive policies, such as incentives and rewards for industries that adopt effective waste management practices, can encourage the development of innovative and environmentally friendly solutions. Evidence suggests that providing incentives to palm oil farmers for integrated waste management has improved production sustainability and reduced negative environmental impacts[34].

Further research and development are crucial for advancing palm oil waste management. Future studies should focus on developing more efficient waste processing technologies, improving environmental impact measurement methods, and gaining a deeper understanding of the social impacts and benefits for local communities. These efforts will provide a robust foundation for sustainable palm oil waste management.

3.3 The prospects of oil palm waste as a renewable new energy biomass producer

Southeast Asia, including Indonesia, is rich in biomass resources, such as palm oil, sugarcane, coconut, and cassava residues, which can all be utilized as raw materials for biofuel production[35]. Several countries in the region have implemented policies and regulations to support biofuel development, including tax incentives and biofuel blending mandates[36]. The region's population and economic growth have increased energy demand, creating a significant market potential for biofuels[37]. However, the development and adoption of biofuel technologies face challenges, such as high production costs and low efficiency[38]. Additionally, land use for biofuel feedstock production often competes with food production and forestry needs, potentially leading to conflicts and environmental issues. Inadequate investment and funding also pose major barriers to developing biofuel infrastructure and research[39)].

Recently, biofuel production from palm oil waste has garnered attention. Palm oil waste can be converted into biodiesel through the transesterification process, which helps reduce dependence on fossil fuels and mitigates the environmental impacts of the palm oil industry[40)].

Based on our research, some technologies could be utilized to convert palm oil waste into energy. One notable technology is anaerobic digestion, which decomposes organic matter using microbes to produce biogas, primarily methane, which can be used as an alternative fuel[20)]. Thermal conversion processes such as pyrolysis and gasification can also be employed. Pyrolysis involves heating palm oil waste in an oxygen-free environment to produce biochar, bio-oil, and gas[101)]. Meanwhile, gasification[102)] involves a controlled reaction between various palm oil waste such as empty fruit bunches[41)], palm kernel shell[42)], fronds[43)], branches[44)], or other biomass[45)] and gasification agents to generate syngas, which can be utilized as biofuel or chemicals.

Biodiesel development is a necessity and a challenge for Indonesia. The need for renewable energy (NRE) is growing in response to environmental demands and the economic demands of independence of petroleum imports[46)]. The Indonesian government strongly encourages biodiesel development through the B30 Mandate policy, which began in January 2020 and is outlined in regulation of the Minister of Energy and Mineral Resources No. 12 of 2015, which is the Third Amendment of the regulation No. 32 of 2008 concerning the provision, utilization, and trade of biofuel as an alternative fuel.

Biofuel can be produced from several types of plants, including the oil palm, which has the highest productivity compared to vegetable oils produced by other plants[47)]. Palm oil also has a positive energy balance and a net reduction of greenhouse gas emissions compared to diesel, with a payback time for a tropical forest of 39 years[48)]. Indonesia, as the world's largest producer of oil palm, can lower its dependency on fossil fuels by processing Crude Palm Oil into biodiesel. In 2021, Indonesia is estimated to have 15,081,021 ha of oil palm plantations and produce 49,710,345 tons (about 3.3 tons ha^{-1} $year^{-1}$) of palm oil[49)]. A productivity of 3.6 - 4 tons ha^{-1} $year^{-1}$ of palm oil can produce 31,914,476 kiloliters of biodiesel. Therefore, this tremendous potential for biodiesel production needs to be managed properly to support national energy resilience and address economic and environmental impacts[50)].

Biodiesel is a type of Biofuel (BBN) produced from biological raw materials or other biomass sources[51)] that have undergone the esterification/transesterification process[101)]. This process simplifies the triglyceride compound chain into a monoglyceride methyl ester chain with short-chain alcohols like methanol[52)]. Pure biodiesel comprises Fatty Acid Methyl Ester (FAME). Currently, biodiesel production has been widely developed using CPO as the raw material. This research introduces an innovation that produces CPO from Palm Sludge Oil (PSO), a waste product from palm oil mills. This research's results could solve the increasing demand for CPO, especially in the food and oleochemical sectors.

