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CASE STUDY

Exploring the potential of palm oil plantation waste for local communities using mixed methods

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ABSTRACT

BACKGROUND AND OBJECTIVES: Riau is Indonesia's largest palm oil supplier region, part of which is managed by smallholder farmers. The escalation in the worldwide need for palm oil has resulted in the expansion of plantations, consequently causing a rise in palm oil waste. Small-scale farmers lack sufficient knowledge and resources for waste management. The study aims to estimate and forecast the volume of palm oil waste generated and the utilization inventory by indigenous populations in Riau province.

METHODS: The present study employs a combination of quantitative and qualitative methodologies. Utilizing secondary data obtained from the Central Statistics Agency, the research calculates the volume of waste generated by smallholder oil palm plantations and forecasts the quantity of palm oil waste. The prediction method uses the time series modeler method with the help of a statistical package for the social sciences 23. Subsequently, surveys were employed to gather quantitative information regarding the utilization of palm oil waste by indigenous populations in the province of Riau. The respondents involved were 112 people using the convenience sampling method. Descriptive statistics are utilized in data analysis to determine the quantity of waste and to gain insight into the local population's utilization. Interviews were also conducted with seven local people who work as farmers regarding the management and use of palm oil waste. Interview data were analyzed using descriptive qualitative methods.

FINDINGS: Analysis of smallholder plantation waste in Riau shows that the most significant type is stem parts at 82 percent. Palm oil waste will increase to 236.37 million tons in the next decade. Approximately 80 percent of local communities handle plantation waste by depositing it on plantations for natural decomposition.

CONCLUSION: The amount of smallholder plantation waste is enormous and will continue to increase. It is crucial to prioritize the improvement of waste management standards at the local community level in order to promote the sustainability of palm oil plantations. The findings significantly contribute to promoting sustainable environmental management, providing actionable insights for policymakers and environmental activists.

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INTRODUCTION

Palm oil is derived from the fruit of the oil palm tree (*Elaeis guineensis Jacq*.), a species that thrives in tropical regions. Oil palm grows well in tropical rainforest areas with an annual rainfall of 1780–2280 milimeter (mm) and an environmental temperature interval of 24–30 degrees Celsius (°C) (Urugo *et al.,* 2021). Indonesia is a country that has more than 80 percent (%) of tropical rainforest in Southeast Asia (Indrajaya *et al.,* 2022), making it suitable for oil palm plantations (Petrenko *et al.,* 2016). Xu *et al*. (2022) stated that forested land cover decreased due to the expansion of oil palm plantations. Since its initial introduction in 1911, this plant has made substantial progress in Indonesia, evolving into a key commodity by 1970 (Hambali and Rivai, 2017). The process of establishing oil palm plantations commences with the clearance of land designated for cultivation. This involves the utilization of heavy machinery, logs, and controlled burning techniques by individuals involved in the industry. Oil palm seedlings are planted in polybags for 10–12 months in a nursery (Rosenani *et al*., 2016) and then planted at a density of approximately 150 palm trees/hectare (ha) (Woittiez *et al*., 2017). The maturation period for oil palm trees is approximately three years, during which they generate a one fresh fruit bunch (FFB) every 10–21 days (Lai *et al*., 2023). The development of palm fruit until maturity takes approximately 180 days (Romero *et al*., 2021). Oil palm plants are replanted when they are 25–30 years old because of the complex harvesting process (Woittiez *et al*., 2017). Indonesia is the leading producer of palm oil globally, with oil palm plantations spanning 26 provinces, particularly concentrated in Sumatra, Kalimantan, parts of Sulawesi, and Papua (BPS, 2022b). The amount of palm oil supplied exceeds 85% of the global supply, and is the world's leading market supplier of vegetable oils (Petrenko *et al*., 2016). Indonesia supplied 42.5 million tons of palm oil in 2020. The prevalence of this dominance is closely linked to the extensive expanse of oil palm plantations, spanning 16.38 million hectares, and the substantial production output of 54.3 million tons in the year 2022. The optimal tropical weather conditions are conducive for the growth of oil palm plantations. High rainfall and sufficient sunlight support the optimization of oil palm growth. Significant assistance has been extended by the Indonesian government to the palm oil sector through various means such as subsidies, incentives, and regulatory frameworks that promote industrial advancement (Murphy *et al*., 2021). The government focuses more on calculating crude palm oil (CPO) production and pays less attention to the amount of waste produced. Riau Province is the region with the largest palm oil supplier in Indonesia. Riau has been designated as a center for palm oil production and has become a barometer in the palm oil industry in Indonesia. The recorded oil palm plantation area in this region is 3.38 million hectares, representing 20.68% of the total oil palm plantation area in Indonesia (Raharja *et al*., 2020). In 2022, Riau province will have an area of 2.87 million ha or 18.70 % of the total area of oil palm plantations in Indonesia. Meanwhile, community-managed oil palm plantations reach 1.7 million ha (BPS, 2022b). Palm oil plantation commodities play a significant role in the economic activities of Riau due to their high potential for palm oil production in the industrial sector. The most significant CPO production in 2022 will come from Riau Province, with production of 8.74 million tons or around 18.67% of Indonesia's total production, which is supplied from smallholder plantations (55.13%), state plantations (4.5%) and private plantations (40.36%) (BPS, 2022b). The escalation in global palm oil demand has resulted in the increased expansion of palm oil plantations worldwide. The government is essential in supporting farmers to realize sustainable palm oil plantations (Cifuentes-Espinosa *et al*., 2023). Government efforts should mainstream the commitment to implementing RSPO certification in order to increase crop yields (Hassan *et al*., 2024) and environmental issues (Rodthong *et al*., 2023). The large amount of palm biomass produced includes empty fruit bunches (EFB), palm kernel shells, mesocarp fiber, palm oil mill effluent (POME), stems, and leaves. Improper management of palm oil plantation waste can negatively impact the environment, such as water, soil, and air pollution. This can endanger human health (Ayompe *et al*., 2021), disrupt ecosystems (Teng *et al*., 2020) and climate change (Ahmed *et al*., 2021). This study has the potential to make a substantial impact on the development of palm oil waste management strategies in Riau Province. This research is the first research to specifically investigate oil palm waste by smallholder plantations in Riau Province by applying a mixed-method approach. The

