PALM OIL MILL EFFLUENT RECYCLING SYSTEM FOR SUSTAINABLE PALM OIL INDUSTRIES

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ABSTRACT

Having sustainable is a key issue in the development of palm oil industries in Indonesia. Palm oil mill effluent (POME) is a largest waste from palm oil mill with very high concentration of organic matter. Several methods have been developed to treat the POME but it is rather difficult to fulfil the national effluent standard. The objective of this research is to evaluate the environmental impact of some currently implemented methods of POME treatment, such as: (1) open lagoon and land application of treated POME (as a base line), (2) methane capture and land application of treated POME, and (3) co-composting of empty fruit bunches (EFB) and POME. Green House Gases (GHG) emission reduction and renewable energy production were evaluated. Results showed that compared to open lagoon system, methane capture followed by land application of treated POME was estimated to successfully produce renewable energy about 55,3 kWh/ton of fresh fruit bunches (FFB) and GHG emission reduction about 241.2 $kgCO_2e$/ton FFB. Utilization of treated POME as liquid fertilizer improved soil quality and increased FFB production by about 13%. Co-composting of EFB and POME was estimated to successfully reduce GHG emission about 115.9 $kgCO_2e$/ton FFB and 191.9 $kgCO_2e$/ton FFB for 30 and 70 days composting periods, respectively. Compost application also improved soil quality and increased FFP production about 5-10%.

Keywords: palm oil mill effluent, GHG emission, methane capture, compost

INTRODUCTION

Indonesia is the biggest Crude Palm Oil (CPO) producer with a share of about 46.6% of the world [1]. In 2013 the total CPO production in Indonesia has reached 27.64 million ton. It is projected that by 2015 and 2020 the CPO production will be 32.36 million ton in 2015 and 43.93 million ton in 2020 [2]. On the other side, it is predicted that the total world demand of palm oil was about 64.5 million ton in 2015 and increase to 95.7 million ton in 2025 [3]. This situation indicates that palm oil industries will continuously grow to fulfil the world demand. The growth of CPO production in Indonesia is about 7.8% per year; it is higher than that of Malaysia's being only 4.2% per year [4].

Palm oil mill effluent (POME) is the biggest waste and the main source of environmental pollution in the palm oil mill. Each ton of CPO production will produce about 2.5-3.0 m^3 of POME [5] (Saidu *et al.* 2013). Each ton of fresh fruit bunch (FFB) produces about 0.75 – 0.90 m^3 of POME or equivalent to approx. 3.33 m^3 of POME per ton of CPO production [6]. POME is a colloidal suspension containing 95-96 % water, 0.6-0.7 % oil and 4-5 % total solids including 2-4 % suspended solids [7]. The sources of POME are mainly from sterilization (36%), clarification and purification of CPO (60%), and hydro-cyclone (4%) processes. The characteristics of POME are as follows: the biochemical oxygen demand (BOD) ranging from 8,200 to 35,400 mg/L; chemical oxygen demand (COD) from 15.103 to 65,100 mg/L; oil and grease from 2,200 to 4,300 mg/L; total solids from 16,580 to 94,106 mg/L; and suspended solids from 1,330 to 50,700 mg/L [8].

Oxygen depleting potential of POME is about 100 times more than that of domestic sewage. POME caused a major environmental problem in the palm oil industries. Without a proper POME treatment and handling, the palm oil mill becomes synonymous with POME pollution [9].

Wastewater treatment processes in palm oil industries usually use a conventional biological treatment. Generally, we can separate the processes into two types of treatment systems in palm oil industry: a) biological treatment with land application; and b) biological treatment without land application. In biological treatment with land application, the POME is treated in anaerobic ponds until BOD reaches a maximum of 5,000 mg/l, after that the treated POME is transferred the plantation as a liquid fertilizer. Now, the biological treatment with land application is a typical wastewater treatment system in palm oil industries. In Indonesia, land application systems of POME are regulated through the Ministry of Environment Decree number 28 and 29, 2003. According to this regulation, the land application system is prohibited to implement if the oil palm plantation located at: (1) peat soil area, (2) soil with permeability lower than 1,5 cm/h or higher than 15 cm/h, and (3) depth of ground water less than 2 m. The biological treatment without land application system should be implemented in palm oil industries which are not fulfilling the requirement of Decree numbers 28 and 29, 2003 by the Ministry of Environment. In this case, the effluent of POME treatment should fulfil the national effluent standard, which was regulated in Decree number 5, 2014 by the Ministry of Environment and Forestry. To satisfy the national effluent standards, the POME treatment usually consists of anaerobic ponds, facultative ponds, aerobic ponds, and sometimes uses sand bed filters as a polisher. This system needs a lot of energy for aeration and loses a lot of nutrients and organic materials [9].

