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Assessing the Sustainable Development of Oil Palm Industry in Thailand

A Life Cycle Assessment Approach

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Abstract

In 2018, the global palm oil production and consumption were 70.6 million tons and 66.4 million tons, respectively. Thailand is the third largest palm oil producer, accounting for 3.9% of the global palm oil production. In 2018, the total area of oil palm plantation in Thailand reached 922,000 ha, and it has grown by about 4.5% over the past 10 years (2009-2018). In the same period, the output of fresh fruit bunch (FFB) reached 15.39 million tons. About 240,000 workshops on the production and processing of this product have been established. As the oil palm plantation area has been continuously increasing since 2009, greenhouse gas (GHG) emissions have increased yearly, global palm oil inventories are high, and oil palm prices would continue to be pressured by oversupply. In 2016, Thailand's per capita ecological footprint (EF) was 2.5 global hectares (gha), and its per capita biocapacity (BC) was 1.2 gha. Its biocapacity is less than 1.3. In this research, we aim for a sustainable development of Thailand's oil palm industry. System boundaries were formulated for the four oil palm plantation regions in Thailand, namely, the northern, northeastern, central, and southern regions. The life cycle inventory (LCI), a global greenhouse gas calculation model, and an EF calculation method were used to determine the GHG emissions palm oil in each of these regions in Thailand and Thailand's EF. GHG emissions are expressed in terms of carbon dioxide equivalent (CO_2eq) and net value. Thailand's oil palm plantations and palm oil processing areas are mainly distributed in the south. The CO_2eq per ton of FFBs in Thailand's oil palm plantations is 113.8 kgCO_2eq. The CO_2 eq per ton of CPO produced by a palm oil processing plant is 1000.4 kgCO_2eq, excluding biogas recovery equipment. The average EF of Thai oil palm is 21.6 gha/ha-year. The ratio of income to EF is 53.9 USD/gha. The ratio of income to EF in the southern area is 69.3 USD/gha. Although the total amount of GHG emissions in southern Thailand is high, the CO_2eq harvested per ton of FFBs is the smallest and the ratio of revenue to EF is the highest. Compared with the southern region, the northern and eastern regions need to invest more fertilizers and energy in oil palm cultivation. The cost is higher, and the market price of CPO is less competitive.

Keywords: GHG emission, Sustainable development, Ecological footprint

Introduction

At present, the main producers of palm oil are the members of the Association of Southeast Asian Nations (ASEAN). In 2018, the global palm oil production and consumption were 70.6 million tons and 66.4 million tons, respectively. Palm oil accounted for 35.7 and 38.6% of global vegetable oil production and consumption, respectively. Fig. 1 shows the Land use for palm oil production and production in 2018. Currently, Malaysia and Indonesia are the world's biggest palm oil producers where the production of both countries is 84% of the world palm oil production. Thailand is the third largest palm oil producer, accounting for 3.9% of the global palm oil production [1].

With the continuous expansion of the palm oil industry in Thailand, primary forests are often logged to establish oil palm plantations. Fig. 1 shows that land use for palm oil production was 922000 hectares in 2018, and it has grown by about 4.5% over the past 10 years (2009–2018). The rapid development of the palm oil industry has negative effects on sustainability, especially the impact of land use changes and greenhouse gas (GHG) emissions on the environment [2,3].

Thailand's palm oil production chain is complete, including oil palm plantations, crude palm oil extraction, edible oil refining, and biodiesel production. The production of crude palm oil (CPO) is mainly divided into the wet and dry extraction processes. Our survey showed that the wet extraction process is generally used to convert FFBs into CPO in Thailand. To promote the sustainable production of CPO, good system management is required to reduce the impact of solid waste, wastewater, and GHG emissions on the environment. International organizations, such as the Intergovernmental Panel on Climate Change (IPCC) and the United Nations Framework Convention on Climate Change (UNFCCC), which contribute to decreasing national GHG emissions, and clean development mechanism projects, developed a method that takes into account GHG emissions. In 2016, the per capita EF in Thailand was 2.5 gha, whereas the per capita BC was 1.2 gha. Its biocapacity deficit was 1.3 gha. The lack of biocapacity mainly comes from the carbon footprint component in the ecological footprint assessment. This result shows that Thailand must use resources elsewhere to maintain the lifestyle of the country's current population [2,4].