study conducts an analysis and forecasts the quantity of oil palm residue produced by small-scale farms, while also gathering information on the utilization of palm oil waste by individuals. The results of previous research regarding the assessment of oil palm plantations in Riau include the formulation of institutional strategies for oil palm cultivation to improve the economy of local communities (Syahza and Asmit, 2020), gender analysis in the management of oil palm plantations (Retnaningsih *et al.,* 2022), analysis of ownership conflicts in oil palm plantation land (Manurung *et al.,* 2021), appropriate technology for processing palm oil waste biomass for the community (Nasution *et al.,* 2021). The current emphasis of the government remains on the enhancement of the extensive palm oil sector. Waste management in oil palm plantations overseen by governmental bodies and private entities is well-equipped, however, it lacks provisions for small-scale farmers. The farmers need more knowledge and skills in managing waste. A significant increase in waste will impact environmental quality. Enhancing the oil palm plantation within the economic sphere necessitates a comprehensive evaluation of its social and environmental implications. Palm oil waste still receives little attention in smallholder plantations, even though it is crucial for the sustainability of palm oil plantations in the future. It is crucial to examine how smallholder farmers utilize palm oil waste, especially given their limited understanding of plantation management and access to advanced technological resources in comparison to state and private sector management. The main waste of small farmers is stems and leaves, which have commercial potential and could be used to make them more valuable (Pulingam *et al.,* 2022). Smallholders in Riau Province possess 55.13% of the total oil palm plantation area (BPS, 2022b). Independent smallholders manage almost half of the total land, whose contribution to total palm oil production in Indonesia ranges between 27% and 38% (Raharja *et al.,* 2020). The aim of study to quantify the volume of palm oil waste generated by smallholder oil palm plantations, forecast its accumulation over the course of several decades, and assess the extent of the Riau community's understanding ofits utilization. This study was carried out in Riau province, Indonesia, in 2024.

MATERIALS AND METHODS

The study area

The research used a mixed-method explanatory design. The method was specifically chosen so that the problem of potential oil palm plantation waste at the research location could be explained well and in detail. This study design integrates both quantitative and qualitative methods of data gathering and analysis to provide a comprehensive understanding of a particular phenomenon (Creswell and Guetterman, 2019). This study was conducted in Riau Province, Indonesia, as presented in Fig. 1.

This study follows the research stages of Creswell and Guetterman (2019), encompassing the following procedures; i) first collecting quantitative data; ii) quantitative data analysis; iii) gathering qualitative data based on quantitative data findings; iv) collecting qualitative data; v) interpreting quantitative data through qualitative findings. The rationale behind this method is that quantitative data outcomes offer a broad overview of the research issue. Additional examination using qualitative data gathering may elucidate the overall context of quantitative data. Quantitative data consists of calculating the amount of waste using secondary data from the Central Statistics Agency (BPS) and inventorying the use of palm oil waste by local communities. The waste utilization survey used a questionnaire. Descriptive statistics were employed to analyze the questionnaires and calculate the volume of palm oil waste. Qualitative data collection was interviews with small oil palm farmers. Observations on oil palm plantations were also carried out to obtain empirical data and directly observe farmers' activities. Descriptive-qualitative analysis was conducted on the results obtained from interviews and observations. The interpretation of interviews and observations conducted in the field can provide insights into the quantitative data findings.. These steps are explained through a flowchart in Fig.2

Data collection

The study gathers numerical information by utilizing surveys to catalog the expertise of the local community in managing palm oil waste. The number of respondents involved in the research was 112 people using the convenience sampling method. The instrument indicators encompass familiarity

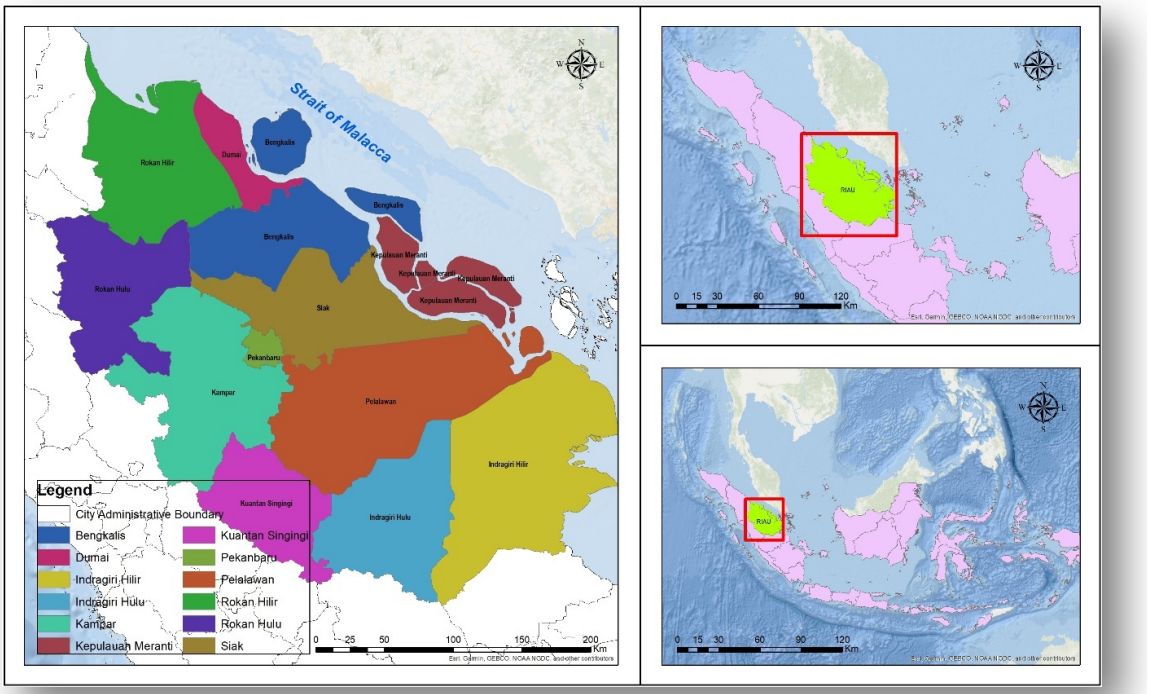


Fig. 1: Georaphic location of the study arae in Riau province, Indonesia

Table 1: Stakeholder of palm oil plantation

Stakeholders	Number of informants	Information
Palm oil plantation owner	2	Oil palm plantation owners who also manage oil palm plantations
Palm oil plantation workers	4	Local communities as workers on oil palm plantations
Cattle breeders	1	Local communities that have cattle farms in oil palm plantation areas

with the utilization of palm oil waste in the realms of medicine, agriculture, energy, handicrafts, and animal husbandry. Data analysis was carried out using descriptive statistics. The secondary data used is oil palm plantation data by smallholder farmers in Riau from 2006 to 2022 to calculate and predict palm oil waste. This data on oil palm plantations managed by smallholder farmers was obtained from BPS Riau Province (BPS, 2022a). To deepen the quantitative findings, interviews were conducted with farmers who manage oil palm plantations. Respondents were selected using snowball sampling. This technique involves incorporating advice from reputable sources with expertise in the area of oil palm management. They were invited to talk about processing palm oil waste on their plantations. Interviews were conducted in oil palm plantation areas so that they could demonstrate their activities directly. The study included seven farmers from Kampar Regency, consisting of owners of oil palm plantations, laborers on oil palm plantations, and cattle breeders (Table 1).

