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COMPARATIVE ANALYSIS OF CURRENT BIOMASS UTILISATION BY PALM OIL MILLS IN PENINSULAR MALAYSIA

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Abstract: Oil palm biomass, which includes empty fruit bunches (EFB), mesocarp fibres (MF), palm kernel shells (PKS), and palm oil mill effluent (POME), are no longer seen as low-value residue, but as valuable economic resources that may contribute positively to national wealth. These oil palm biomasses can be converted into high value-added products, which can in turn generate additional revenue for the country. This study aims to identify the current biomass utilisation by palm oil mills in Peninsular Malaysia and examine the economic viability of biomass products generated by these mills across different categories. This study uses primary data obtained through a census of all 242 Malaysian Palm Oil Board-licensed palm oil mills in Peninsular Malaysia. The data were analysed using descriptive analysis and independent samples t-test. The study found that incineration is the most profitable approach for EFB, followed by selling EFB to other parties. However, due to environmental regulation and the lack of market for EFB, most of the resources (62.4%) were either returned to plantations or sent to landfills. In addition, 92.4% of MF generated were utilised for electricity generation through in-house boilers and this alternative has been proven to provide maximum profit to palm oil mills. The study also found that although selling PKS to other parties was proven to provide better profits to the palm oil mills, the PKS were mostly utilised for electricity generation through in-house boilers. Lastly, for the sludge from POME, there was no significant difference in the utilisation of the sludge, either if it was used for plantations or sold to other parties.

Keywords: Empty fruit bunch, mesocarp fibre, oil palm biomass, palm kernel shell, palm oil mill effluent.

Introduction

Biomass accumulates in various sectors of business and society. Brosowski *et al.* (2016) indicated that its sources range from agriculture and forestry to industrial manufacturing and municipal waste. Biomass products in Malaysia encompass several waste materials, including from timber, oil palm, rice husk, coconut fibres, municipal waste, and sugarcane waste (Abas *et al.,* 2011). Given the vast size of the agricultural commodity industries in Malaysia, such as palm oil, rubber, and timber, as well as other agricultural industries such as rice, coconut, and sugar, the country generates an abundance of biomass waste resources. These organic materials have the potential to be explored either in the manufacturing sector for value-added eco products or in the energy sector for generating power. Currently, the potential of biomass in Malaysia has not been fully tapped and is sometimes unused despite its plentiful supply. Supeni *et al.* (2004) estimated that Malaysia produces 60 million tonnes of biomass annually, excluding the 1,200 tonnes of municipal solid waste generated daily.

Over the past few decades, the Malaysian palm oil industry has experienced dramatic growth. The oil palm planted area expanded by 18.4% from 4.85 million hectares in 2010 to 5.74 million hectares in 2021 (Malaysian Palm Oil Board [MPOB], 2022) (Figure 1). The expansion of the oil palm planted area has contributed to the increase in crude palm oil (CPO) production (Nambiappan, 2018), which has grown by 6.7% from 16.99 million tonnes in 2010 to 18.12 million tonnes in 2021 (MPOB, 2022; Parveez *et al.,* 2022). This has resulted in a 78.3% increase in the contribution of this industry to the national export revenue from RM59.73 billion in 2010 to RM108.50 billion in 2021 [MPOB, 2022; The Department of Statistics Malaysia (DOSM), 2022] (Figure 2).

Table 1 shows the number of palm oil mills in operation and their capacities from 2010 until 2021. In 2010, there were only 418 operational palm oil mills in Malaysia, with a total processing capacity of 96.99 million tonnes of fresh fruit bunches (FFB). By 2021, the number had increased to 451 mills, with a total processing capacity of 115.87 million tonnes (MPOB, 2022). In terms of regional distribution (Figure 3), in 2021, 52.5% or 237 mills were located in Peninsular Malaysia, with a total processing capacity of 57.50 million tonnes, 132 mills were located in Sabah, and the remaining 82 in Sarawak (Parveez *et al.,* 2022).