In economic terms, converting waste into biodiesel represents a form of circular economy within the palm oil industry, where the byproducts of waste processing can be reused as production inputs[53)]. From an environmental perspective, it also has a positive impact on the management of factory waste, which will decrease environmental impact[54)]. Waste that reacts with air and water undergoes oxidation, leading to sedimentation at the bottom of storage tanks. This sediment is also known as sludge. For every 1000 kg of Fresh Fruit Bunches (FFB) processed, around 500 kg of sludge is generated, accounting for approximately 50% of the output (Fig. 2). Palm sludge oil typically consists of residual components of palm oil, such as triglycerides, fatty acids, and other constituents.

Therefore, a method is needed to prevent this sludge waste to be a source of environmental pollution. One approach to achieve this is by using thermal desorption methods[55)]. Thermal desorption is a physical process. It does not involve a chemical reaction like combustion processes where oxidation reactions take place[56)]. The lack of chemical reactions in this process means that it does not produce air pollutants. The residues that have been adsorbed and are in vapor form are easier to collect by cooling; the vapor condenses, gathers, and does not spread. Meanwhile, organic materials that are resistant to vaporization will break down (carbonize) into charcoal. The charcoal produced in this process manifests as charcoal powder, and laboratory tests are needed to determine whether this charcoal is toxic or non-toxic. If the charcoal is non-toxic, it can be safely used and molded into charcoal briquettes[57)].

The utilization of palm oil waste for energy production presents substantial economic advantages. However, a cost-benefit assessment is required to evaluate the accurate economic feasibility. Research has shown that converting palm oil waste into energy can yield profitable returns on investment over the long term, making it a financially viable option for sustainable energy development[58)]. Nevertheless, the cost-benefit analysis should consider several key factors, including the initial investments required for infrastructure and technology, ongoing operational costs, and the economic benefits derived from the project. These benefits may include energy savings and revenue generated from the sale of the produced energy. By considering these elements, the analysis can provide a comprehensive understanding of the financial viability and potential returns of utilizing palm oil waste for energy production[59)].

By factoring in these social dimensions, the analysis can offer a more holistic view of the positive outcomes associated with palm oil waste utilization, contributing to economic growth and social well-being in the regions where these initiatives are implemented. In addition to financial aspects, it is crucial to consider the social impacts[60] of palm oil waste utilization, which include job creation, improved livelihoods, skills development, and broader economic development opportunities in rural areas[61]. By factoring in these social dimensions[62], the analysis can offer a holistic view of the positive outcomes, such as reducing dependence on the primary palm oil sector with the establishment of palm oil waste processing and renewable energy industries[63] and creating new job opportunities in areas that often face limited economic prospects. These initiatives contribute to both economic growth[64] and social well-being[65] in the regions where they are implemented.

3.4 The potential of down-streaming organic waste from ISH oil palm plantation communities in Indonesia with local wisdom

Large private palm oil industries typically have strong capital[66], extensive downstream technologies and product lines, and are accustomed to integrating their operations with comprehensive waste management[67], such as processing shells and fibers into boiler fuel, converting empty fruit bunches and POME into organic fertilizers for their plantations, or selling them to third parties as biomass for energy, animal feed, and raw materials for other products[68].

Meanwhile, the Indonesian Ministry of Agriculture has introduced Smallholder Replanting Programs to support smallholder palm oil farmers[69]. These initiatives often include financial incentives, subsidies, technical assistance, and high-quality seedlings to encourage smallholders to replant their palm oil plantations with high-yielding and sustainable varieties[70].