Data analysis

Quantitative data pertaining to the inventory of local community knowledge in the processing of palm oil waste was analyzed by computing the frequency

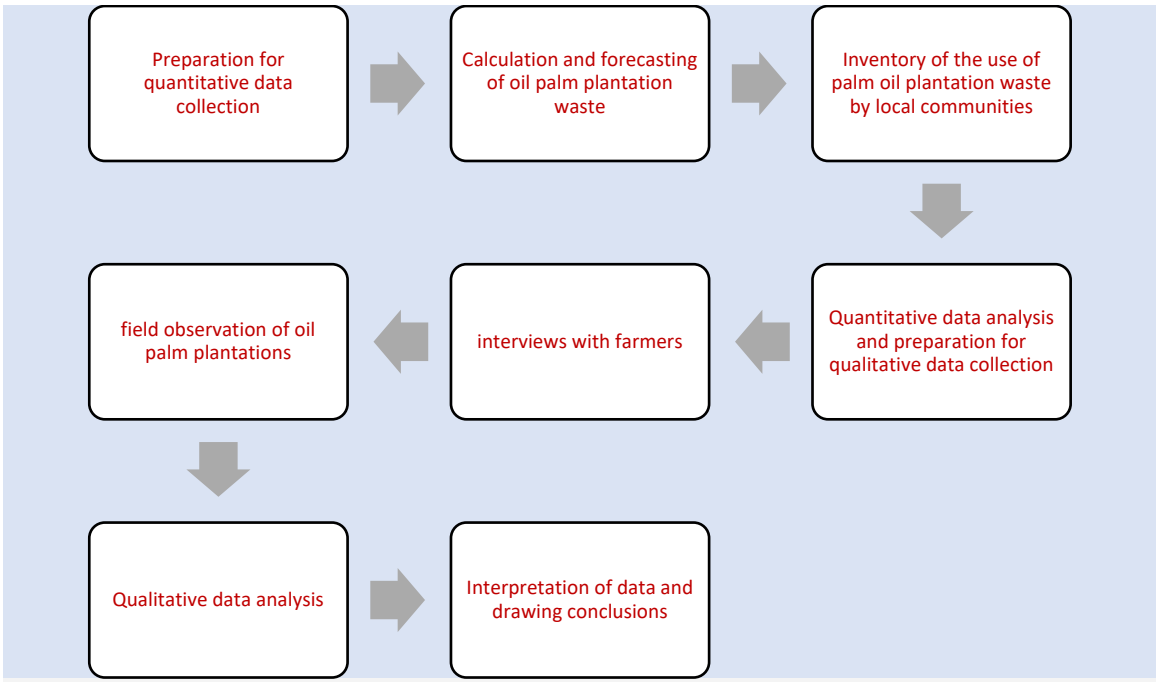


Fig. 2: Flowchart of the study procedure

and percentage of responses provided by participants in the survey. To measure predictions of palm oil waste, researchers used secondary data on oil palm plantations managed by smallholder farmers from 2006-2022 (BPS, 2022a). CPO production data is used to calculate palm oil waste, as presented in Fig. 3. In palm oil processing, 0.24% of CPO is obtained from FFB (BPDPKS, 2022). The calculation results of the palm biomass waste used were plantation waste and FFB processing waste. Plantation residue comprises of leaves and stalks, with quantities determined by the size of the plantation. The frond biomass was calculated at 12 tons/ha per year, and the stem biomass was calculated at 74.5 tons/ha per year (Sung, 2016). FFB waste consists of EFB, shells, and fiber. Calculation of FFB waste biomass is calculated based on CPO production using the mass balance of palm fruit processing, EFB 21%, shells 6.4%, fiber 14.4% (BPDPKS, 2022). The time series modeller method was employed in conducting forecasting analysis, utilizing the Statistical Package for the Social Sciences (SPSS) 23 application, in order to project the quantity of waste expected in the upcoming decade. Data analysis using descriptive statistics and regression. Interview data was analyzed using descriptive-qualitative tools. Data analysis consists of using data reduction, data presentation, and drawing conclusions to provide descriptive answers to research questions (Barrett and Twycross, 2018).

RESULTS AND DISCUSSION

Measurement of palm oil waste from smallholder plantations in Riau province

Palm oil waste consists of plantation waste and FFB waste. Plantation waste consists of fronds and stems. Frond waste is produced every time the fronds are pruned during harvest or maintenance. One or two fronds are usually pruned monthly in old oil palm plantations (Rhebergen *et al*., 2020), producing a dry weight of 12 tonnes/ha per year. Pruning is an essential task in the upkeep of oil palm trees, aimed at managing their growth effectively. Trimming the fronds of oil palm trees helps minimize potential losses, ultimately leading to enhanced productivity. Stem waste usually occurs during the replanting process. The process of replacing oil palm plants that are no longer productive/economical (>25 years) or have low productivity (<10 tonnes of FFB/ha/year). This process produces stem biomass of 74.5 tons/ha per year. People's oil palm plantations in Riau province

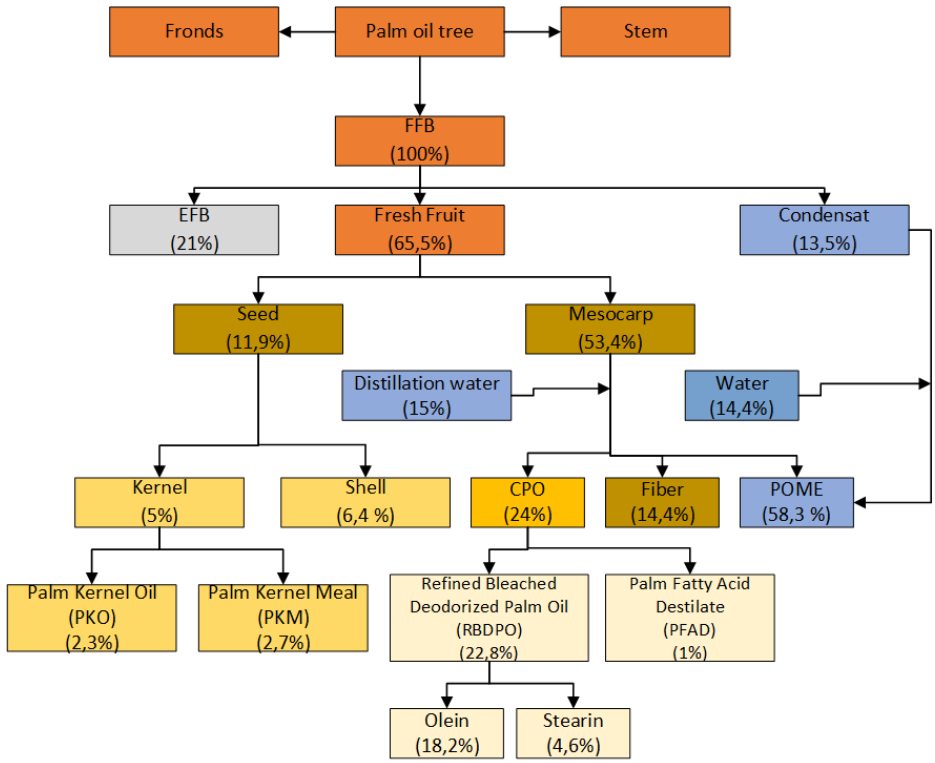


Fig. 3: Mass balance calculation for palm oil processing (BPDPKS, 2022)

continue to expand and have the impact of increasing the waste produced By the year 2022, there will be a total of 1.7 million hectares of smallholder oil palm plantations, yielding a production output of 4.8 million tons. The most enormous waste produced is stems, amounting to 131 million tonnes, and stems, amounting to 21 million tonnes. Meanwhile, FFB waste shows higher EFB than shells and fiber, as seen in Table 2.