In this paper, we characterize the current Thai palm oil industry by formulating the research system boundary on the basis of oil palm planting and palm oil production using the GWAPP method to calculate greenhouse gas emissions. Then we discuss oil palm planting and palm oil production, and the main greenhouse gas emission process. The greenhouse gas emissions were quantified for every ton of FFBs harvested, every ton of CPO processed and produced in the Thai palm oil industry. Combined with the carbon footprint analysis model of oil palm planting, the economic benefits in terms of net oil palm income were determined. When calculating the ratio of revenue to EF, the EF of oil palm plantations was used. The purpose of this study is to determine the EF of palm plantations, evaluate the EF of FFBs of oil palm plantations, and determine the ratio of oil palm plantation revenue to EF [4].

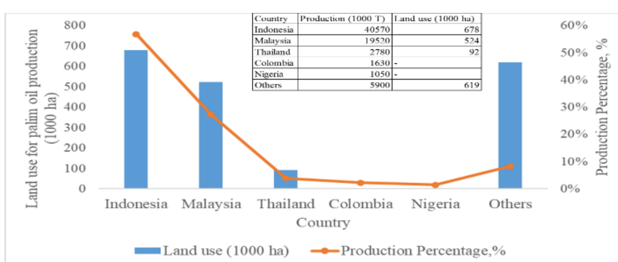

Figure 1: Land use for palm oil production and production in 2018

1 Oil palm planting and palm oil production

1.1 Oil palm cultivation, geographical and climatic factors

Thailand is located between latitudes 5°37′N to 20°27′N and longitudes 97°22′E to 105°37′E, with a total area of 513,115 km^2. Thailand has a tropical monsoon climate. There are three seasons a year. The annual temperature is no lower than 18°C, the average temperature is about 28°C, and the average annual precipitation is about 1,000 mm. The precipitation is relatively abundant, but it is affected by the topography and monsoon [5]. Because oil palms have certain requirements in climate and soil fertility, the current palm production is divided into four regions in Thailand, according to geographical environmental factors and planting and processing conditions: the north, northeast, central, and southern regions. Figure 2 shows the oil palm plantation areas and harvested areas in Thailand in 2012,2018. The Thai oil palm plantations are mainly distributed in the central and southern regions and their areas are increasing yearly [2,5].

1.2 Production, harvesting, and processing

Thailand's palm oil processing industry chain is complete, mainly including oil palm plantations, CPO extraction and processing, CPO refining, and biodiesel production. Thailand has about 240,000 family workshops participating in oil palm plantation (upstream), CPO processing mills (midstream), and palm oil extraction facilities (downstream). Among the family workshops, 79% are small [6]. The production cost of palm oil in Thailand is higher than those in Indonesia and Malaysia, sometimes as high as 110%. Therefore, Thailand's palm oil export has no advantage.

1.3 System boundary of the study

In this study, we combined two environmental sustainability assessment tools, namely, life cycle greenhouse gas (LC-GHG) emission assessment and ecological footprint assessment, to assess the environmental sustainability of oil palm cultivation in different regions of Thailand. In this study, we calculated the total greenhouse gas emissions from the production, transportation, processing, and waste disposal in the palm industry, as well as the ecological footprint of the palm planting process. Figure 3 shows the scope of the greenhouse gas and ecological footprint assessments, including the 25-year economic life and raw material transportation of palm nursery plants and palm plantations. We also investigated the types of land use before the conversion to new oil palm plantations and the areas planted after 2006[1,2,4].