Huge amount of POME with high concentration of organic content implicates a high potential to cause environmental pollutions if it is not properly treated. In contrary, the utilization of POME can produce some valuable materials or energy which is important to support the sustainability of palm oil industries. Sustainable POME management is crucial to developing a sustainable palm oil industry [10]. The appropriate technology of sustainable POME management for each palm oil mill is depending on the condition of the palm oil mill and plantation, such as energy supply and utilization, soil characteristic of oil palm plantations, and how much the management pays attention to greenhouse gases emission reduction initiative. The objective of this research is to evaluate the environmental impact of some current implementing method of POME treatment, such as: (1) open lagoon and land application of treated POME (as a base line), (2) methane capture and land application of treated POME, and (3) co-composting of empty fruit bunches (EFB) and POME.

MATERIALS AND METHODS

Research was conducted in two palm oil mills: one in Lampung with POME treatment using open lagoon followed by land application, and the other in Central Kalimantan with POME treatment using methane capture followed by land application and co-composting of EFB and POME. Quantity of palm oil mill effluent (POME) was observed in both mills. POME characteristic (before and after treatment) was evaluated from its concentration on COD (chemical oxygen demand) and its carbon content. Compost yield and its characteristic were observed from a composting plant. Effect of EFB compost and treated POME application in soil was evaluated by microbial existence in the soil.

Analysis

COD of POME was analyzed using closed reflux method (Hach DRB 200) followed by spectrophotometry (Hach DR/4000 U). Carbon content was analyzed using elemental analyzer (Elementar Vario EL Cube, Germany). Microbial community structure in the soil was evaluated from quinone analysis. The detail procedure of quinone analysis has been previously described [6].

Calculation

Greenhouse emission from POME treatment in open lagoon was estimated using equation 1:

$$GHG\ emission\ \left(\frac{kg\,CO2}{ton\ FFB}\right) = \frac{CODin - CODout}{1000} x F x 0.25 x\ 21 \quad \text{......................(1)}$$

Where:

CODin = COD of untreated POME; CODout = COD of treated POME; F = Volume of POME per ton of FFB; 0.25 = IPCC default value (0,25 kg CH_4 per kg COD removal; 21 = Ratio of Global Warming Potential of CH_4 and CO_2

Greenhouse emission reduction from POME treatment ponds was estimated from COD values of influent and effluent POME. Energy potential from methane capture was calculated based on methane content of the biogas produced from covered lagoon facility. Greenhouse gas emission reduction (GHG_R) resulted from co-composting of EBP and POME is calculated by using :

$$GHG_R = E_0X - (E_C + E_L + E_F) \quad (2)$$

where E_0 is baseline GHG emission from POME treatment pond without methane capture, X is fraction of POME used for EBP composting (%), E_C is GHG emission from composting piles, E_L is GHG emission from leachate pond, and E_F is GHG emission from fossil fuel used for composting operation process.

RESULTS AND DISCUSSION

Discussion will be divided base on POME treatment and utilization method. Anaerobic biological treatment in open lagoon is the most common applied to treat POME. This system relatively simple, low cost, and reliable to treat POME, but will emitted methane as one of important GHG with global warming potential 21 times of CO_2. Other method was developed to reduce GHG emission including methane capture and co-composting of EFB and POME in some palm oil mill. Utilization of treated POME through land application was also adapted to prevent water environment pollution as well as utilize nutrient contained in the treated POME.