EFB waste refers to the byproduct that is left behind following the conversion of FFB from oil palm trees into CPO at palm trees into CPO in palm oil mills. The quantity of FFB waste generated has been steadily increasing year-round. EFB stands out as the most prevalent waste product among the diverse range of FFB wastes, with mesocarp fiber and palm kernel shells following closely behind in terms of abundance. Shell waste generation is the lowest compared to the other two fractions. As illustrated in Fig.4, the most significant increases in palm oil waste production occurred in 2012 and 2018. In 2022, EFB waste reached 4.2 million tons, while shell and fiber waste amounted to 1.2 million tons and 2.8 million tons. The upsurge in palm oil byproducts as a result of the enhanced output of oil palm plantations poses a complicated issue. While high waste production indicates efficient oil extraction, it also necessitates sustainable management practices to mitigate environmental impacts. FFB waste, if not properly utilized, can pollute soil and water bodies. The primary by-product known as empty fruit bunch (EFB) has the potential to decompose and emit methane, a powerful greenhouse gas. Uncontrolled accumulation of EFB can further degrade soil and water quality while also harboring pests and diseases. The study conducted by Asadpour *et al*. (2021) reveals that adapted fiber sourced from EFB can function as a cost-effective absorbent material for addressing oil spills in the marine environment. POME waste is also waste that requires serious handling. Rakhmania *et al*. (2023) show POME can be processed using electrocoagulation to reduce COD, color, and fat effectively. Using platinum as an anode and graphite as a cathode has proven effective

Table 2: Area, CPO Production, FFB, and palm oil waste in smallholder plantations in Riau province 2006-2022

Year	Area (thousands ha)	CPO production (milion Ton)	FFB (million Ton)	EFB (million Ton)	Shells (million Ton)	Fiber (million Ton)	Fronds (million Ton)	Stem (milion Ton)
2006	748	1,779	7,411	1,556	0,474	1,067	8,980	55,753
2007	806	2,055	8,562	1,798	0,548	1,233	9,671	60,043
2008	845	2,368	9,867	2,072	0,631	1,421	10,143	62,970
2009	890	2,658	11,075	2,326	0,709	1,595	10,679	66,299
2010	1.056	2,894	12,060	2,533	0,772	1,737	12,667	78,638
2011	1.205	3,174	13,226	2,777	0,846	1,905	14,466	89,810
2012	1.297	3,485	14,522	3,050	0,929	2,091	15,568	96,648
2013	1.348	3,692	15,384	3,231	0,985	2,215	16,177	100,432
2014	1.358	3,707	15,445	3,244	0,989	2,224	16,294	101,158
2015	1.355	3,612	15,049	3,160	0,963	2,167	16,254	100,910
2016	1.383	3,885	16,186	3,399	1,036	2,331	16,600	103,059
2017	1.529	3,918	16,326	3,429	1,045	2,351	18,348	113,911
2018	1.734	4,789	19,955	4,191	1,277	2,874	20,808	129,180
2019	1.734	4,789	19,955	4,191	1,277	2,874	20,808	129,180
2020	1.762	4,732	19,716	4,140	1,262	2,839	21,146	131,281
2021	1.762	4,818	20,074	4,216	1,285	2,891	21,146	131,281
2022	1.762	4,818	20,076	4,216	1,285	2,891	21,146	131,281

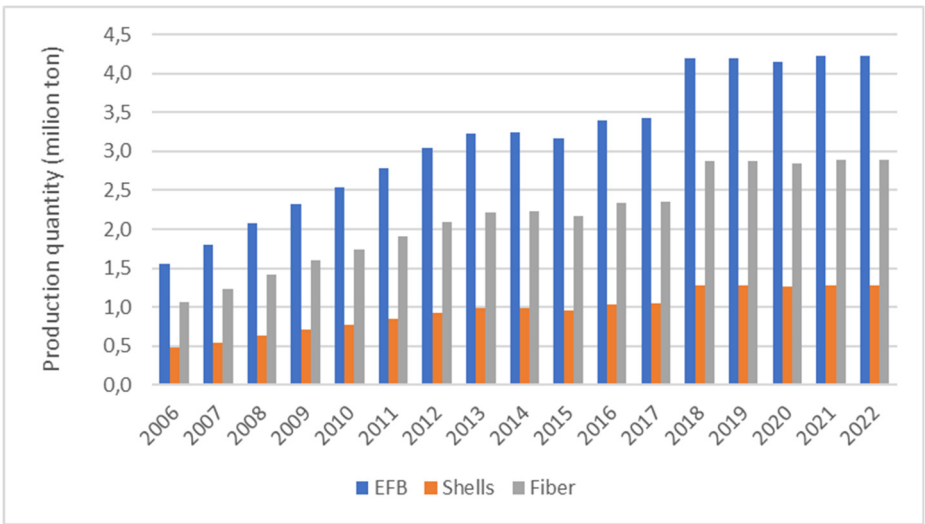


Fig. 4: Palm oil fresh fruit bunch waste in people's plantations in Riau province

in the electrochemical oxidation process of POME (Rakhmania *et al*., 2022). Jadhav *et al*. (2024) show POME can act as a medium for making biogas. Palm fruit fibers, a residual product of palm oil extraction, may also present possible environmental hazards. It is crucial to prioritize sustainable management strategies for palm oil waste in order to minimize adverse environmental effects. Prioritizing sustainable management strategies for palm oil waste is critical to mitigate negative environmental impacts. EFB waste holds the potential to be transformed into a valuable environmental resource. The elevated level of organic matter present enables the conversion into premium-grade compost. Utilizing such compost can enhance soil fertility, thereby reducing reliance on chemical fertilizers. EFB can be converted into biogas, a clean and renewable energy source.