The palm oil industry is capable of generating vast quantities of oil palm biomass due to its large scale. Oil palm biomass originates from two different sources, namely plantations and mills (Foo & Hameed, 2010; Abdullah & Sulaiman, 2013; Oseghale *et al.,* 2017). Plantation biomass mainly comprise trunks and fronds, with the trunks becoming available primarily during replanting, while fronds are obtained through pruning, but are often left on the ground for fertilisation purposes. On the other hand, mill biomass consists of empty fruit bunches (EFB), palm kernel shells (PKS), mesocarp fibres (MF), and palm oil mill effluent (POME). These biomasses are produced daily and are more consistent in terms of supply compared with oil palm trunks. Biomass products such as PKS and MF are generally burnt to generate steam for mills while EFB

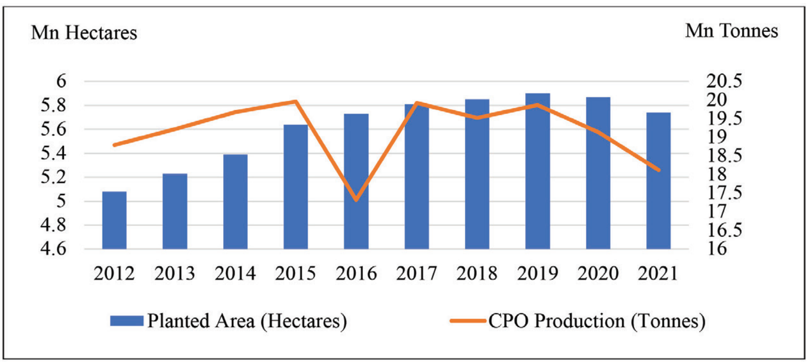

Figure 1: Malaysian oil palm planted area and crude palm oil (CPO) production
Source: MPOB (2022)

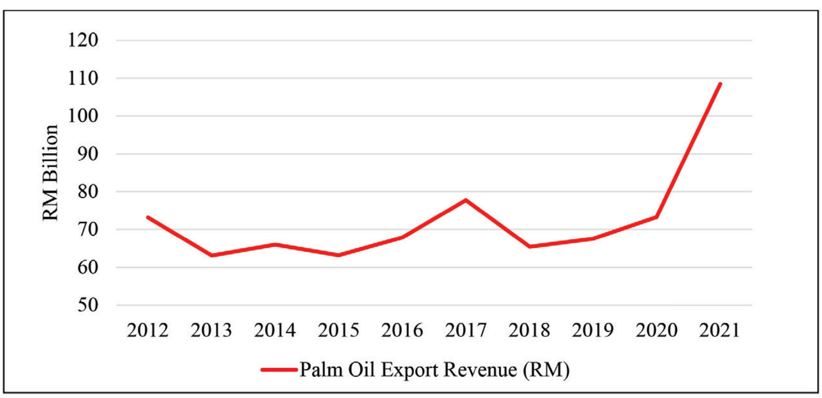

Figure 2: Malaysian palm oil export revenue
Source: MPOB (2022); DOSM (2022)

Table 1: Number of operational palm oil mills and their capacities in Malaysia (2010-2021)

Year	No. of Mills	Processing Capacity (Million Tonnes)
2010	418	96.99
2011	423	99.44
2012	429	101.96
2013	434	104.09
2014	439	105.76
2015	445	108.40
2016	453	110.33
2017	454	112.19
2018	451	112.42
2019	452	112.91
2020	457	116.81
2021	451	115.87

Source: MPOB (2022)

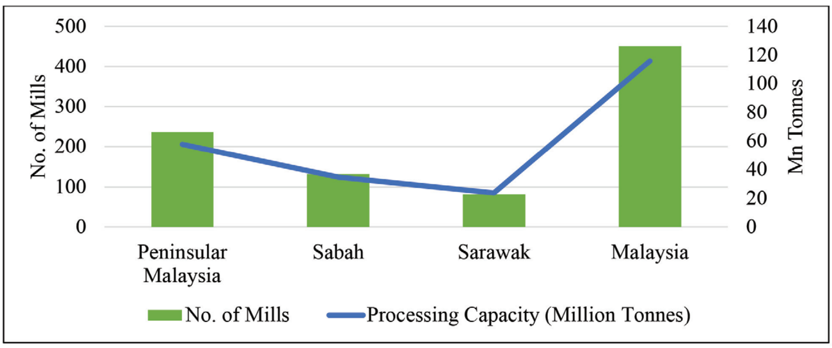

Figure 3: Number of palm oil mills in operation and capacity by region in 2021
Source: Parveez *et al.* (2022)

is usually returned to plantations and POME undergoes treatment before it is discharged.