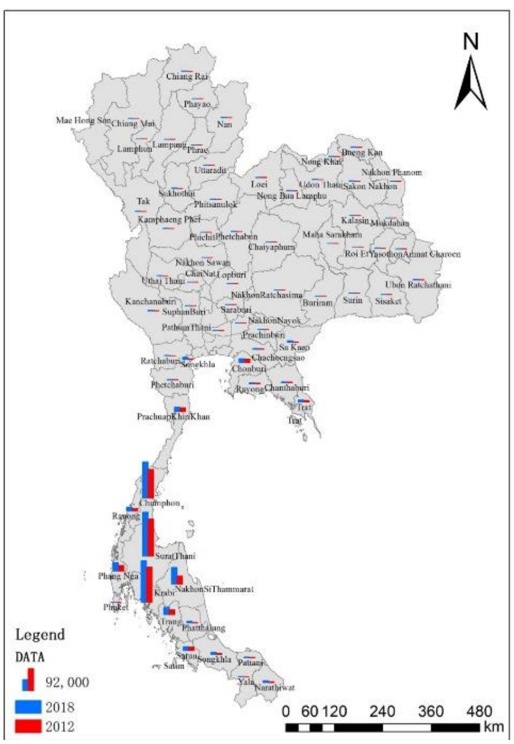

Figure 2. Palm plantation areas and harvested areas in Thailand in 2012,2018

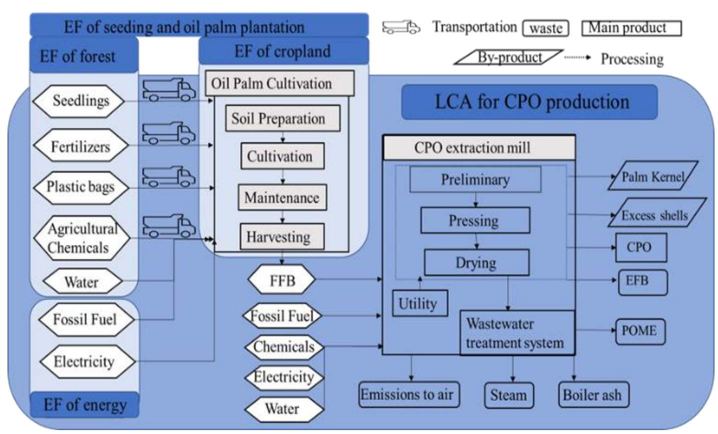

Figure 3: System boundaries of LCA for CPO production and ecological footprints

2 Methodology

2.1 Technology

The oil palm cultivation system is mainly composed of seedling cultivation and oil palm cultivation. The economic life of oil palm is about 25 years, and the frequency of a harvest cycle is about 10–15 days or 2–3 times a month. In this research, 32 mills using a wet extraction process with a production. The EFBs and palm oil mill effluent (POME) produced by the wet extraction process are classified as waste, as shown in Fig. 3. The wastewater generated by wet extraction is discharged to wastewater treatment equipment [7].

In this study, the ecological footprint (EF) evaluation index is combined with the greenhouse gas emissions during an oil palm life cycle to evaluate the sustainable development of the Thai oil palm industry. In our study, we considered the environmental impacts using the ecological footprint evaluation index. This work is the first to combine the environmental impacts of oil palm plantation nursery and oil palm cultivation on the total land and water ecosystem demand for providing resources and absorbers of emissions with greenhouse gas emissions. The total EF is the sum of energy, forest, and arable land EFs, as shown in Fig. 3. In this study, EF was selected for evaluating oil palm plantations because it can be used as an independent indicator of life-cycle environmental impact, as well as a screening indicator of environmental performance [2,7]. The system boundaries are shown in Fig. 3.

2.2 EF of oil palm plantation

The method of calculating EF is shown in Eq. (1). EF is defined as the sum of the EFs of direct and indirect land, water, fuel, and power applications, CO_2 emissions, and chemical and material use.

$$EF = EF_{direct} + EF_{indirect} \qquad (1)$$

EF_{direct} is the EF for direct land occupation, and $EF_{indirect}$ is the EF for indirect land occupation.

