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Material flow analysis for resource management towards resilient palm oil production

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Abstract. Biomass waste generated from palm oil mill can be considered not only as the feedstock of renewable energy but also as the nutrient-rich resources to produce organic fertilizer. This study explored the appropriate resource management towards resilient palm oil production by applying material flow analysis. This study was conducted based on two palm oil mills in Lampung, Indonesia. The results showed that the empty fruit bunch (EFB) has the largest potential in terms of amount and energy among the biomass waste. The results also showed that the palm oil mills themselves had already self-managed their energy consumption thatwas obtained from palm kernel shell and palm press fiber. Finally, this study recommended the several utilization options of EFB for improvement of soil sustainability to contribute towards resilient palm oil production.

1. Introduction

Agro-industries such as palm oil mill, sugar cane mill and cassava mill are recognized as the leading industries in Indonesia, because the main products such as palm oil, sugar and tapioca have been widely used as beneficial dairy products. On the other hand, generally, only 25% or less amount of the raw materials are converted into the beneficial products while the rest of them is discharged as waste. The effective use of these wastes can contribute not only for sustainable production of renewable energy and renewable resources but also to prevent general waste issues such as waste pollution and illegal disposal.

Palm oil mill is well known as a surplus energy industry by utilization of these biomass waste. The potential of waste biomass utilization in palm oil mill has been shown by several studies [1, 2, 3, 4, 5, 6]. These studies indicated that the surplus energy can be obtained by utilizing biomass waste such as palm kernel shell (PKS), palm pressed fiber (PPF) and empty fruit bunch (EFB), and also the biogas produced from palm oil mill effluent (POME).

However, they paid less attention on the soil sustainability of oil palm plantation. For example, soil pH, organic C and total N in Johor, Malaysian oil palm plantation have seen decline from 1967 to 2000 [7]. Losing nutrients in the soil can be the cause of the decline of palm oil productivity. For this reason, maintaining the soil organic matter and nutrients in soils are important for the sustainability of

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palm oil production. The alternative resource management for resilient palm oil production is required to contribute to archive renewable energy production and soil sustainability. Therefore, the purpose of this study is to explore the appropriate resource management for sustainable palm oil production by evaluating the energy as well as nutrient balances of palm oil mill and plantation. Understanding these balances are possible to lead to resilient palm oil production.

2. Experimental procedure and methodology

2.1. Material flow analysis and indicators

Material flow analysis (MFA) is defined as a method to analyse the flow and stock of materials in a system systematically [8]. MFA describes the amount of material in each process, namely material generation, intermediate and final form. MFA is a useful tool to determine resource management, waste management and environmental management because it is possible to determine input and output in a system based on the law of conservation of mass [8]. This study applied MFA to resource management for sustainable palm oil production. First, this study identified material flow of biomass through palm oil production. Secondly, this study evaluated energy and nutrient potential of biomass wastes. Finally, this study discussed about the appropriate resource management by reviewing several relating researches.

2.2. Palm oil mills and plantation

This research was conducted based on two palm oil mills with production capacity of 25 t and 40 t of fresh fruit bunches (FFB) per hour, respectively. The latter palm oil mill has palm kernel milling process. These mills are managed by Indonesian state own company that are located in Lampung Province, Indonesia. Composition of biomass residue was obtained from reference elsewhere [9].

3. Results and discussions

3.1. Material flow in palm oil mills

Productivity of palm oil varies from company to company due to different factors such as soil, climate, and processing conditions. Companies that have better management would result into higher productivity. For instance, certain company produced an average of 23 t-FFB/hectare/year with an average of 24% of oil extraction rate (OER). Some companies produced less, for instance only an average of 13 t-FFB with 18% of OER. Based on this information, it was estimated that about 80% of FFB are considered as biomass waste.