Oil palm plantations produce substantial amounts of biomass waste, with fronds and stems comprising the largest portion of this waste. This waste production

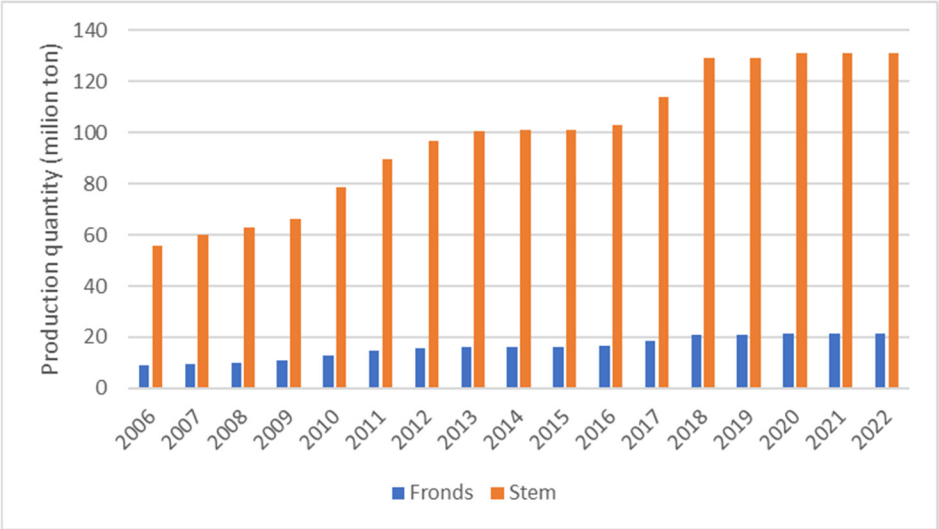


Fig. 5: Palm oil frond and stem waste in people's plantations in Riau province

exhibits a continuous upward trend throughout the year, with fronds exceeding stem waste in quantity. It is important to highlight that these two waste streams exceed EFB, shells, and fibers in terms of total waste generation. The observed rise in waste production coincides with substantial expansion of plantation areas, particularly in 2012 and 2018. As of 2022, projections indicate stem waste reaching 131.2 million tonnes, while frond waste is expected to reach 21.1 million tonnes (Fig. 5).

An oil palm frond comprises roughly 100 leaves, each possessing a lamina, midrib, petiole, and petiole base. The length of these leaves usually falls within the range of 55 to 65 centimeters (cm), while their width narrows down to 2-4 cm in width. Mature fronds can reach up to 7.5 cm in width, with a leaf stalk measuring approximately one-quarter of the total frond length. Frond length can vary between 5-9 meter (m). (Hambali and Rivai, 2017). This frond has a high-fiber lignocellulosic material consisting of cellulose (31,5%) and hemicellulose (19,2%) (Ooi *et al.*, 2017) and representing 65% of the total fiber content (Ikubar *et al.*, 2018). Frond biomass, a crucial secondary product of the oil palm sector, originates from two main sources: the replanting of mature oil palm trees (aged 25-30 years) and regular pruning procedures. Oil palm plantations can be categorized into three stages: mature, immature, and non-mature. This study indicated that there will be a sustained growth in the establishment of oil palm plantations over the next 15 years. Government policies play a crucial role in managing this expansion. Regional regulations, exemplified by Riau Province's Provincial Spatial Planning (RTRWP) outlined in Regional Regulation No. 10 of 2018, set limitations on the total plantation area (restricted to 3.1 million ha in this case). Presidential Instruction No. 8 of 2018 pertains to the postponement of palm oil plantation licensing evaluations. Addressing the issue of palm oil waste necessitates a comprehensive strategy that goes beyond mere policy interventions. Enhancing the caliber of human capital is of equal significance. The education sector can significantly contribute by fostering awareness of sustainable palm oil practices within the younger generation. The educational emphasis aims to prepare upcoming decision-makers with the necessary knowledge and abilities to manage the intricate equilibrium between the expansion of the palm oil industry growth and environmental sustainability.

Forecasting palm oil waste from smallholder plantations in Riau Province 2023-2035

Production projections for EFB, shells, fibers, palm fronds, and palm stems from smallholder plantations were calculated using data spanning 2006 to 2022 (Table 3). The study utilized a time series modeling technique to predict the amount of waste generated, aiming to assess the future potential of palm oil waste production in Riau Province for the upcoming decade.

Table 3: Forecasting of palm oil waste in smallholder plantations in Riau province 2023-2035

Year	EFB (million Ton)	Shells (million Ton)	Fiber (million Ton)	Fronds (million Ton)	Stem (milion Ton)
2023	4,382	1,336	3,005	21,906	136,002
2024	4,548	1,386	3,119	22,667	140,722
2025	4,715	1,437	3,233	23,427	145,443
2026	4,881	1,488	3,347	24,187	150,163
2027	5,047	1,538	3,461	24,948	154,884
2028	5,213	1,589	3,575	25,708	159,604
2029	5,380	1,639	3,689	26,468	164,325
2030	5,546	1,690	3,803	27,229	169,045
2031	5,712	1,741	3,917	27,989	173,766
2032	5,878	1,791	4,031	28,749	178,486
2033	6,044	1,842	4,145	29,510	183,207
2034	6,211	1,893	4,259	30,270	187,927
2035	6,377	1,943	4,373	31,030	192,647

This approach enables estimation of the anticipated waste quantities in the coming years. The resulting projections will illuminate the potential scale of palm oil waste production in Riau Province by 2035.

Projections indicate a notable increase in the generation of palm oil waste in the upcoming years. It is anticipated that by the year 2035, the production of stem and frond waste will escalate to 192 million tonnes and 31 million tonnes, respectively.FFB waste, categorized as EFB, shells, and fibers, is projected to reach 6.3 million tonnes, 1.9 million tonnes, and 4.3 million tonnes. This upward trend contrasts with the 2030 target year for achieving the sustainable development goals (SDGs). In 2030, the reported production of EFB waste, shells, fibers, palm fronds, and palm stems was 5.5 million tonnes, 1.6 million tonnes, 3.8 million tonnes, 27.2 million tonnes, and 169 million tonnes. The data presented underscores a pressing issue for individuals invested in the palm oil sector. Effectively handling the increasing amount of palm oil byproducts is crucial for maintaining an environmentally sustainable framework. The concerning forecast of rising palm waste is further illustrated in Figs. 6 and 7.

The establishment of plantations, particularly those of oil palm, demonstrates a significant level of public interest in this particular crop. The cultivation of oil palms has resulted in improved living standards for rural populations engaged in various aspects of the oil palm agribusiness (Hariyanti *et al*., 2024). Palm oil has been a superior commodity for both the community and agribusiness companies. For the community, especially farmers, oil palm is a coveted crop and a source of family income that leads to prosperity. The rural economy has experienced a significant increase as a result of the expansion of palm oil agribusiness.