Managing the large amounts of waste generated is a significant challenge for the palm oil industry (Anyaoha *et al.,* 2018). In palm oil mills, FFB are sterilised, after which CPO can be separated from the bunches. EFB are left as residues and the fruits are pressed at the press station. In a typical oil palm plantation, almost 70% of the FFB is turned into waste in the form of EFB, MF, and PKS, as well as liquid effluent. These by-products can be converted into value-added goods or energy to generate additional profit for the palm oil industry.

In the current market, significant emphasis is placed on oil palm biomass as the oil palm industry is regarded as a key indicator of the country's economic performance. The potential profit that can be gained from the production of oil palm biomass products drives the development of the oil palm biomass industry. This potential has piqued interest and attracted more investors to participate in the sector. Surplus oil palm biomass is used either for local consumption or export, especially to Japan and South Korea.

Considerable efforts have been directed towards leveraging technology to make optimal use of the abundant oil palm biomass, aligning with the circular economy concept. Ongoing research has explored various processes aimed at enhancing the value of oil palm biomass, presenting an opportunity to develop valuable product proposals for commercialisation. This includes the development of bio-products utilising oil palm biomass, such as biochar, activated carbon, bio-oil, compost, nanocellulose, bio sugar, bioelectricity, biohythane, bioplastic, and bioenergy (Norrahim *et al*., 2022). In essence, the application of emerging technologies in this context opens possibilities for creating valuable and commercially viable products from oil palm biomass.

Looking at the potential demand for oil palm biomass as raw materials for value-added products, this study aims to identify current biomass utilisation practices and examine the economic viability of biomass products generated across different categories, which will facilitate the formulation of policies and directions on the potential of oil palm biomass as a new commodity in the country's palm oil industry.

Methodology

This study uses primary data obtained through a census of all 237 MPOB-licensed palm oil mills in Peninsular Malaysia, including those operated by Felda, IOI, Sime Darby, Kuala Lumpur Kepong, and others. The highest concentration of palm oil mills is found in Pahang, with 70 mills having a total processing capacity of 15.85 million tonnes of FFB in 2021. This is followed by Johor with 60 mills and Perak with 45 mills, having total FFB processing capacities of 16.49 million tonnes and 10.72 million tonnes, respectively (Table 2). The number of mills in other states is relatively small by comparison.

The data were collected through a questionnaire that was mailed to all palm oil mills. A structured questionnaire was designed to assist palm oil mills in providing information on their current biomass utilisation practices.

To date, there has been limited information on the biomass produced by palm oil mills in Malaysia. Therefore, a census of palm oil mills in Peninsular Malaysia was conducted to gather information on the availability and utilisation of oil palm biomass, production costs and sales, and market destinations for exports. The information will be used to estimate profits for each approach, aiding in investment decision-making processes.

Table 2: Number of operating palm oil mills and capacity by state

State	No. of Mills	Processing Capacity (Million Tonnes)
Pahang	70	15.85
Johor	60	16.49
Perak	45	10.72
Selangor	16	3.27
Negeri Sembilan	15	3.84
Terengganu	11	2.99
Kelantan	10	1.76
Kedah	6	1.60
Melaka	3	7.60
Pulau Pinang	1	2.16
Total	**237**	**57.50**

The data were analysed using descriptive statistics with the aid of SPSS version 20.0. Descriptive statistics provide a simple summary of the samples and observations made. This summary may either form the basis of the initial description of the data as part of a more extensive statistical analysis, or they may be sufficient in and of themselves for a particular investigation.

The independent samples t-test was employed to compare the means of two independent groups and determine whether there is statistical evidence that the associated population means are significantly different. This test is a parametric method.

The independent samples t-test can compare the means between only two groups. Each group should have at least six subjects, although having more is preferable as too few subjects will render the inferences for the population more tenuous. A balanced design (i.e., the same number of subjects in each group) is ideal as extremely unbalanced designs increase the risk of violating the test's requirements and assumptions, which may compromise the validity of the independent samples t-test.

The null hypothesis (H_0) and alternative hypothesis (H_1) for the independent samples t-test can be expressed as follows:

H_0: $\mu 1 = \mu 2$ (the two population means are equal)

H_1: $\mu 1 \neq \mu 2$ (the two population means are not equal)

Here, μ_1 and μ_2 are the population means for groups 1 and 2, respectively.