The government's intervention is critical for expediting the transition of smallholders' oil palm practices toward a global sustainability agenda[71]. Other forms of support from national and local governments are access to credit[72] and financing facilities[73], training and capacity building on palm oil cultivation[74], sustainable farming practices[75], efficient land management[72], and support in sustainability certifications[76] to open up markets and opportunities for smallholders by demonstrating their commitment to environmental and social responsibility[77]. Moreover, there are specific welfare programs for ISH oil palm farmers, including healthcare services, education, and housing improvements for workers and their families[78]. There are also promotion efforts for community-based management of palm oil plantations to empower local communities by involving them in decision-making and revenue-sharing processes[79], research and development of improved palm oil varieties[80], pest and disease management, addressing of land tenure and land conflicts issues[75], and streamlining export regulations[81].

Unlike private enterprises, ISH operators often lack integrated agricultural systems and typically do not own Palm Oil Mills. Usually, ISH operators sell their palm oil harvest directly to companies or cooperatives that own mills[82], leaving the potential for downstream utilization of palm oil waste, particularly through the integration of local wisdom, largely untapped[83]. These potential products represent a significant opportunity for generating additional income for the communities living around ISH oil palm plantations[84].

Such businesses are typically organized by community members living around ISH oil palm plantation areas in Tanjung Leban, Riau Province. However, among the 58 ISH and 36 Oil Palm community members surveyed in Tanjung Leban Village, only 15 (less than 16 percent) actively engaged in palm oil waste management using local wisdom as a source of livelihood. Local products commonly produced from palm oil waste include handicrafts made from rattan palm fronds, laths from palm leaves, and other products. Encouraging greater participation in transforming agricultural waste into creative industry products with low capital investment could significantly enhance the community's economic development.

Fig. 3: Products Created by Local Communities in Tanjung Leban Village from Processing Palm Plantation Waste.

Figure 3 shows examples of commercialized products by local communities, such as household items like plates, brooms, baskets, chairs, and handicrafts like bags and buttons.

In managing oil palm waste with local wisdom, it is essential to consider local conditions, involve stakeholders, and strive to reduce negative environmental impacts while supporting the local community's well-being. The process also involves the application of methods and practices that consider local needs and conditions, such as:

1. Utilization of organic waste: Palm waste, such as empty fruit bunches, fiber, and shells, can be used as raw materials for bioenergy production, such as biomass for power generation or alternative fuel[85].
2. Composting: Palm waste can be composted to produce organic fertilizer for local agricultural uses. Proper composting methods can be implemented, and phytoremediation methods can be applied to clean or treat industrial

wastewater before it is released into the environment.

3. Wastewater Treatment: Wastewater from palm oil mills needs to be treated before being discharged. Wastewater treatment technologies such as sedimentation, filtration, and phytoremediation can clean the wastewater before it is released into the environment.
4. Reforestation and Land Conservation: Palm waste management activities should include efforts to rehabilitate degraded land. Reforestation with locally resilient species can help restore ecosystem balance.
5. Community Education and Awareness: Involving the local community in palm waste management is essential. Education and awareness about the importance of sustainable practices can help change the community's attitudes and behaviors in addressing environmental issues.

3.5 The future prospects of palm oil waste management

The processing of palm oil waste has undergone significant advancements in recent years, particularly through the use of bioenergy technology to convert waste into renewable energy. Intensive research and development efforts have been directed toward integrating renewable energy systems[86)] within the palm oil industry[87)]. Using biomass and biogas technology[88)] can generate sustainable energy and reduce greenhouse gas emissions[89)]. For example, biogas power generation from palm oil mill effluent can reduce GHG emissions by 1131 tons CO2-eq/month and provide economic benefits with a payback period of 10.8 years[90)]. Implementing this technology can contribute to achieving SDGs.

Additionally, palm oil waste management presents further opportunities for research and development. Investigating the environmental impacts of converting waste into renewable energy, particularly through life cycle assessments (LCA), can provide valuable insights into the sustainability and effectiveness of waste-to-energy processes, guiding future advancements.

Next, partnerships between the government and industry are essential for advancing sustainable practices within the palm oil sector. The government needs to provide supportive policies[91)] and regulations[92)], including incentives and stimuli for industries that adopt environmentally friendly waste management technologies and practices. This collaboration can drive the growth of a sustainable industry and benefit the environment and society[93)].

