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Greenhouse Gas Emission of Electricity Generation and Field Abandonment Scenarios Using Empty Fruit Bunches at a Palm Oil Mill, Surat Thani Province, Thailand

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In Indonesia, Malaysia, and Thailand, the pile abandonment of empty fruit bunches (EFBs) in the fields of palm oil mills is a common practice. This practice results in environmental issues such as generation of unpleasant odors and methane production due to anaerobic decomposition. In the present study, an abandoned moist EFB sample from Rubber Oil Co. Limited, a palm oil mill in the Thachi sub-district municipality, Surat Thani Province, southern Thailand, was collected and sun dried for physical analysis. The bulk density at 13.2% moisture content was 0.118 kg/L. Greenhouse gas (GHG) emissions for electricity generation and methane production due to anaerobic decomposition were compared applying life cycle assessment. A cargo capacity of 621 kg of EFBs and a 59 km distance to the Surat Thani Biomass Power Plant in Surat Thani province were adapted with reference to Thailand's GHG emission factors. The system boundary included the EFBs in the palm oil mill and the nearest power plant. The CO₂ equivalent GHG emissions per kg of EFB for the transportation, generation, and field abandonment (methane emission) were 0.077, -0.877, and 2.136 kg-CO₂e, respectively; a sum of -0.8 kg-CO₂e emission via electricity generation use was noted as a significant environmental advantage.

インドネシア、マレーシア、タイではアブラヤシ空果房 (EFB) のパーム油工場空地での堆積放棄が常習化している。この慣習は悪臭や EFB 嫌気分解によるメタンガスの発生という環境問題を生みだしている。本研究では、タイ南部、スラタニ県、タチ小自治区に位置するパーム油工場にて放棄された湿潤 EFB サンプルを採取し、天日乾燥させて、物理計測に供した。13.2%含水率でのかさ密度は 0.118 kg/L であった。LCA 手法により発電および EFB 嫌気分解によるメタン発生による温室効果ガス (GHG) 排出を比較した。パーム油工場から 59 km 離れたスラタニ・バイオマス発電所まで EFB を 621 kg 積載した 4 トントラックにて輸送する条件にてタイ国の GHG 排出係数を適用した。システム境界は EFB が放棄されるパーム油工場および上記最寄りのバイオマス発電所までを含めた。EFB 1 kg あたりの輸送、発電および堆積放棄 (メタン発生) の GHG 排出量はそれぞれ 0.077、-0.877 および 2.136 kg-CO₂e であった。一方、発電使用した場合は合計 -0.8 kg-CO₂e 換算と、より少ない GHG 排出量であった。

Key Words

Empty fruit bunch (EFB), Greenhouse gas (GHG), Life cycle assessment (LCA)

1. Introduction

Utilization of empty fruit bunches (EFBs) of oil palms has received little attention, given its low economic value. Moreover, the large size of EFBs causes difficulty in transportation and handling. In all oil palm plantation

regions of Indonesia, Malaysia, and Thailand, abandonment of EFBs in the fields of palm oil mills is a common practice, resulting in odors, methane generation, and other environmental issues¹⁾²⁾.

The Surat Thani Biomass Power Generation Project in Thailand was the first to use EFBs of oil palms as the primary fuel for electricity generation; this resource is abundant in the region as agricultural waste. The project was conducted under the framework of the United Nations Framework Convention on Climate Change with the

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support of the New Energy and Industrial Technology Development Organization of Japan³⁾. Under the project, a biomass thermal power plant of 8.9 MW net capacity began operation in March 2008. A total GHG reduction of 746,142 t CO₂e over seven years, until March 2015, has been estimated.

An environmental impact assessment of EFB utilization at a biomass power plant in Thailand was completed by Chanlongphitak *et al.* (2015)⁴⁾, using the life cycle assessment approach. According to this study, the global warming potential (GWP) of 1 MWh of electrical generation for the stages of oil palm plantation, crude palm oil extraction, electricity generation at the power plant, and transportation were 35.38 kg-CO₂e, 14.89 kg-CO₂e, 89.51 kg-CO₂e, and 9.92 kg-CO₂e, respectively. They considered EFBs as one of the co-products (*i.e.* crude palm oil and palm kernel), and the environmental impacts of palm oil plantations were allocated to these co-products based on energy content. Although abandonment of EFBs on agricultural land was a common practice, this impact was not included in their study.

Therefore, our study took an impact of abandonment of EFBs into account and focused on GHG emission reduction via electricity generation using EFBs; EFBs were presumed to be the substitutes for fossil fuels.