Inventory of local community knowledge in palm oil waste processing

A compilation of their expertise was created in order to evaluate the local community's comprehension of waste utilization methods. This study collected information on demographics as well as knowledge-based data. The demographic data encompassed variables such as sex, age, marital status, educational attainment, employment status, and geographical background. Knowledge-based data focused on specific areas of waste application, encompassing medicine, agriculture, energy production, handicrafts, and animal husbandry. As shown in Table 4, a total of 112 individuals participated in the survey. The survey indicated a significant level of consciousness among the residents of Riau concerning the existence of oil palm plantations. Table 4 further details the regional distribution of respondents across various regencies within Riau province. The Meranti Islands

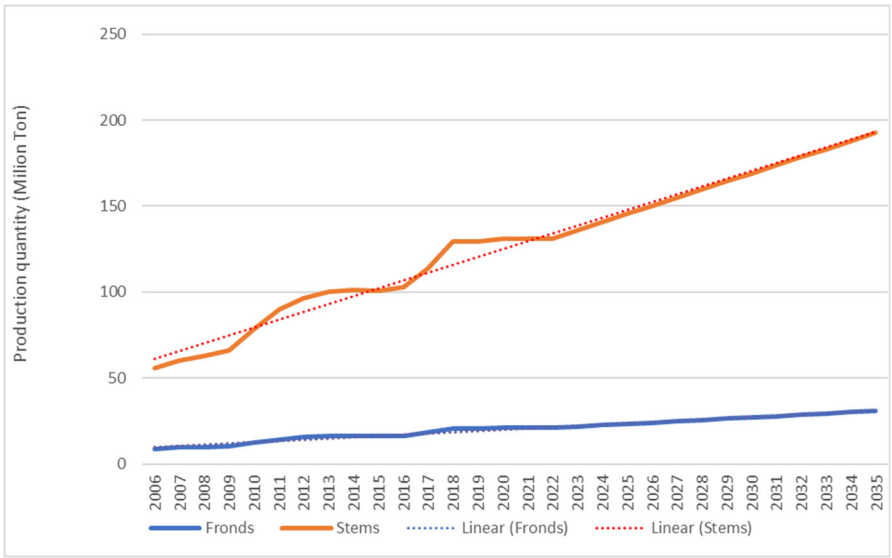


Fig. 6: Trend of fronds and stems waste from palm oil plantations 2006-2035

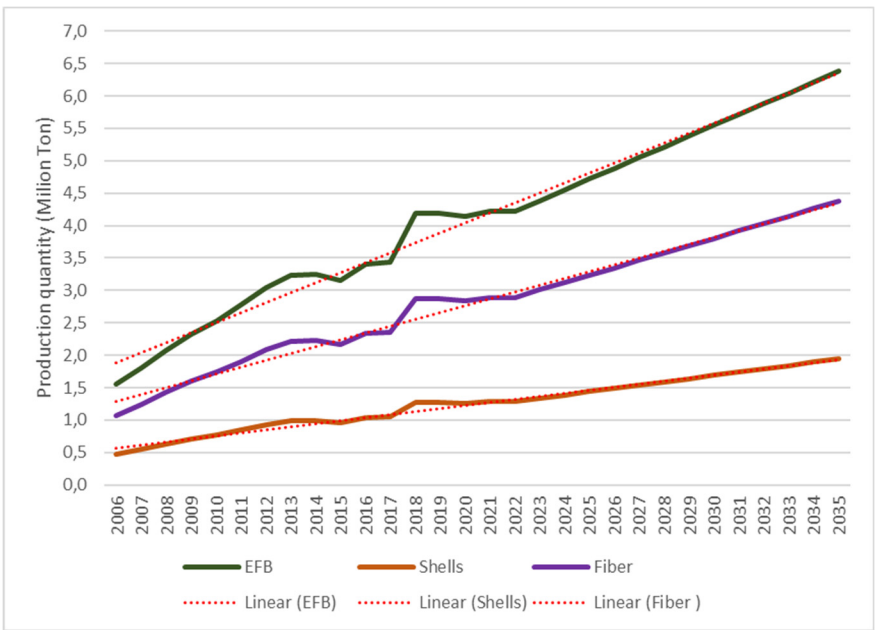


Fig. 7: Trends in EFB, Shell, and Fiber Waste 2006-2035

district stands out as the sole region lacking oil palm plantations. The lack of presence in this area can be explained by a mix of environmental and infrastructural constraints, as well as the choice of the local government to withhold permits for the expansion of palm oil production. Community members have voiced worries about the sinking of land, a possible outcome that may jeopardize the sustainability of the area given its close proximity to sea level.

The local community has utilized a portion of plantation waste products. Organic fertilizer,

Table 4: Knowledge of palm oil waste management by the people of Riau

Aspect	Indicator	frequency	Percentage
	Demographic data		
Gender	Male	23	21%
	Female	88	79%
Age	15 - 18 years	7	6%
	19 - 24 years	90	81%
	> 25 years	14	13%
Marital status	Married	14	13%
	Unmarried	97	87%
Education level	Doctoral degree	1	1%
	Master's degree	6	5%
	Bachelor's degree	33	30%
	High School	71	64%
Occupation	Local community	84	76%
	Farmer	27	24%
Place/Regency	Bengkalis	5	5%
	Indragiri Hilir	6	5%
	Indragiri Hulu	5	5%
	Kampar	13	12%
	Kuantan Singingi	8	7%
	Pelalawan	16	14%
	Rokan Hilir	12	11%
	Rokan Hulu	12	11%
	Siak	7	6%
	Dumai	4	4%
	Pekanbaru	23	21%
	Knowledge		
Medicine	Wound healer	10	9%
	Hypertension	1	1%
	Muscle pain	2	2%
	Stomachache	1	1%
	Anti-inflammatory	1	1%
Agriculture	Organic fertilizer	87	78%
	Mushroom growing medium	40	36%
Energy	Firewood	64	58%
	Briquette	21	19%
Handicraft	Broom	29	26%
	Roof	8	7%
	Woven plate	13	12%
	Woven basket	2	2%
	Mat	3	3%
	Hat	3	3%
	Bag	3	3%
Animal husbandry	Animal pen construction	11	10%
	Livestock feed	44	40%

employed by 78% of the community, and mushroom cultivation medium (36%) are the primary applications for this waste. EFB, palm fronds, and seashells have the potential to be decomposed into organic fertilizer, leading to improved soil quality and increased agricultural productivity. The manufacturing procedure is simple and economical. EFB Waste or palm shells are composted through

microbial breakdown. A substantial portion of the community relies on natural decomposition without additional interventions. Local communities directly utilize palm waste, mainly leaves, for composting purposes. The palm fronds that have been pruned from the trees are carefully positioned among the palm trunks, as depicted in Fig. 8. Some farmers create a circular arrangement around each palm tree to optimize nutrient absorption. This method is rooted in the belief that the breakdown of leaves adds crucial nutrients to support the growth of palm oil.