Open Lagoon and Land Application

POME production and FFB processed were collected from Palm Oil Mill during October 2014 until April 2015. Untreated COD of POME was also measured during similar period. GHG emission potential was calculated using equation 1 based on IPPC default value [11]. Table 1 showed the POME production, COD concentration, and potential of GHG emission from open lagoon of POME treatment. Table 1 showed that the potential of GHG emission from POME is about 14.36 kg CH_4/ton FFB or 301.48 kg CO_2/ton FFB. If the yield of CPO is 23% of FFB, the CO_2 emission is about 1,310.78 kg CO_2/ton CPO. This number is quite big due to POME production and COD concentration relatively high. Research by [5] reported that POME production was 2.5-3.0 m^3 for each ton of CPO production (equivalent to 0.55-0.65 m^3 per ton FFB with 21.8% yield). Another research by [8] reported that untreated POME has COD values varied from 15,103 to 65,100 mg/l. Reducing POME generation and POME concentration will reduce GHG emission and in other side will also increase the oil yield. High COD value of untreated POME usually has correlation with high oil losses; it is due to oil content in untreated POME will increase COD value.

Table 1. FFB and POME production, COD concentration, and GHG emission potential from POME treatment in open lagoon

Parameters	Unit	Value	Average
FFB processed (Oct 2014-Apr 2015	ton	330834.5	330834.5
POME production (Oct 2014-Apr 2015	m^3	265614.4	265614.4
COD of untreated POME	mg/l	99900	80250
		92100	
		66500	
		66300	
		87900	
		89100	
		69700	
		70500	
COD of treated POME	mg/l	11360	8725
		11740	
		6650	
		5150	
POME production/ton FFB	m^3/ton	0.8029	0.8029
Emission factor (IPCC, 2006)	$kgCH_4$/Kg COD removal	0.25	0.25
CH_4 emission/ton FFB	$kgCH_4$/ton FFB	14.36	14.36
CO_2 emission/ton FFB	$kgCO_2$/ton FFB	301.48	301.48
CO_2 emission/ton CPO[*)]	$kgCO_2$/ton CPO	1,310.78	1,310.78

[*)] Assumed CPO Yield 23% of FFB

Land application of treated POME in oil palm plantation is becoming common practice after launch of the Ministry of Environment Decree number 28 and 29 at 2003. This method has dramatically reducing the potential of water pollution due to POME. Also, nutrient contain in the treated POME was utilized as organic fertilizer for oil palm and increase soil quality.

Microbial quinone analysis was conducted to evaluate the impact of land application of treated POME on soil quality. Quinone profile analysis can be used as an index to characterize microorganism community [12][13] and as biomass index [13][14]. Microorganisms were known much contribute on environmental conservation due to organic matter was predominantly degraded through microbial processes in ecosystem [15][16][17]. The capacity of each an ecosystem to degrade organic matters and the response of it to the changes in environmental conditions do not only depend on the total population of microorganisms present in that system but also depend on microbial community structure of that system [18][19]. Microbial community structure in natural mixed culture such as soil can be used as an indicator of soil conditions, such as: fertility, biodiversity, and structure condition of soil. Soil organic carbon has close correlation with microbial community structure; but soil which has high concentration of organic carbon was not always has high number and species of microbe. Microbes community in the soil need not only organic carbon for growth and multiplied, but also need other organic matter such as N, P. Therefore, microbial community structure can be promoted as more representative indicator of soil quality than soil organic carbon.

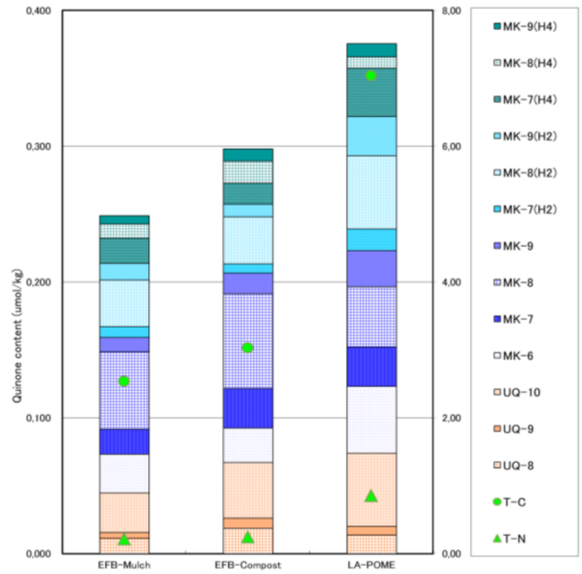

Figure 1. Impact of EFB mulch, compost, and treated POME land application on microbial quinone content, total carbon, and total nitrogen

Figure 1 indicate that land application improve the number of quinone which is indicate that the number of microorganism also improve. Total carbon and nitrogen also improve due to land application of treated POME. The treated POME land application will influence the soil health which is identified by changes of microbial community structure in soils leading to the increase of oil palm plantation productivity. Figure 1 also showed the impact of EFB mulching and EFB compost land application to the quinone content, total carbon, and total nitrogen. Treated POME land application has highest impact on quinone content, total carbon, and total nitrogen in the soil, but has not impact to the changes of quinone species.