2.3 GHG emitted sources and calculation

In this study, we established a "global warming assessment of palm oil production" model based on the obtained data, and we determined the system boundaries of the model calculation, as shown in Fig.3. The standard Intergovernmental Panel on Climate Change (IPCC) conversion factors was used to convert GHGs into carbon dioxide equivalent (CO_2eq). The crop cycle length is fixed at 25 years. In this study, we assessed in detail various factors involved in the production of palm oil, including transportation, fertilizer use, and the amount of CH_4 generated from palm oil plant wastewater, and we linked the amount of nitrogen fertilizer used with the output of FFBs. The net amount of carbon dioxide per hectare per ton of palm oil and the net amount of overall CO_2 emissions from the Thai palm oil industry were calculated [4,7].

E_{FFB} come from FFB production and FFB transport, as shown in Eq. (2).

$$E_{FFB} = E_{FFB,production} + E_{FFB,transport} \qquad (2)$$

The greenhouse gases emissions from the wastewater treatment system were calculated in this study by the UNFCCC method [8]. In this study, we mainly calculated for the situation where there is no biogas recovery device in the wastewater treatment system. Therefore, in this case, only $E_{Wastewater\ treatment}$ is calculated as

$$E_{Wastewater,treatment} = \sum_i Q_{ww,i,y} \times COD_{removed,i,y} \times MCF_{ww,treatment,BL,i} \times B_{O,ww} \times UF_{BL} \times GWP_{CH4} \ . \qquad (3)$$

The conversion formula of the greenhouse gas carbon equivalent is

$$e_p\left[\frac{kgCO_2eq}{ton}\right]=\frac{(E_{Energy}+E_{FFB}+E_{Chemical}+E_{Wastewater})\left[\frac{kgCO_2eq}{yr}\right]}{yield\ product\left[\frac{ton}{yr}\right]}. \quad (4)$$

2.4 Data collection

In this study, we analyzed the CPO production capacity of 32 palm oil processing plants in Thailand. When calculating greenhouse gas emissions of palm oil processing, we used the numbers of inputs and outputs involved in the transportation process and waste disposal. EFs represent the value of converting these quantities into greenhouse gas emissions. These data were from the Thai National LCI database, Ecoinvent database [9], and literature. In the calculation of the ecological footprint, the life cycle inventory (LCI) data of oil palm plantations were from Thailand's national LCI database. In this study, we merged the data of eastern Thailand and central Thailand.

3 Results and discussion

3.1 CPO extraction process

In the palm oil mill the inputs used for the production of CPO were composed of FFB, diesel oil, electricity and water supply as shown in Table 1. The averaged FFB of 6.04 T (32 mills) was required to produce 1 ton of CPO. For the electricity consumption, two important sources of electricity were supplied to the mills. Firstly, the major supply was produced from the steam turbine generator in the mill in which fibers were used as biomass fuel for the boiler. Secondly, it was supplied from the grid connection.

The CPO production caused a large amount of wastewater. Processing 1 ton of FFB generated average wastewater of about 0.65 m^3 (32 mills). The wastewater treatment plants of the palm oil mills had an average chemical oxygen demand (COD) of raw wastewater, wastewater inflow, wastewater outflow, and treated wastewater from the final pond of 102607, 69984, 13697 and 3157 mg/L, respectively (Table 2).

Table 1: Production of 1 ton CPO

Parameter	Unit	Average [a] GHG emission (32 mills)
Inputs		
Fresh fruit bunches (FFB)	ton	6.04
Water consumption	m^3	7.09
Energy consumption from EGAT	kWh	8.76
Diesel oil consumption	L	3.73
Outputs		
Main product		
-CPO	ton	1
Solid waste		
-EFB	ton	1.33
Wastewater		
-Palm oil mill effluent (POME)	m^3	3.96

[a] Weighted average

Table 2: Characteristics of wastewater from the palm oil mills

Parameter	Unit	Range	Average [a] GHG emission (32 mills)
Palm oil mill effluent (POME)	m^3	9086-206908	102607

COD inflow wastewater	mg/L	62743-114782	69984
COD outflow wastewater	mg/L	3150-29432	13697
COD final pond	mg/L	327-19797	3157