Oil palm cultivation necessitates regular pruning of fronds to maintain tree health and productivity. he fronds are commonly collected in a circular heap around the trunk for the purpose of composting. Despite seeming simple at first, certain farmers opt to position the pruned fronds directly among the palm trees. This practice allows palm roots to grow beneath the accumulating frond layer. it's crucial to note that palm fronds are non-productive biomass requiring regular removal to ensure tree health. The decomposition of palm fronds is a complex procedure that encompasses a variety of microbial populations. The initial decomposition phase involves primary decomposers like bacteria and fungi, which break down readily available organic components like sugars and amino acids. These microorganisms tackle more complex organic matter such as cellulose, hemicellulose, and lignin (Uke *et al*., 2021). The process of composting effectively boosts soil fertility through the augmentation of organic matter levels, consequently stimulating the development of oil palm and various other crops (Azman *et al*., 2023). Palmoil waste holds potential in the medical sector, particularly for wound healing, muscle pain relief, and reducing inflammation. Wound healing is the most prevalent application. People have used traditionaly palm fronds and palm oil itself to treat wounds. The findings from the study conducted by Rajoo *et al*. (2021) indicated that palm oil has the potential to enhance the proliferation of fibroblasts, which play a vital role in the healing process of burn injuries. This effect is attributed to the presence of flavonoids, particularly flavonoid C-glycosides, within palm oil. demonstrate therapeutic advantages by functioning as antioxidants and facilitating the process of wound healing. Tow *et al*., (2021) in their research showed that similar properties are found in palm leaves, which are rich in these same flavonoid



Fig. 8: Use of palm fronds as compost a) arranging palm fronds in a circle b) arranging palm fronds between trees c) new roots growing under a pile of palm fronds

C-glycosidesPalm leaves possess antioxidant and anti-inflammatory properties, which make them promising candidates for wound-healing agents (Zain *et al*., 2020). These leaves contain alkaloids, tannins, and saponins, all with established antimicrobial properties, which aid in combating bacteria and other microorganisms that can impede wound healing. People awareness regarding the utilization of palm oil waste for energy generation is still lacking. A study revealed that most individuals (58%) are acquainted with the practice of using palm oil waste as firewood, whereas only 19% are aware of its potential for producin briquettes. This highlights a gap in public knowledge concerning more sustainable and efficient energy utilization from palm oil waste. The research results of Bazargan *et al*. (2018) demonstrated that briquettes produced from palm oil shell waste meet high-quality standards. The briquettes present notable benefits in comparison to conventional fossil fuels. EFB can also be utilized as a raw material for briquettes due to its high carbon content (44.9%) (Farid *et al*., 2020). Research results Amrullah *et al*. (2020) showed that EFB briquettes boast the highest heating value among various options, reaching 5,475 cal/g. The high carbon content in EFB (46.62%) further reinforces its suitability for bio-briquette production. The briquettes are not just eco-friendly, producing reduced levels of greenhouse gas emissions, but they are also economical and easily accessible (Musabbikhah *et al*., 2015). The utilization of palm oil waste for the production of briquettes offers fresh prospects for economic growth within communities, with the potential to bolster income levels and foster job creation. To bridge the knowledge gap, educational initiatives are crucial to raise public awareness regarding the potential of palm oil waste briquettes as a sustainable and beneficial energy source. Palm oil byproducts are utilized in the creation of handicrafts, with a particular focus on leaves, fronds, and sticks. The processed house products include brooms (26%), roofs (7%), plates (12%), baskets (2%), mats (3%), hats (3%) and bags (3%). The majority of people make brooms from palm tree sticks. Using palm oil waste as raw material for handicrafts shows people's creativity and concern for the environment. Previously considered waste products, palm leaves, fronds, and stalks can be upcycled into a diverse range of unique and valuable handicraft goods. The transition to using these resources offers a substantial chance for economic growth. The resulting handicrafts, often employing stick-weaving techniques, hold potential for both domestic and international markets. Oil Palm tree components, from delicate fronds to sturdy stalks, can be transformed into a variety of functional and decorative items, including household furniture and home decor accents. The accessibility of these raw materials helps to reduce production expenses due to their low initial investment requirements. The selling price of stick crafts such as hats, hats, and bags has a high selling value (Abdullah *et al*., 2020). Craft training for palm oil farmers is an important step to improve their economy and welfare. Fitria *et al*. (2021) showed that training for local communities can increase their creativity in utilizing palm oil waste. The creative products produced can increase people's income (Kemala *et al*., 2023). In addition to their economic significance, handicrafts made from palm oil waste also possess ecological value. Utilizing this waste contributes to reducing environmental pollution and minimizing the accumulation of waste in palm oil plantations. In the livestock sector, local communities use plantation waste to make pens (10%) and animal feed (40%). Livestock enclosures are constructed by the community utilizing resources sourced from palm stems and palm fronds. Durable and resilient palm oil stems are transformed into the necessary raw materials. The main thing for making cages is that the broad and waterproof palm fronds are used as roofs. The stem's lignin content varies between 6.213% and 33.702%, showing an increase in lignin value from the base middle section to a decrease towards the tip. The palm oil waste processing process carried out by the community can contribute to reducing environmental pollution and minimizing the accumulation of waste in palm oil plantations. Aligned with research by Sumiyati *et al*. (2024), effective and efficient agricultural waste management can contribute to climate change mitigation and the establishment of a circular economy. Apart from that, palm oil waste processing can contribute to reducing environmental pollution and minimizing the accumulation of waste in palm oil plantations. Palm oil plantations are further utilized in the production of animal feed that is abundant in essential nutrients. Palm leaves, bunch skin, and palm kernel cake can be fermented or processed using other processes to produce cheap, high-quality animal feed. Palm oil

