Life Cycle Assessment of Palm Empty Fruit Bunch Utilization for Power Plants in Thailand

Sarunya Chanlongphitak[1], Seksan Papong[2,*], Pomthong Malakul[3], Thumrongrut Mungcharoen[4]

***Abstract*—**This study aims to evaluate the environmental impacts of electricity production using palm empty fruit bunch as fuel in southern Thailand based on life cycle approach. The system boundary includes the oil palm plantation and harvesting, crude palm oil (CPO) production, electricity production, and all transportation activities throughout its life cycle from "cradle-to-gate". Inventory data were collected from palm oil mills and biomass power plants located in Suratthani province, south of Thailand. SimaPro software with CML baseline 2000 method used to evaluate the relevant environmental impacts such as global warming potential (GWP), acidification potential (AP), eutrophication potential (EP), and human toxicity potential (HTP) based on a functional unit of 1 MWh of electricity. The results found that the electricity production stage has highest environmental impact followed by oil palm plantation, CPO extraction and transportation except EP. In EP impact category, oil palm plantation has highest impact more than electricity generation, CPO extraction, and transportation, respective.

***Keywords*—** Life Cycle Assessment, Palm Empty Fruit Bunch, Power Generation

I. INTRODUCTION

THAILAND is the top palm oil producer, is ranked third in the world after Indonesia and Malaysia, respectively, with a total area of 654,400 ha of oil palm plantation and the yield about 18.96 tonnes of fresh fruit bunch (FFB) per hectare [1].

Biomass is the production of industrial-agricultural waste such as rice husk, bagasse, palm solid residues and so on [2]. In Thailand have large amount of biomass available from industry especially empty fruit bunch (EFB). The amount of biomass available from the stated EFB is listed in Table I.

In the palm oil mill, after oil extraction process there will be large amount of palm solid residues biomass. Especially EFB which is prevalent in Southern of Thailand, during the year 2013 has average quantities up to 2,385,765 tonnes. Only 97,049 tonnes was still left unusefully. That has a heating value can be used as fuel for electricity production. When calculating the heat capacity, this can be a potential capacity up to 46.47 MW per year [3].

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TABLE I
THE AMOUNT OF BIOMASS AVAILABLE OF 2013 IN THAILAND

Biomass available from industry	Quantity (T)	Heat capacity (cj)	Potential oil eq. (ktoe)	Capacity (MW)
Empty Fruit Bunch	9.70E+05	7.03E+06	1.67E+02	4.65E+01
Rice Husk (in-season)	3.11E+05	4.21E+06	1.00E+02	2.79E+01
Rice Husk (off-season)	1.13E+05	1.52E+06	3.61E+01	1.01E+01
Bagasse	2.00E-02	1.00E-01	0.00E+00	0.00E+00
Cob	1.03E+05	9.95E+05	2.36E+01	6.58E+00
Sawdust	5.71E+03	3.75E+04	8.90E-01	2.50E-01
Coconut Bunch	2.72E+04	4.19E+05	9.95E+00	2.77E+00

Source: Map Tree Potential of Biomass potential in Thailand [3]

Currently, petroleum price has increased accordingly to the fuel price mechanism in the global market. As a result, industrial sectors, instead of using petroleum fuel, used biomass fuel to replace petroleum fuels to reduce cost of production and to eliminate waste in the plant [4].

Thailand has an interest in the use of alternative energy sources more. Thailand has conducted research for support the EFB to bring it back to beneficial use. In the south of the country is used it as fuel to generate electricity [5]. Therefore, this research aims to study the environmental impact of EFB utilization in electricity generation.

Technology for produce electricity in this study is the steam turbine generator. Because of this technology is actually used to bring the EFB used as fuel in Thailand. The benefit expected from this research is the quantification of the environmental impact of EFB as a fuel in electricity production such as greenhouse effect, acidification, eutrophication, and human toxicity. This result can use for decision support to improve the production processes for less environmental impact.