[a] Weighted average

3.2 Greenhouse gas emissions from the palm oil industry

3.2.1 Greenhouse gas emissions from seed cultivation, FFB harvest and CPO production

Table 3 shows the greenhouse gas emissions the four major palm growing regions in Thailand. Greenhouse gas emissions are expressed as CO_2 equivalents emitted per ton of harvested FFBs. The CPO production and processing conditions in the four palm plantation regions are same (the CPO processing plant in the south is closer to the plantation, and the amount of greenhouse gases emitted during transportation is approximately 0). In all these regions, there is no biogas recovery. The amount of greenhouse gases emitted by producing 1 ton of CPO is shown in Table 4.

Table 3: Weighted average life cycle GHG emissions major oil-palm-growing regions

	North	Northeast	Central	South
GHG emissions (kg CO_2eq/t FFB)	141(114-167)	189(126-231)	112(69-149)	93(77-102)

Table 4: Comparative GHG emissions 1 ton of CPO with biogas emissions and without allocation

Output	Boiler emissions	Electricity from grid	Diesel	Mill consumption	Transportation of diesel to mill	Biogas	Total
GHG emissions for 1 ton CPO (without allocation) kg CO_2eq	64.01	0.50	-	12.19	12.11	911.62	1000.43

According to calculations based on available data, palm planting in Southern Thailand has the highest greenhouse gas emission (CO_2 equivalent per ton FFBs), 189 kg CO_2eq/t FFBs. The southern region has the smallest emission of 93 kg CO_2eq/t FFB. From table 4, we can see that for CPO production and processing, the CO_2 equivalent of each ton of CPO produced is 1,000.43 kg, and the greenhouse gas equivalent emitted from the biogas is relatively high. The table also shows the CO_2 eq from by boiler combustion.

3.3 EF in Thailand's palm oil industry

3.3.1 EF of palm plantation (FFBs)

The EF of palm plantation is shown in Table 5. The EF of palm plantations in southern Thailand is the smallest, about 17.58 gha/ha-year. For plantations in northern Thailand, the EF is determined to be 24.59 gha/ha-year. Planted forests in northern Thailand consume the most resources per unit area. The oil palm plantations in northern Thailand have the highest EF, which may be related to water consumption and fuel and chemical use. Planted forests per unit area in the northern provinces require large amounts of water, especially irrigation water. Large amounts of chemicals are used in the central region because cultivators prefer to use herbicides to remove weeds instead of manually removing them in Chonburi Province [2]. The southern provinces consume the lowest resources. The soil and climatic environment in southern Thailand are more conducive to palm tree planting than the northern areas. Therefore, in terms of palm planting, the EFs of plantations from north to south in Thailand are gradually decreasing.

Table 5: EFs of oil palm plantations

Regions	EF of oil palm plantation (gha/ha-year)			
	EF of energy	EF of forest	EF of cropland	Total
North	0.987	23.2	0.402	24.59
Northeast	0.843	21.1	0.402	22.35
Central	0.703	20.8	0.402	21.9
South	0.21	16.97	0.402	17.58
Weighted average	0.686	20.52	0.402	21.6

3.3.2 EF and greenhouse gas emissions FFBs

The maximum EF used for FFB production in Thailand's four palm growing regions was determined. The production of FFBs per unit area in northern Thailand requires relatively larger amounts of fertilizers and irrigation water, whereas that in other regions requires smaller amounts. As shown in Fig. 4, in the palm cultivation and FFB harvesting in Thailand, the southern region has a high overall greenhouse gas emission owing to the extensive planting areas. However, as shown in Table 3, the greenhouse gas emission for every ton of FFBs harvested in southern Thailand is 93 kg, and the EF value per hectare of plantations in the southern region is also the smallest. Overall, the oil palm plantation in southern Thailand requires the least ecological resources and emits the least amount of greenhouse gases per unit area.