The impact of treated POME land application was evaluated by [6]. Application of treated POME can lead to increased productivity about 13%, bunches/trees number and average weight of palm oil fruit bunches. Better soil characteristics and structure lead to improved conditions of mineralization process in the soils. Treated POME contains some essential elements providing the soils with nitrogen, phosphorus, and potassium. The application of treated POME provides nitrogen, phosphorus, and potassium which are important nutrients for oil palm growth.

Methane Capture and Treated POME Land Application

Methane capturing from POME can be carried out using the anaerobic digestion in several types of bioreactors, such as: covered in the ground anaerobic reactor (CIGAR), continuous stirred tank reactor (CSTR), and anaerobic baffled reactor (ABR). Anaerobic digestion is a common technology to treat POME. Conventional palm oil mills usually use open anaerobic lagoon to treat POME. By covering the surface of lagoon using the high-density polyethylene (HDPE), the open anaerobic lagoon will change to CIGAR. Benefits of methane capturing from POME are additional revenues from sale of surplus energy and carbon credits, reducing the carbon footprint of the palm oil mill, which is important to increase market competitiveness of palm products, mainly palm biodiesel to environmentally-sensitive markets such as the European Union and the United States. Figure 2 showed the benefit of methane capture from POME and their impacts to reduce global and local environmental burdens. Methane capturing from POME and their utilization to generate steam or electricity will also reduce the dependence on fossil fuel, enhances fuel diversity and security of energy supply, and encourages technology innovation on POME sustainable management [9].

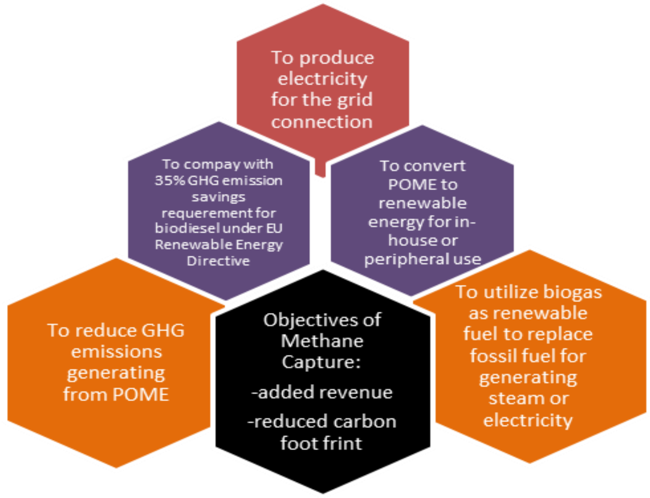

Figure 2. The objectives of methane capture of POME and their impact to reduce global and local environmental burden [9]

The utilization of POME for generating heat and electricity in a palm oil mill has increased the potential of energy produced from palm oil mill biomass waste. Figure 3 showed the process design of anaerobic treatment and utilization of POME. Through the anaerobic digestion, a biogas plant reduced the COD load by about 90%. Based on the data in Table 1 with 80% efficiency, palm oil mill with a capacity of 45 ton FFB/hour with operation 20 hour/day will produce electricity about 49.78 MWh/day or 2.07 MWe power plant capacities from POME treatment. In addition, the biogas utilization for energy also will reduce GHGs emission by about 10.34 ton of CH_4/day, which is equivalent to about 217.07 ton of CO_2e/day or reduce about 78%.

Effluent from biogas reactor is suitable for land application similar with treated POME from anaerobic lagoon. POME reduction and recycling through methane capturing and land application of treated POME will not only reduce the environmental impact of POME significantly, but also will produce some valuable products, increase energy efficiency, maximize renewable energy utilization, and reduce GHGs emission. The fast growth of palm oil industries also has a high potential to give some additional revenue and other intangible benefits from POME [9].