Figure 1 and Figure 2 showed the material and energy flow in the observed palm oil industries. It was shown that the OER value was about 21.8% from FFB. Table 1 showed biomass waste generation rate in palm oil mills, Lampung (this study) and Aceh [6], Indonesia and Thailand [3]. Biomass waste generation rates were not much different in each palm oil mills. Based on the calculation, palm oil process produced solid waste in the forms of EFB, fiber and shell, which were about 40-45% of the total FFB. From the observation, palm oil mills in Lampung have already used the biomass waste (PPF and PKS) to generate electricity and steam for palm oil processing. Diesel oil was used to generate electricity only in the start-up stage. After the start-up was achieved, steam which is generated from PPF and PKS would take place as the source of energy for palm oil processing. 85% of total PPF and 55% of total PKS were directly used as fuel in the boiler system of the factory to generate electricity and steam for palm oil processing. It was predicted that 15.6 t/day of PPF and 18 t/day of PKS would be remained in the cases of production capacity 40 t-FFB/hour or about 800 t-FFB/day. In common practice, EFB is used as a mulching for soil conditioner and nutrients recycling in oil palm plantation, nevertheless such practice might cause increasing of soil toxicity. Energy consumption of palm oil mill came only from PKS and PPF except diesel oil during start-up. Furthermore, biogas production from POME was also expected as a renewable energy production. POME can produces a tremendous amount of biogas by anaerobic digestion method for self utilization in the palm oil mill. However for small and medium scale factory, the investment cost for biogas utilization is considered as relatively high.

3.2. Palm oil biomass potential for soil quality improvement

Palm oil mill produced several biomass waste containing energy and nutrients. At the same time, oil palm plantation itself applies several chemical fertilizers. Hence the biomass waste can not only used to displace the chemical fertilizers, but also to maintain the soil fertility. Maintaining soil health of the plantation is one of the important aspects for the sustainability of crop production. Therefore, this paper considered both energy and nutrients potential of biomass waste from the palm oil mill.

Table 2 showed the energy and nutrients potential of biomass waste from palm oil mill. FFB yield of this plantation was 17.6 t/ha/year. Based on this yield, EFB has the highest potential of energy. Generally, nitrogen fertilizer consumes more energy than other fertilizers in the production process. The oil palm plantation applied about 280 kg/ha/year of urea relevant with 131 kg/ha/year of nitrogen [4]. On the other hand, total nitrogen potential of biomass waste generated from palm oil was 57 kg-N/ha/year (see Table 2). Therefore, the estimation of this study can roughly fulfill 44% of chemical fertilizers use in oil palm plantation.

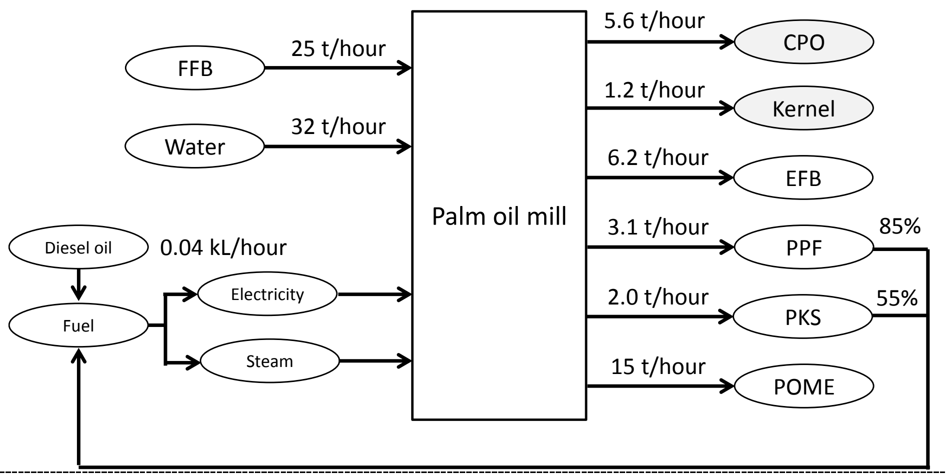

Figure 1. Material and energy flow in palm oil mill (25 t-FFB/hour).