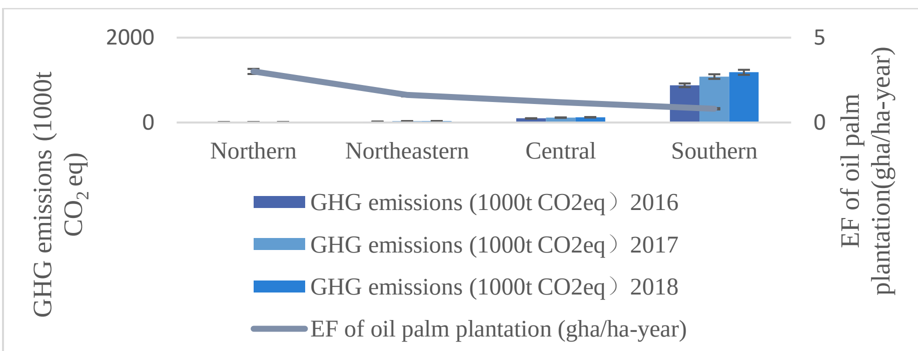

Figure 4: GHG emissions and EF of Thailand's four major oil palm plantation regions (FFB harvested)

3.3.3 Ratio of plantation forest income to EF

The ratio of the economic benefits of plantations to EF represents the benefits of using the land and water ecosystems obtained from oil palm plantations to provide resources and absorb emissions. Table 6 shows the ratio of economic benefits of Thai oil palm industry to EF.

Table 6: Ratios of economic benefits to EF

Plantation	USD/gha (2009-2018)		
	Minimum	Maximum	Average
North	20.7	83.1	39.7
Northeast	23.1	86.4	46.9
Central	25.2	91.1	59.4
South	30.4	107.2	69.3
Average	24.9	115.0	53.9

Table 6 shows the average ratios of economic benefits of oil palm plantations to EF in the northern, northeastern, central, and southern regions from 2009 to 2018, which were 39.7, 46.9, 59.4, and 69.3 USD/gha, respectively. It can be said that the oil palm plantations in the southern region have brought the greatest benefits to planters, because compared with other regions, the ratio of economic benefits to EF of plantation in the southern region is higher, and FFB production is also high. The plantation in the northern region has the lowest profit per hectare and the lowest yield, considering that plantation in the northern region requires large amounts of water and fertilizer. Because the soil and climatic environment in southern Thailand are more conducive to palm tree planting than those in the north, Thailand's water and fertilizer inputs from the north to the south are gradually decreasing. The economic value of palm planting basically conforms to this frond, that is the economic value per unit area increases from the north to the south.

4 Conclusions

Thai oil palm plantations are mainly distributed in the southern region, followed by the central region. The northern and northeastern regions are relatively small, accounting for only 13.6% of the total area. The CO_2 equivalent per ton of FFB harvested in Thailand's plantations is about 133.8 kgCO_2eq, and those in the north, northeast, center, and south are 141, 189, 112, and 93 kgCO_2eq, respectively. The CO_2 equivalent per ton of CPO produced by the palm oil processing plant in Thailand without using a biogas recovery device is 1000.43 kgCO_2eq. The total CO_2 equivalent of the oil palm industry in Thailand is about 4.342 million tons, accounting for about 1.44% of Thailand's annual carbon emissions, of which 29,800 tons is in the north, 71,000 tons in the northeast, 355,300 tons in the center, and 3,886,100 tons in the south. Although the total palm plantation area in the southern region is relatively large, the southern region produces the lowest unit CO_2 equivalent during palm tree planting and harvesting palm fresh fruit bunches. The average EF of Thai oil palm plantations is 21.6 gha/ha-year. The ratio of earnings to EF is 53.9 USD/gha. The ratio of revenue to EF in the southern region is 69.3 USD/gha. The EF of oil palm plantations in the southern region is relatively small, and the ratio of income to EF is the highest. This means that the southern region of Thailand has lower investment in oil palm planting than the other regions in Thailand. Palm planting requires greater investments on chemical fertilizers and energy, its cost is higher, and its CPO price is not competitive.

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