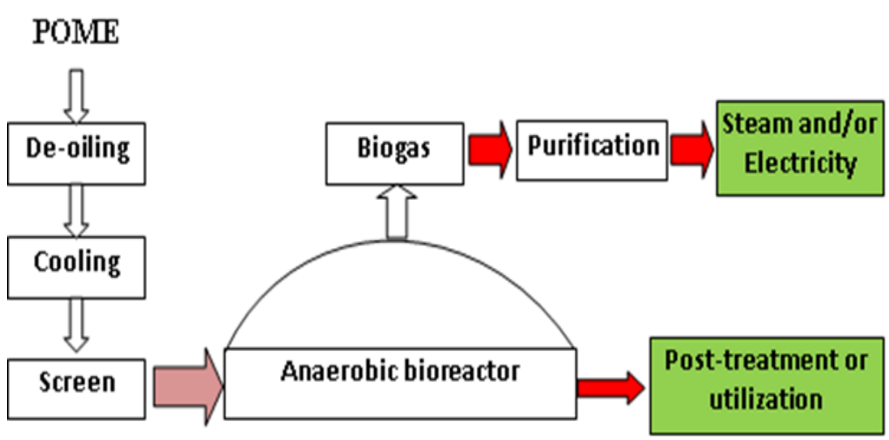

Figure 3. The process design of POME treatment and utilization (Hasanudin and Setiadi, 2016)

Co-Composting of EFB and POME

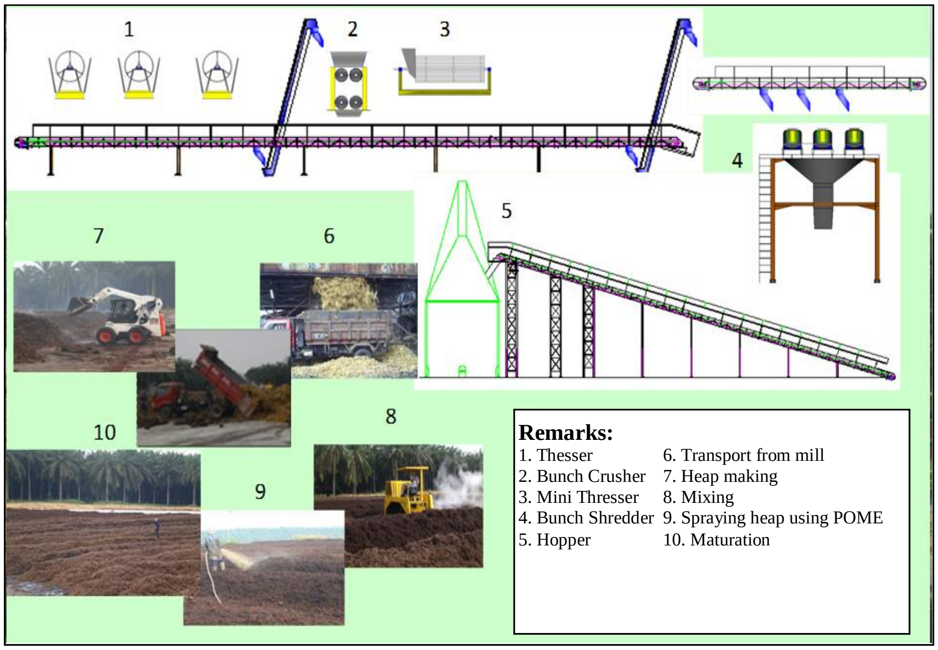

Figure 4. Diagram of EFB-POME compost production process

The current common practice in palm oil industries are utilize EFB for mulching and treated POME as a liquid fertilizer through land application system. Some other industries are using the EFB and POME together to produce compost. Composting of EFB together with POME can minimize of nutrient losses and concentrate all nutrients from POME and EFB into one product. Figure 4 showed the procedure of compost production. Using co-composting of EFB and POME, almost all (depend on how much POME is produced per ton FFB) of POME was used to keep the moisture around 60% during the composting process [20]. A case study at an EFB-POME co-composting plant shows that about 0.347 m^3 of wastewater/ton of FFB or about 43.18% of POME was utilized during 30 days composting process and about 0.627 m^3 of wastewater/ton of FFB or about 78.04% of POME was utilized during 70 days composting process.