2. Method

2.1 Physical measurement of EFB

An abandoned moist EFB sample from Rubber Oil Co. Limited, a palm oil mill in the Thachi sub-district municipality, Surat Thani Province, southern Thailand, was collected and sun dried for physical analysis. The bulk density at 13.2% moisture content was 0.118 kg/L.

2.2 System boundary

The system boundary of the GHG emission analysis is shown in Fig. 1. The functional unit (FU) in the study was designated as 1 kg of treated oil palm EFBs, for an electricity generation scenario and a field abandonment scenario. The system boundary of the former scenario consists of transportation from the palm oil mill to the Surat Thani Biomass Power Plant, in Surat Thani province, and generation processes, as shown Fig. 1 (a).

The system boundary of the latter scenario is shown in Fig. 1 (b). It indicates no transportation and subsequent processes involved, as the EFB was abandoned at the palm oil mill. However, machinery and other infrastructure involved in piling EFBs on the ground, loading cargo, and the unloading cargo (at the thermal generation plant) were excluded, as these are dependent upon palm oil mills and

*The same amount of grid electricity was substituted as a credit

Fig. 1 System boundary of the GHG emissions analysis

power stations, and are not the focus of this study. Notably, the GHG emissions from decomposition of EFBs in drying process were not considered as they were immediately dried and processed during steam turbine electricity generation¹⁾.

2.3 Life cycle assessment

Life cycle assessment were performed for both the electricity generation and field abandonment scenarios. Energy inputs/outputs of the electricity generation, transportation, and methane (CH₄) emission caused by anaerobic decomposition were quantified.

In the inventory analysis of transportation, a load bed of a common 4-t truck was calculated, assuming a loading platform dimensions of 6,200 mm (length), 2,130 mm (width), and 400 mm (height). Subsequently, the loading capacity (in terms of weight) was calculated using the loading volume and the bulk density of the treated EFBs.

GHG emissions during the processes of EFB transportation and electrical generation were derived from IDEA v.2⁵⁾. The power generation efficiency using biomass is variable (24–36%)⁶⁾. In this study, we assumed this efficiency to be 30% for the thermal power generation, with a lower heating value.

The anaerobic decomposition of the field-abandoned EFBs was estimated using the Intergovernmental Panel on Climate Change (IPCC) method⁷⁾ as follows:

$$\text{CH}_4\text{_{IPCCdecay}} = (\text{MCF} * \text{DOC} * \text{DOCF} * \text{F} * 16/12) \quad (1)$$

where CH₄_IPCCdecay is the CH₄ emission factor for decaying biomass (kg-CH₄/kg-biomass), MCF is the methane correction factor (default: 0.4), DOC is degradable organic carbon (default: 0.3), DOCF is the fraction of DOC dissimilated to landfill gas (default: 0.77), and F is the fraction of CH₄ in the landfill gas (default: 0.5). In this

study, we adopted the default values for the calculation. Notably, We only took consideration on CH₄ emission in the decomposition processes of field abandoned EFBs, and all amount of CH₄ was converted into CO₂ equivalent.

2.4 Impact assessment

Each GHG was converted to a CO₂e value using the latest GWP[®]. Because CO₂ released upon the combustion of oil palm EFBs was originally fixed from the CO₂ in the atmosphere, the CO₂ emissions were considered to be zero (carbon neutral). In this study, only CO₂ derived from fossil fuels was evaluated; hence, the analyses added and deducted GHG emissions, corresponding to the transportation and generated electricity, respectively, in the EFB-use for electricity generation. Meanwhile, the anaerobic CH₄ emissions from abandoned EFBs were converted to a CO₂e value.

3. Results

Calculations of the electricity generation scenario are shown in **Table 1**. At a bulk density of 0.117 kg/L, the loading capacity was estimated as 621 kg/truck for a 5.28 m³ truck bed. The GHG emission was calculated to be a 0.877 kg-CO₂e. based on 30% generation efficiency.

Table 1 Calculations of the electricity generation scenario

Process	Item	Value	Unit
Transportation of 59 km	Bulk density	0.117	kg/L
	Volume of 4 t truck bed	5.28	m ³
	Loading capacity*	621	kg/truck
	Loading ratio	0.155	
	GHG emission factor of 4 t truck (10%)	1.31	kg-CO ₂ e/tkm
	GHG emission by transportation	0.077	kg-CO ₂ e
Electrical generation	Generation efficiency	30	%
	EFB lower heating value	17.6	MJ/kg
	Electric generation	1.47	kWh
	GHG emission reduction by generation	0.877	kg-CO ₂ e

* Length 6,200 mm · Width 2,130 mm · Height 400 mm

Table 2 Calculations of the field abandonment scenario

Item	Value	Unit
CH ₄ emission factor	0.0616	kg-CH ₄ /kg-dry-EFB
Reference flow	1.00	kg-dry-EFB
CH ₄ emission	0.0616	kg-CH ₄
CH ₄ emission as CO ₂ e	1.54	kg-CO ₂ e

Calculations of the field abandonment scenario are shown in **Table 2**. The CH₄ emission of 0.0616 kg-CH₄ had the highest value of 1.54 kg-CO₂e, as methane has 25 times the GWP of CO₂.