Table 2 showed the moisture content and C/N ratio as well. Generally, C/N ratio of 30 and moisture content of 50-60% are considered as the suitable conditions for compost production [10]. Producing compost from EFB has been succeeded by co-composting with partially tresated POME [11] and anaerobic treated POME [12]. The products of co-composting of EFB and anaerobic treated POME have a nutrient value of 2.31% N, 1.36% P, and 1.04% K [12]. It was assumed that 1 t of EFB compost was equivalent to the chemical fertilizer, i.e., 47.8 kg of N fertilizer, 25.6 kg P fertilizer, and 46.5 kg K fertilizer [13]. Additionally, co-fermentation with POME on anaerobic digestion is also possible to produce biogas as renewable energy, as well as the production of organic fertilizer [14]. This integrated waste treatment technology is also expected to reduce greenhouse gas emissions of biomass waste treatment in palm oil mill [15]. Further study is expected to clarify the dynamic effects of this technology to the life cycle of palm oil production.

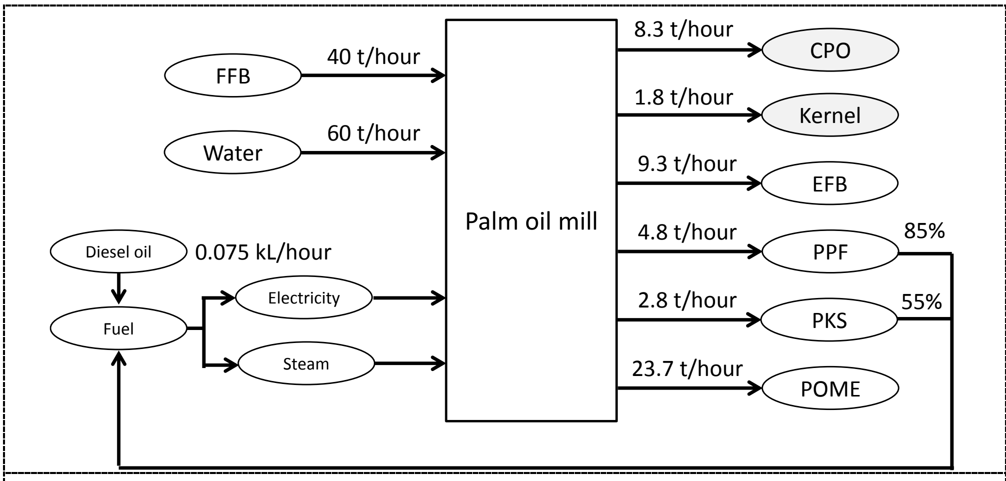

Figure 2. Material and energy flow in palm oil mill (40 t-FFB/hour).

Table 1. Biomass waste generation rate (%-FFB) of palm oil mills.

	Lampung, Indonesia (25 t-FFB/hour) This study	Lampung, Indonesia (40 t-FFB/hour) This study	Aceh, Indonesia, [6]	Thailand, [3]
EFB	24.8	23.3	21.5	24.0
PPF	12.4	12.0	12.3	14.0
PKS	8.0	7.0	6.1	6.1
Total	45.2	42.3	39.9	44.1

Table 2. Energy and nutrients potential of biomass waste from palm oil mill.

Parameters		PPF	PKS	EFB
Amount	t/ha/year	2.5	0.9	4.4
Nitrogen potential	kg-N/ha/year	28	9.5	20
Carbon potential	kg-C/ha/year	1,164	440	2,003
Energy potential	GJ-LHV/ha/year	49	17	75
Moisture content	%	37	21	57
C/N ratio	-	42	46	101
Lower heating value (LHV)	MJ/kg	20	18	17
Carbon content per 1 MJ of LHV	g-C/MJ	24	25	27
Nitrogen content per 1 M of LHV	mg-N/MJ	571	546	264

4. Conclusion

This study evaluated the energy and nutrient balance of palm oil production by applying material flow analysis for two palm oil mills in Lampung, Indonesia. The results highlighted the importance of biomass residue utilization to contribute on the soil sustainability towards resilient palm oil production. The potential of nitrogen fertilizer was roughly estimated as 44% of total nitrogen chemical fertilizer. These palm oil mills were already self-managed their energy consumption by burning PKS and PPF. Therefore, the utilization of EFB is a crucial task with high priority. The co-composting of EFB with POME would be an atrractive alternative technique to produce biogas and compost from EFB. Further practice was recommended to enhance the resilience of palm oil production.

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