Several projects for converting palm oil waste into renewable energy have been successfully implemented in Indonesia. Some examples are the biomass power plant projects using palm oil waste in South Sumatra[94)] and East Kalimantan[95)], and other location such as Java, Sulawesi, and Papua[96)]. These projects can serve as a successful model and provide valuable insights for developing similar initiatives in other regions and industries that generate organic waste.

However, several challenges exist in palm oil waste management. The main challenges include technical issues, such as the efficiency and reliability of the technology[97)], and financial issues related to the required investments in waste processing technology[98)]. Additionally, strategies are needed to address the logistical and transportation challenges of palm oil waste scattered across various locations[99)].

Therefore, fostering collaboration and knowledge exchange among government entities, industry stakeholders, and research institutions is essential for overcoming these obstacles and developing sustainable palm oil waste management practices[100)]. Adopting best practices from successful initiatives can also help to scale solutions effectively.

In Indonesia, replicating projects that convert palm oil waste into renewable energy across various regions and industries holds significant promise. As one of the world's largest palm oil producers, Indonesia has numerous areas with substantial potentials of utilizing palm oil waste. Thus, the experience gained from successful projects can be adapted and applied while considering each region's conditions and specific needs.

Overall, palm oil waste management can continue to be improved through ongoing research, collaboration between the government, industry, and research institutions, and increased public awareness. In this regard, sustainability and effective waste management should be the primary focus.

4. Conclusion

This article has highlighted the importance of utilizing palm oil waste in the context of sustainable development. The utilization of palm oil waste for energy production can reduce environmental impacts and provide economic benefits. The research findings indicate that with appropriate technology and cooperation between the government and the industry, palm oil waste can become a sustainable renewable energy source. For instance, harnessing biogas from POME or utilizing palm kernel shells for biomass energy can contribute to cleaner energy production. These methods align with the theme's focus on transforming energy technology towards a decarbonized society by replacing conventional energy sources with sustainable alternatives.

Furthermore, appropriate policy recommendations are needed to promote the utilization of palm oil waste. First, the government should incentivize the palm oil industry to adopt sustainable waste management practices. These incentives can take the form of tax breaks, subsidies, or funding for investments in waste processing technology. Additionally, stringent regulations are required to drive the transition to sustainable energy. These regulations can include renewable energy mix targets, greenhouse gas emission standards, and requirements for environmentally friendly waste processing technologies. The strategy involves developing a comprehensive waste management system tailored to the specific needs of smallholder palm plantations. This strategy includes the responsible disposal of EFBs, palm fronds, and other byproducts generated during the palm oil production process. Innovative techniques such as composting or bioenergy generation from waste materials can also be explored to ensure a holistic and environmentally friendly approach.

Finally, the utilization of palm oil waste for energy production has significant economic benefits. By encouraging community-based initiatives and utilizing local wisdom, smallholder communities can generate additional income and contribute to economic development. Through careful cost-benefit analyses and appropriate investments, palm oil waste can become a sustainable energy source and contribute to economic development in rural areas while considering the social impact and benefits to local communities.

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Conflict of Interest

The authors affirm that no conflicts of interest are associated with this manuscript's publication. Furthermore, the authors have diligently adhered to all ethical considerations, including plagiarism, informed consent, research misconduct, data fabrication and falsification, duplicate publication and submission, and redundancy avoidance.

Nomenclature

BBN	Bio-Based Newcomer
CPO	Crude Palm Oil
EFB	Empty Fresh Bunch
FAME	Fatty Acid Methyl Ester
FFB	Fresh Fruit Bunch
GDP	Gross Domestic Product
ISH	Independent Smallholder
LCA	Life Cycle Assessment
MEMR	Ministry of Energy, Mineral and Resources
NRE	New Renewable Energy
POME	Palm Oil Mill Effluent
PSO	Palm Sludge Oil
RNE	Renewable Energy
SDGs	Sustainable Development Goals
TFFB	Total Fresh Fruit Bunches

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