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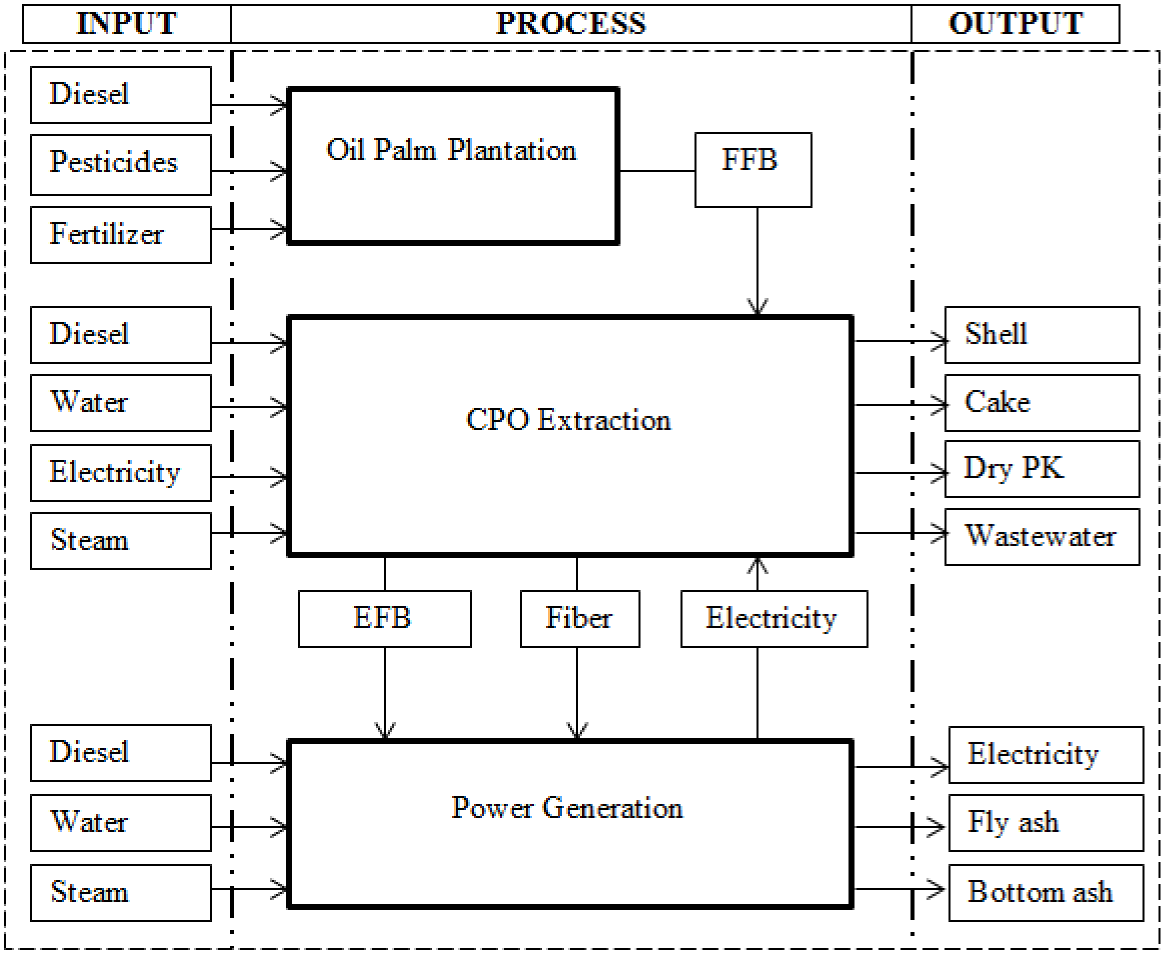

Fig. 1 System boundary of this study with allocation

II. Methodology

LCA is a technique to assess the environmental aspects and potential impacts associated with a product or service. The International Organization for Standardization (ISO) has described the framework of LCA in four steps comprising the step of defining the goal and scope definition, quantify of energy and raw material requirements and other releases for the entire life cycle of a product (inventory analysis), evaluation of potential human health and environmental impacts of the natural resources and releases identified during the LCI (impact assessment) and systematic technique to identify, quantify, check, and evaluate information from the results of the LCI (interpretation) [6].