The GHG emission of the EFBs used for electricity generation and field abandonment are shown in **Fig. 2**.

The grid electricity production via the EFBs' combustion was 0.877 kg-CO₂e and the balance of environmental impact was 0.0800 kg-CO₂ taking the power substitution into the account and the surplus GHG emission derived from the 59-km transportation distance from the palm oil mill to the biomass thermal power plant in Surat Thani province. The difference in the GHG emissions between the two studied scenarios was 2.136 kg-CO₂e for every 1 kg of dry EFBs.

4. Discussion and Conclusions

Although the low bulk density of dried EFBs (0.117 kg/L), is among the major constraints for EFB-usage, our life cycle assessment of EFBs for electricity generation resulted in a substantial GHG emission credit of 0.8 kg-CO₂e compared to the surplus GHG emission of 1.337 kg-CO₂e during the anaerobic decomposition scenario emitting methane via field abandonment of EFBs, a common practice

Fig. 2 Greenhouse gas emission of electricity generation and abandonment scenarios (kg-CO₂e/functional unit)

in most oil palm plantations.

In the Thachi sub-district municipality, EFBs are currently sold to farmers for use as fungal culture at approximately 600 Baht/t, and some of oil palm plantations also cultivate straw mushroom in the plantations. These are transported from neighboring palm oil mills to local farmers in the region. However, some palm oil mills distribute EFBs free of charge if the farmers transport EFBs by themselves. In addition, EFBs are also used as a material for composting, but its use is limited given its slow decomposition (personal citations by Chaisomphob).

The consumption of EFBs for the aforementioned agricultural uses does not correspond to the EFB outputs from palm oil mills. Therefore, a substantial amount of EFBs are stocked unused, making field abandonment the only solution unless they are utilized as fuel. This study clearly indicated the environmental advantage of electricity generation using EFBs compared to the field abandonment scenario.

Table 3 shows a comparison of the GWP of Chanlongphitak *et al.* (2015)⁴⁾ and the results of this study. Chanlongphitak *et al.*⁴⁾ included GHG emissions of palm oil plantations and attributed its impacts to a variety of palm oil products based on energy content. However, we considered that the environmental impact for acquiring EFBs was zero because a certain amount of EFBs was not utilized. Furthermore, Chanlongphitak *et al.*⁴⁾ indicated that the power generation process caused GHG emissions because of the high moisture content of EFBs, while in our study the EFBs were sun-dried, and their resulting moisture content was presumed to be insignificant. Therefore, the GHG emissions in our study were less than that of Chanlongphitak *et al.*⁴⁾. Regarding GHG emissions from transportation, our study results were more than 5 times greater than that of Chanlongphitak *et al.*⁴⁾. Because the transport distance was nearly the same, our calculation was more conservatively done.

This clearly indicated that the magnitude of the CO₂ emission reduction by substituting the EFB electrical generation was significantly larger than that via combustion of EFBs. However, the handling difficulties, including less efficiency in transportation given EFBs' remarkable bulk density, even when sun dried, remains a large constraint.

To address this constraint, grounding and pelletizing

the EFBs is recommended, before it is used for thermal power generation, facilitating and possibly improving combustion efficiency in the furnace of thermal power plants.

A large EFB plant project was proposed for EFB pelletizing and using it as a substitute for coal in ordinary thermal power plants, using the process of potassium extraction via hydrothermal treatments, as high potassium content in the EFBs causes damage to furnaces of thermal power plants⁹⁾. Furthermore, the economic aspect was not assessed in this study. To improve the feasibility of utilization of EFBs, the cost of the system should be also considered in the future studies.

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Table 3 Comparison of the present study to Chanlongphitak *et al.* (2015)

Reference	GHG emission (g-CO ₂ e/kWh)	Allocation method
Chanlongphitak <i>et al.</i> (2015) ⁴⁾	149.7 (including 9.92 from 50-100 km transport)	Energy content (allocation among EFB, palm fiber, palm shell, palm kernel, and crude palm oil)
This study	52.8	Cut-off (environmental impact for acquiring EFB was zero)

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