Results and Discussion

Empty Fruit Bunches (EFB)

From the study, the average EFB generated per mill per year was 39,123.49 tonnes. The majority of the palm oil mills have the facilities to process EFB, namely EFB shredders/crushers and EFB presses. Through these shredding/crushing and pressing activities, palm oil mills were able to extract 14,475.70 tonnes of CPO from the EFB generated, worth RM39.1 million.

Several approaches are currently being practised by palm oil mills in managing EFB (Table 3). The choice of approach depends on the availability of facility to shred EFB. For mills equipped with a shredding facility, the preferred method is to return the processed EFB to their plantations to be used as fertiliser. Palm oil mills also have the option of sending the EFB to landfills, selling them to other parties, giving them away for free, or incinerating the EFB for the production of bunch ash, which is usually the last option. Bunch ash is generally used as organic fertiliser.

It is worth noting that palm oil mills without shredding facilities often choose to send their EFB to landfills because they lack the capacity to process them further. About 25% of them opt to return the unprocessed EFB to their plantations for fertilisation purposes. Some mills prefer to sell the unprocessed EFB to other parties or give them away for free. These two approaches can provide additional profit or cost savings in terms of fertiliser expenditure. Only 6.8% of the respondents in this category chose to incinerate EFB for bunch ash production.

Table 3: Approaches to managing EFB

Activity	Total (%)	With Facilities (%)	Without Facilities (%)
Returned to plantations	41.2	45.8	25.0
Sent to landfills	21.2	18.3	31.8
Sold to other parties	18.2	17.2	21.7
Given away for free	15.5	15.8	14.7
Incineration	3.8	2.9	6.8

Table 4 shows the average cost of production, selling price and profits associated with EFB management according to the different approaches. It was found that the cost of managing EFB with shredding and pressing facilities is between RM2.95 to RM33.75 per tonne of EFB processed after deducting the value of oil retrieved from the process.

The highest cost of production for palm oil mills with facilities was associated with incinerating EFB. This approach incurred higher production costs compared with other methods, as it included additional costs for incinerating the EFB. Meanwhile, palm oil mills without EFB processing facilities also experienced the highest production costs with incineration, compared with selling EFB to other parties. However, returning EFB to plantations, giving them away for free, or sending them to landfills incurred no production costs, as no development costs were involved for these methods.

In terms of the selling price, incineration commands the highest value for palm oil mills with or without processing facilities. In comparison, in terms of profit, incineration of EFB, whether with or without facilities, yielded the highest returns, followed by selling to other parties. Conversely, returning EFB to plantations, giving them away for free, or sending them to landfills resulted in negative profits for palm oil mills with facilities due to the additional costs associated with shredding/crushing and pressing the EFB.

Based on Table 5, there was sufficient evidence to support that incineration, with or without facilities, yielded the highest profit for palm oil mills compared with all other approaches. However, this option is no longer legally viable due current policies on air pollution.

There is also enough evidence to conclude that selling EFB to other parties is more profitable than returning them to plantations, giving them away for free, or sending them to landfills. This applies to both palm oil mills with and without EFB processing facilities. Despite being less profitable, returning EFB to plantations was the most preferred approach among palm oil plantations due to the lack of market for EFB and better economic approach (least negative) compared with giving them away for free or sending them to landfills.

Mesocarp Fibres (MF)

On average, every palm oil mill generated 26,871.58 tonnes of MF per year. As shown in Figure 4, most of the MF generated (92.4%) were used for in-house boilers while the remaining 7.6% were sold to other parties at an average price of RM50.00 per tonne.

Table 4: Average costs of production, selling prices, and profits associated with EFB according to approaches

Activity		Average Cost of Production (RM/tonne)	Average Selling Price (RM/tonne)	Average Profit (RM/tonne)
With facilities	Returned to plantations	2.95	-	(2.95)
	Given away for free	3.70	-	(3.70)
	Sold to other parties	3.92	4.00	0.08
	Incinerate	33.75	108.81	75.06
	Sent to landfills	4.45	-	(4.45)
Without facilities	Returned to plantations	-	-	-
	Given away for free	-	-	-
	Sold to other parties	2.00	3.40	1.40
	Incinerate	32.70	186.40	153.70
	Sent to landfills	-	-	-