In this study, LCA technique is conducted based on the ISO 14040 series. The SimaPro 7.3.3 with CML baseline 2000 method used for data processing and assess the environmental impacts.

A. Goal and Scope Definition

1. Goal

The goal of this study was to evaluate the environmental impacts of electricity generation from EFB based on life cycle perspective.

2. Functional Unit

The functional unit (FU) of this study was defined as 1 MWh of electricity produced from EFB.

3. Scope and System Boundary

The scope includes the oil palm plantation and harvesting, crude palm oil production, electricity production, and all transportation activities throughout its life cycle from “cradle-to-gate”. Fig. 1 shows the system boundary of this study.

4. Allocation Procedure

In this research, the life cycle stages of an EFB power plant are as follows:

First, oil palm plantation is the process of acquiring raw materials. The main product of this process is oil palm fruit or fresh fruit bunch (FFB).

Second, CPO extraction is the process for separating palm oil via four stage as follow; 1) sterilization 2) stripping 3) oil extraction and 4) clarification. EFB will be separated in the stripping stage.

Finally, power generation of this study is used steam turbine generation technology. The environmental burdens from all stage are allocated based on energy content. The proportions of allocation factor are presented in Table II.

TABLE II
ALLOCATION FACTOR OF EFB AS FUEL

Type of Fuel	Energy Content (MJ-Ton^{-1})	Allocation Factor (%)
EFB	8036	13
Palm Fiber	14,166	13
Palm Shell	16,639	6
Palm Kernel	25,947	22
Crude Palm Oil	39,212	46

Source: R. Kaewmaia, A. H-Kittikunb, and C. Musikavonga (2012) [7]

Table II shows the energy content factor for allocation of EFB production chain.

B. Life Cycle Inventory (LCI)

The all data that use for evaluate the environmental impact in this study as shown in Table III. For almost all process of this study are primary data from site survey except oil palm plantation and harvesting stage is secondary data from national LCI database which conducted by the Life Cycle Assessment Laboratory of National Metal and Materials Technology Center (MTEC).

TABLE III
SOURCE OF DATA FOR EFB UTILIZATION AS FUEL

LCI Process	Sources of Data	
	Primary Data	Secondary Data
Plantation and harvesting		✓
CPO production	✓	
Electricity generation	✓	
Transportation	✓	

1. Oil Palm Plantation

In Thailand, most of oil palm plantations are grown in the south of country, particularly in Surat Thani, Krabi, and Chumphon province, respectively. Therefore, the south region of Thailand is indicated as the highest potential region for use in this case study.

The inventory data of oil palm plantation in this study is secondary data from National Metal and Materials Technology Center. The site area of plantation is Krabi and Surat Thani provinces which located in the south of Thailand [8].

2. EFB Production

EFB is a solid waste residue generated from palm oil mills after extract oil out. EFB is in the process of extracting crude palm oil, through the oven with steam to palm off the pole easily. The EFB is stripping by a separate machine from the palm fruit bunches. EFB is being singled out in this step [9, 10]. The utilization of EFB as fuel for produce electricity in case study used biomass energy 23 GJ-MWh-1

3. Transportation

Transportation involve in the life cycle of EFB utilization for electricity production. FFB transport from farm to CPO mill in ranged 50-100 km (round-trip) and EFB transport to power plant in ranged 100-150 km (one way). Fuel consumption data were collected for different transportation modes by site survey, estimation, and calculations.