Composting is a controlled biological process which converts biodegradable solid organic matter into a stable humus-like substance which is suitable for use as a soil conditioner and has a certain nutrient value, too. Composting is an accelerated version of natural decomposition of organic waste achieved through the provision of favourable conditions for microorganisms. In this way, EFB is piled longitudinally in the form of hill-like with 1.5 m height, whilst POME is sprayed over periodically. Aeration is essential for metabolic heat generation from aerobic microbes and become important factor influencing successful composting [21]. Therefore, the pile is turned over for some periods to increase mixing between EFB and POME as well as to facilitate oxygen and temperature management. POME utilization for co-composting process significantly reduces the amount of POME treated in the waste water treatment plant (WTP) which of course decreases GHG emission. From our field experiment found that due to the period of turned over is 2 days, some methane gas was produced during co-composting of EFB and POME. Methane emission from composting pile was estimated using Carbon balance which is illustrated in Fig. 5.

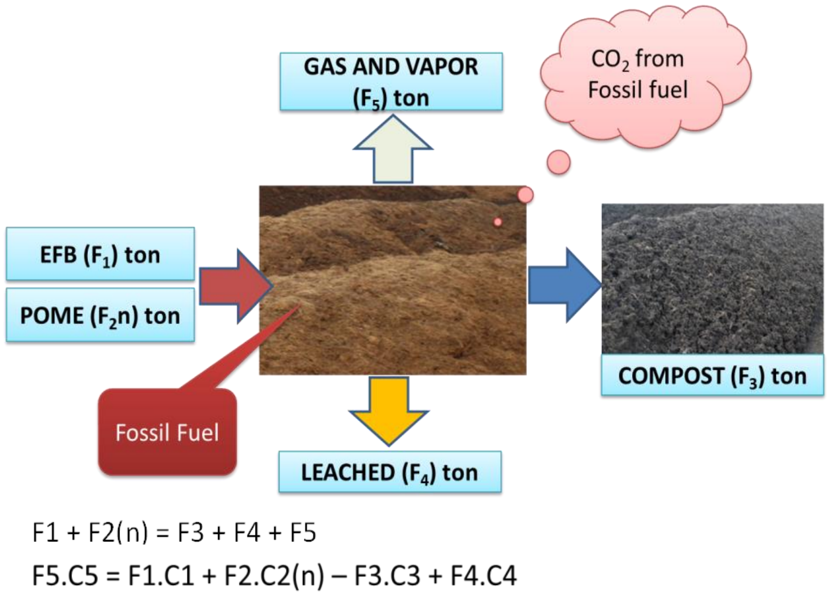

Figure 5. Material and carbon balance in co-composting of EFB and POME

Using the materials balance in Figure 2 was estimated that GHG emission during 30 days composting process is about 13.98 kg CO_2/ton FFB from EFB pile and 0.3 kg CO_2/ton FFB from fossil fuel consumption. Similar method was implemented for estimation of GHG emission during 70 days composting process. GHG emission during 70 days composting process is about 42.72 kg CO_2/ton FFB from EFB pile and 0.7 kg CO_2/ton FFB from fossil fuel consumption. GHG emission reduction was estimated using equation 2 and found that GHG emission decrease from 301.48 kg CO_2/ton FFB to 185.59 kg CO_2/ton FFB or decrease about 38.44% and from 301.48 kg CO_2/ton FFB to 109.62 kg CO_2/ton FFB or decrease about 63.64% for 30 and 70 days composting process. In other word, co-composting of EFB and POME was estimated to successfully reduced GHG emission about 115.9 kgCO_2e/ton FFB and 191.9 kgCO_2e/ton FFB for 30 and 70 days composting, respectively. Application of EFB compost increased number of microorganism in the soil which is described in Figure 1 and increase FFB production about 5-10% [22]. Co-composting of EFB and POME has successfully to reduce GHG emission, improve soil quality, increase FFB production, but has not potential to produce renewable energy.

CONCLUSION

POME treatment and utilization in open lagoon system has potential to emitted high amount of GHG. Implementing of methane capture system has not only successfully to reduce GHG emission, but also produce renewable energy, improve soil quality, and FFB production. Co-composting method has also potential to reduce GHG emission, improve soil quality and FFB production, but has not potential to produce renewable energy.

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