cake can serve as a valuable feed option for cattle (Grinnell *et al*., 2022). Integrating oil palm plantations and cattle farming is a viable strategy for small farmers to increase resource use efficiency on plantations (Tohiran *et al*., 2019) and beef self-sufficiency (Grinnell *et al*., 2022). Cattle farmers use palm oil waste, known as solid. Local people often call it *blondho* palm. Solid palm oil has a soft texture like tofu dregs, is dark brown, and has a sweet and sour smell. It contains 1.5% CPO oil, so in the open air, it quickly becomes rancid, and if left for 2-3 days, mold will appear. The fungi were recognized as *Monilia sp*. and *Candida sp*. and pose no threat. (Saelor *et al*., 2024). The product finds application in reducing reliance on traditional grass feed while simultaneously promoting increased cattle weight gain. It can be offered to cattle in either their fresh form or a compressed block format, known as "solid bread". The incorporation of palm solids into the diet of cattle provides farmers with a flexible feeding option through this approach. This "solid bread" contains solid palm oil and other basic ingredients such as palm kernel meal, molasses, salt, minerals, and protein content. It is made in two forms: fermented and unfermented. The fermenter used is tempeh yeast or effective microorganisms (EM-4), which is widely sold The tempeh yeast is applied to fresh solids, which are subsequently enclosed and left to ferment for a period of seven days. Following the fermentation process, the end product exhibits a unique scent and is adorned with mycelium. The fermented solid product contains the fungi *Aspergillus niger*, *Aspergillus oryzae* and *Aspergillus lumori*. The fermentation process by these fungi has the highest level of non-fiber carbohydrates, 20.3% and 13.94%, which increases the product's nutritional value (Oliveira et al., 2018). The use of solid palm oil for animal feed can increase body weight because it improves nutritional quality and rumen digestibility in vitro (Rofiq et al., 2021). Using this bread can reduce feed costs and does not cause negative effects. Solid palm oil has great potential as a source of animal feed. The significance of this study lies in its contribution to advancing the development of sustainable palm oil plantations in Riau Province. Oil palm plantations have become deeply ingrained in the regional identity. Riau boasts the highest CPO production nationwide, contributing substantially to the Indonesian economy. Findings highligh the high volume of palm oil waste and inadequate waste management practices employed by small-scale farmers raise concerns. The continuous growth of these agricultural estates requires particular attention from governmental regulatory agencies. Socialization of regulations established by the Roundtable on Sustainable Palm Oil (RSPO) and Indonesian Sustainable Palm Oil (ISPO) initiatives is crucial for promoting environmentally responsible practices in palm oil production. The limitation of this study is that it only takes an inventory of the use of palm oil waste in Riau Province, so it could be utilized more if explored in other areas. This study delves into the waste accounting and management strategies employed in local communities, presenting factual discoveries and implications that could guide influential policy proposals. Land-use planning policies should prioritize a balanced approach, considering the correlation between plantation area and waste management. Policymakers must prioritize land management strategies that prioritize both economic development and long-term environmental sustainability. The anticipated expansion of oil palm plantations underscores the critical need for robust waste management infrastructure within the region. The commendable actions taken by the government to enhance the capabilities of RSPO and ISPO certification bodies contribute to the promotion of effective and responsible palm oil management practices. Effective policy measures include the implementation of sustainable agricultural practices coupled with appropriate incentives for landowners, particularly during replanting cycles. Adhering to established regulations by implementing suitable replanting stages can significantly decrease land utilization. This aligns with the findings of Siregar *et al* (2024), whose research indicates that uncontrolled plantation expansion can exacerbate deforestation rates. Enhancing farmers' skills in waste management presents an opportunity to unlock economic value. The strategy can be achieved by means of actions like enhancing farmer cooperatives, offering support for infrastructure development, easing the process of obtaining funding, and promoting the marketing of goods resulting from waste management techniques. Community involvement and education initiatives play a critical role in environmental improvement efforts. Engaging local communities and providing them with educational programs fosters awareness

regarding the importance of environmental protection. Policy frameworks must place a strong emphasis on community involvement as a fundamental element in fostering the growth of sustainable palm oil plantations. The incorporation of these policy suggestions into comprehensive environmental management plans enables policymakers to protect ecosystems, advance sustainable development, and foster a green economy within Riau Province.

CONCLUSION

The results presented in this study provide crucial information for formulating strategies in waste management aimed at promoting the long-term viability of small-scale oil palm farms. This approach has facilitated a detailed understanding of the waste profile and the extent of use by local communities, thus proving invaluable for ecological studies and the basis of policies for realizing sustainable palm oil plantations. The proliferation of plantations results in a notable rise in the amount of waste generated. Smallholder palm oil plantations will contribute around 121,2 million tons of waste, consisting of 3.1 million tons of EFB, 1 million tons of shells, 2.2 million tons of fiber, 15.9 million tons of fronds, and 98.9 million tons of stems. The rise in global demand for palm oil has led to the expansion and intensification of palm oil plantations worldwide. The prediction results are that the area of oil palm plantations in the next ten years will increase significantly and is directly proportional to the increase in waste production. Based on forecasting methods, the amount of palm oil waste in the next decade will be 236.37 million tons, consisting of 6.37 million tons of EFB, 1.94 million tons of shells, 4.3 million tons of fiber, 31 million tons of fronds and 192.26 million tons of stems. Palm oil waste has been utilized by local communities for medicinal purposes, agricultural activities, energy production, crafting, and animal husbandry. People can use palm oil waste leaves in medicine for wound healing, muscle pain, and anti-inflammation. The majority of people use it more as a wound healer. Most people use the stems as compost by letting the remaining pruning products decompose naturally on plantations. People also use more plantation waste, especially fronds, as firewood. Nevertheless, certain individuals utilize fronds, foliage, and twigs as crafting supplies for the production of domestic tools like dishes, brooms, purses, containers, and rugs. The community uses palm oil waste from CPO processing residues as cattle feed. This combined approach not only determines the amount of waste quantitatively but also obtains findings from the community regarding the management of their plantation waste. The results presented in this study provide crucial information for formulating strategies in waste management aimed at promoting the long-term viability of small-scale oil palm farms. Waste management in small oil palm plantations in Riau shows that it is still low. Policymakers (government) should use these findings. This study offers an insightful analysis on the capacity of palm oil waste to promote the proper handling of palm oil plantation byproducts in order to mitigate environmental contamination. The main challenge in managing palm oil plantation waste in Indonesia is the limited understanding of local farmers about the diversification of palm oil waste use and its potential for strengthening the economy. It is recommended that training initiatives be provided to local communities in order to enhance their abilities and capabilities in carrying out waste management procedures for palm oil plantations. The participation of scholars plays a crucial role in spreading evidence-based information and enhancing community capabilities in handling waste from palm oil plantations. Integrating the traditional ecological knowledge of local communities is also very important in planning and implementing waste management. Establishing farmer associations in partnership with diverse stakeholders has the potential to enhance the economic viability of the community and promote the enhancement of the ecosystem.

AUTHOR CONTRIBUTIONS

T. Hidayat, the corresponding author, contributed to conceptualizing the research idea and instructed other authors to analyze and summarize the research results, including advice on techniques, methods, and manuscript writing. Riandi has participated in the interpretation of the results and the review of the manuscript. A. Ilhami collected, analyzed data and wrote a manuscript.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
◦C	Degree Celsius
BPDPKS	*Badan Pengelola Dana Perkebunan Kelapa sawit* (Palm oil plantation fund management agency)
BPS	*Badan Pusat Statistik* (Central statistics agency)
cal	Calories
cm	Centimeter
CPO	Crude Palm oil
EF	Effective microorganisms
EFB	Empty fruit bunches
FFB	Fresh fruit bunch
g	Gram
ha	Hectare
Inpres	*Instruksi presiden* (Presidential decree)
ISPO	*Indonesian Sustainable Palm Oil*
m	Meter
mm	Milimeter
PFAD	Palm fatty acid destilate
PKO	Palm kernel oil
PKM	Palm kernel meal
POME	Palm oil mill effluent
RBDPO	Refined bleached deodorized palm oil
RSPO	Roundtable on Sustainable Palm Oil practices
RTRWP	*Rencana Tata Ruang Wilayah Provinsi* (Provincial spatial plan)
s	Second
SDGs	*Sustainable development goals*

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