4. Power Generation

Steam turbine electricity generation is technology that used in this case study. Electrical generation using steam turbine generator involves three energy conversions: extracting thermal energy from the fuel and using it to raise steam, converting the thermal energy of the steam into kinetic energy in the turbine, and using a rotary generator to convert the turbine's mechanical energy into electrical energy [11]. The production process showed in Fig. 2.

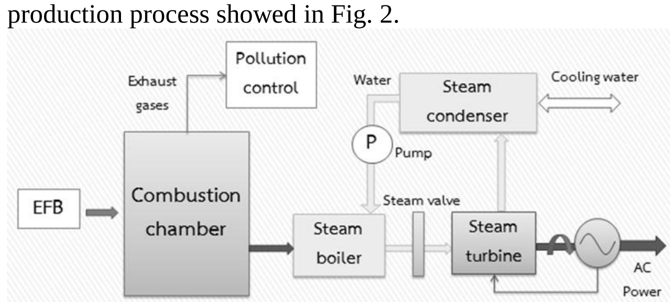

Fig. 2 Biomass power plant based on steam turbine generator

EFB is high moisture content that can cause the effect with boiler and another part of electricity production. As a consequence, EFB preparation is need to shredding EFB fuel.

C. Life Cycle Impact Assessment

The environmental impact categories were selected in this study consists of global warming potential (GWP100), acidification potential (AP), eutrophication potential (EP), and human toxicity potential (HTP). The criteria for evaluating the environmental impacts were selected from environmental problems that significantly in this case study.

D. Life cycle Interpretation

The interpretation of results can provide an explanation of the relationship between resource usage and impacts generated from different processes of power production from EFB.

E. Assumption & Limitation

Emission from derivative production of CPO is not included in this study. Machinery and infrastructure of all technologies are not included. This research is considering with only input materials flows. Percentage of EFB and fiber that use in power generation process are 89% and 11%, respectively. Calculating that mass allocation of EFB is 13%. Emission factor are use from this case study from IPCC (2006) [12] and EMEP/EEA (2013) [13]. Conversion ratio of biomass fuel for this study can show in Table IV.

TABLE IV
CONVERSION RATIO OF EFB UTILIZATION AS FUEL FOR 1 MWH

Type of Fuel	Conversion Ratio	Unit
EFB	3.206	tonne
Fiber	0.415	tonne

III. RESULTS AND DISCUSSIONS

In this study, LCA technique is conducted based on LCA method in the ISO14040 series. The impact assessment was compiled by using SimaPro v7.3.3 software with the CML 2 baseline 2000 method.

A. Process Analysis

The computation of environmental impacts is based on the air emissions released during the life cycle of EFB fuel for power generation. For all process from EFB fuel electricity generation, the highest impact for all categories considered acidification, eutrophication, global warming, and human toxicity comes from power generation process. Details for each impact category are discussed in the sections below.

1. Global Warming Potential (GWP)

GWP is related to emissions of greenhouse gases to air. Factors are expressed as global warming potential for time horizon 100 years (GWP100), in kg carbon dioxide equivalents [14].

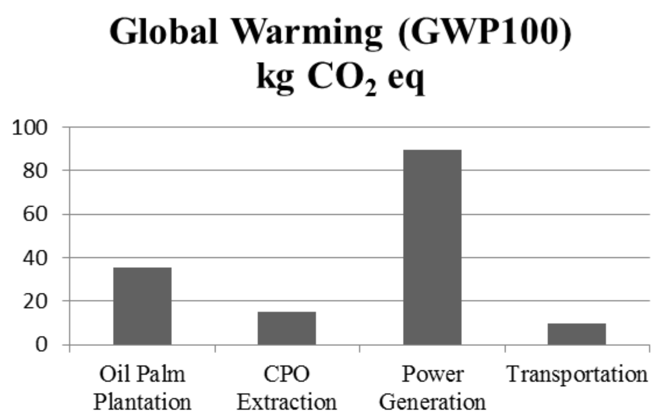

Fig. 3 Global warming potential impact assessment of all stages from 1 MWh of EFB utilization for power generation.