Table 5: Independent sample t-test for EFB

		With Facilities			Without Facilities		
		Returned to Plantations, Given Away for Free and Sent to Landfills	**Sold**	**Incinerate**	**Returned to Plantations, Given Away for Free and Sent to Landfills**	**Sold**	**Incinerate**
With facilities	Returned to plantations, given away for free and sent to landfills	-	0.068**	0.000*	0.205	0.000*	0.005*
	Sold to other parties	-	-	0.000*	0.100**	0.000*	0.000*
	Incinerate	-	-	-	0.000*	0.085**	0.000*
Without facilities	Returned to plantations, given away for free and sent to landfill	-	-	-	-	0.000*	0.000*
	Sold to other parties	-	-	-	-	-	0.014*
	Incinerate	-	-	-	-	-	-

Note: ** Significant at 0.05; * Significant at 0.10

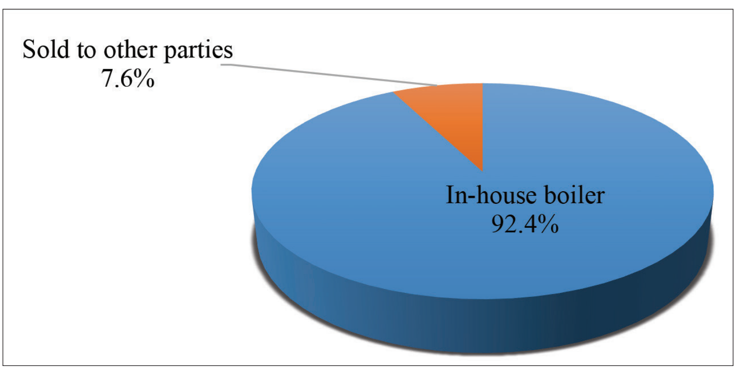

Figure 4: Utilisation of MF

As presented in Table 6, the average cost of production for selling MF to other parties was RM36.74, which was higher than that of palm oil mills producing energy through in-house boilers. Meanwhile, the average cost reduction for electricity was equivalent to RM50.00 per tonne of using MF, exceeding the average selling price of MF sold to other parties. Based on the total profit of the mills, electricity generation through in-house boilers yielded higher profits compared with selling MF to other parties.

Table 6: Average profit of MF according to utilisation

Activity	Average Cost to Produce Energy (RM/tonne)	Average Equivalent Cost Reduction for Electricity (RM/tonne)	Average Profit (RM/tonne)
In-house boiler (energy generation)	15.36	50.00	34.64
	Average Cost of Production (RM/tonne)	**Average Selling Price (RM/tonne)**	**Average Profit (RM/tonne)**
Sold to other parties	36.74	42.33	5.59

According to the result of the independent samples t-test, with evidence at a 5% level of confidence, the profit from electricity generation through in-house boilers was higher than that from selling MF to other parties.

Palm Kernel Shells (PKS)

On average, each palm oil mill generated 12,671.80 tonnes of PKS per year. Most of the PKS generated (67.9%) were utilised for in-house boilers (Figure 5). Furthermore, 30.3% were sold to other parties, including for export in international markets such as Japan and South Korea, at a price range of RM250.00-RM300.00 per tonne. The remaining 1.8% were utilised for their plantations or nurseries.

This study found that the average cost of producing energy through in-house boilers was RM25.99 per tonne of PKS (Table 7). In contrast, the average cost of production for selling PKS

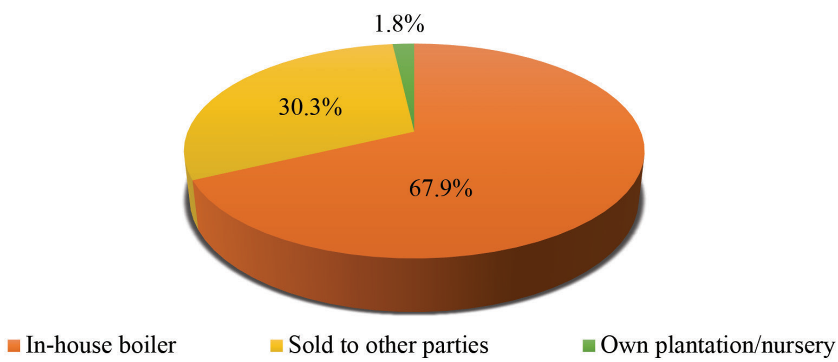

Figure 5: Utilisation of PKS

Table 7: Average profits associated with PKS according to utilisation

Activity	Average Cost to Produce Energy (RM/tonne)	Average Cost Electricity Reduction Equivalent (RM/tonne)	Average Profit (RM/tonne)
In-house boiler (energy generation)	25.99	53.63	27.64
	Average Cost of Production (RM/tonne)	**Average Selling Price (RM/tonne)**	**Average Profit (RM/tonne)**
Sold to other parties	62.50	238.13	175.63

to other parties was RM62.50. Meanwhile, the average cost reduction for electricity through in-house boilers was equivalent to an average of RM53.63 per tonne of PKS, which was lower than the cost if the PKS were sold to other parties. Thus, selling PKS to other parties yielded more profit for palm oil mills than utilising the PKS for in-house boilers.