By considering the whole life cycle of the EFB utilization for power plants, there is a significant potential resulting from power generation, oil palm plantation, CPO extraction, and transportation. From Fig. 3, the GWP are 35.38, 14.89, 89.51, and 9.92 kgCO_2 eq per MWh, respectively.

2. Acidification Potential (AP)

AP is expressed as kg SO_2 equivalents [14]. AP is contributed by NO_x and SO_2 emissions. For the EFB utilization for power generation process, AP is high significant value in the power generation stages followed by oil palm plantation, CPO extraction, and transportation, respectively. Fig. 4 compares all stages of AP impact assessment from EFB utilization. The sorts of most AP impact are 0.515, 0.312, 0.093, and 0.066 kg SO_2 eq per MWh, respectively.

3. Eutrophication Potential (EP)

EP is based on the stoichiometric procedure of Heijungs (1992), and expressed as kg PO_4 equivalents [14].

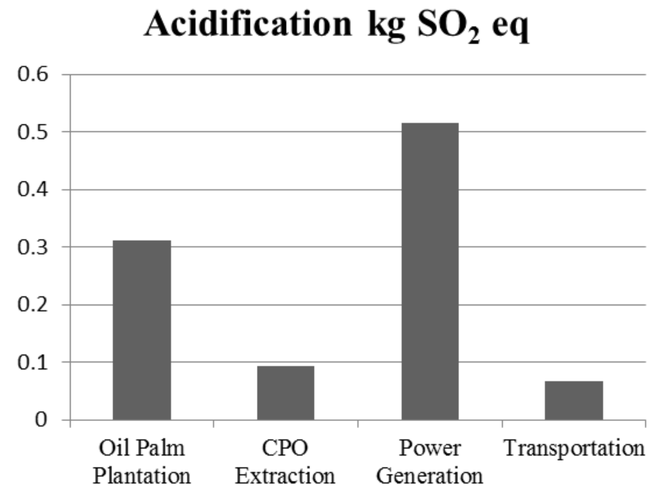

Fig. 4 Acidification impact assessment of all stages from 1 MWh of EFB utilization for power generation

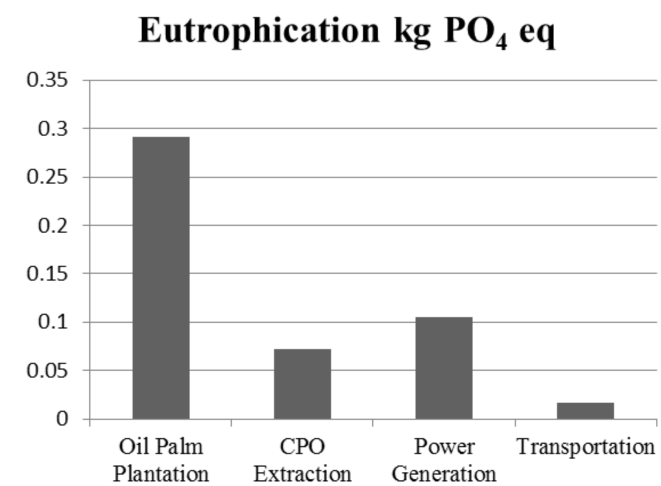

Fig. 5 Eutrophication impact assessment of all stages from 1 MWh of EFB utilization for power generation

From this impact category, oil palm plantation stage is most significant potential more than all stages. EP can cause high value from emissions of nutrients substance to air, water and soil. For instance, oil palm plantation process has a lot of nutrients from fertilizer. From this reasons, oil palm plantation is high significant impact of eutrophication. See Fig. 5, sort of most EP impact are 0.291, 0.104, 0.073, and 0.016 kg PO_4 eq per MWh, respectively.