The results of the independent sample t-test indicate that there is sufficient evidence to statistically conclude that the profit from selling PKS to other parties was higher than electricity generation through in-house boilers. Although selling PKS to other parties is proven to be more profitable, due to the low market demand, only 30.3% of PKS were sold, as shown in Figure 5.

Palm Oil Mill Effluent (POME)

Palm oil mills generated an average of 147,778.37 m^3 of POME per year. Most of the POME sludge (80%) was utilised for their plantations or nurseries as fertiliser while only 1.1% of the POME sludge was sold to other parties (Figure 6). The sludge was sold at an average price of RM100.00 per tonne.

As indicated by Table 8, no costs were incurred when the POME sludge was utilised in plantations since the labour and transportation expenses were absorbed by the plantations. In contrast, the average cost of production for selling the sludge was RM20.00 per tonne while the selling price was RM21.67 per tonne, showing that selling the sludge yielded a profit compared with returning it to plantations.

Nevertheless, the independent samples t-test shows that there was no significant difference in profit between sludge utilised for plantations and sludge sold to other parties at a 5% level of confidence. This suggests that there is not enough evidence to conclude that either method would yield better profit for palm oil mills.

Conclusions

This study focused mainly on the availability of oil palm biomass and current biomass utilisation by palm oil mills in Peninsular Malaysia. There are four products of oil palm biomass from palm oil mills, namely EFB, PKS, MF, and POME. For EFB, the majority of palm oil mills are equipped with shredders/crushers and pressers to process

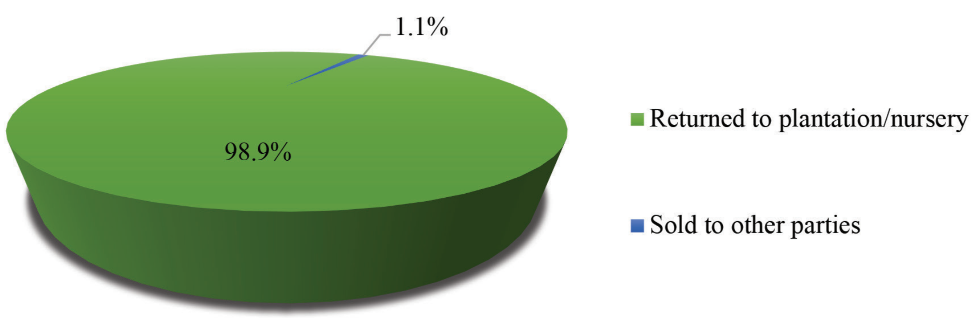

Figure 6: Utilisation of POME

Table 8: Average profit associated with POME sludge according to utilisation

Activity	Average Cost of Production (RM/tonne)	Average Selling Price (RM/tonne)	Average Profit (RM/tonne) *
Sludge utilised for plantations	-	-	-
Sludge sold to other parties	20.00	21.67	1.67

them, and the predominant method of managing EFB is returning them to plantations. However, the independent samples t-test revealed that incinerating EFB, both for palm oil mills with and without facilities, resulted in higher profits compared with the other approaches. Despite its profitability, incineration was less preferable among palm oil mills due to governmental restrictions associated with air pollution. Another alternative that could potentially create good economic value is through the sale of EFB. However, this study found that only a small fraction of generated EFB is being sold, primarily due to a lack of market demand. Regarding MF, the majority of mills used them for in-house boilers to generate energy. There is sufficient evidence showing that generating electricity through in-house boilers yielded higher profits than selling MF to other parties. On the other hand, for PKS, although most mills use them for in-house boilers, this method proved less profitable than selling them to other parties due low market availability relative to the supply. Finally, concerning POME, the majority of palm oil mills utilised the sludge for their plantations or nurseries rather than selling it. However, there were no discernible benefits for mills in terms of sludge utilisation, whether using it as plantation fertiliser or selling it to other parties, as no significant difference was found between the two approaches.

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Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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