4. Human Toxicity Potential (HTP)

This category concerns effects of toxic substances on the human environment. Health risks of exposure in the working environment are not included. For each toxic substance HTP's are expressed as 1, 4-dichlorobenzene equivalents [14].

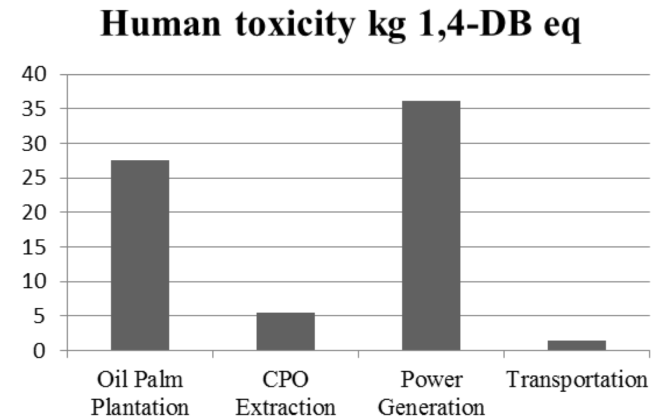

Fig. 6 Human toxicity impact assessment of all stages from 1 MWh of EFB utilization for power generation

Fig. 6 shows the HTP impact assessment of EFB utilization in power generation chain. In this impact category, power generation stage is significant potential more than oil palm plantation, CPO extraction, and transportation, respectively. The HTP impact sort by high potential are 36.18, 27.56, 5.50, and 1.53 kg 1,4-DB eq per MWh, respectively.

B. Comparison with Other Fuel

At the power plant, the type of fuel for power generation is significant to environmental impact. Burning of biomass fuel is environmental friendly than natural gas and coal. Burning natural gas for power generation produces more nitrogen oxides and carbon dioxide [15].

According to Phumpradab *et al.* [16], natural power plant produce has a high significant environmental impact from air emission more than case study. In terms of environmental impact by considering in greenhouse gas emissions found that the biomass power plant is environmental friendly than natural gas. Table V shows the GWP and AP impacts of case study compare with natural gas power plant in Thailand. For both impact categories, EFB utilization for power plants is environmental friendly than natural gas power plants.

TABLE V
COMPARE OF GLOBAL WARMING POTENTIAL AND ACIDIFICATION POTENTIAL OF 1 MWH OF NATURAL GAS POWER PLANT

Impact category	Unit	Case Study	Natural gas power plant [16]
AP	kg SO_2 eq	5.15E-01	7.61E-01
GWP 100	kg CO_2 eq	3.54E+01	5.39E+02

For coal-fired power plant, when coal is burned, carbon dioxide, sulfur dioxide, nitrogen oxides, and mercury compounds are released. Especially sulfur dioxide is high volume from this stage and it can cause acid rain [17]. For that reason, the emission rate is high more than biomass.

TABLE VI
COMPARE OF GLOBAL WARMING POTENTIAL AND ACIDIFICATION POTENTIAL OF 1 MWH OF COAL POWER PLANT

Impact category	Unit	Case Study	Coal-fired power plant (informal) [18]*
AP	kg SO_2 eq	5.15E-01	1.50E+01
GWP 100	kg CO_2 eq	3.54E+01	1.32E+03

Noted*: LCA-NETS Methods

According to Sampattagul *et al.* [18], EFB utilization for power plant is environmental friendly than coal-fired power plant. Table VI shows the GWP and AP of case study compare with coal-fired power plant. The values of both categories show that environmental effect from power generation. For this literature, the data is from the Mae Moh coal-fired power plant that calculated based on the LCA-NETS Method. So there is a possibility that some information may have changed when change the method.

IV. CONCLUSION

The environmental impacts of power generation from EFB based on steam turbine generator technology have been evaluated using LCA technique. The LCA results revealed that EFB utilization for power generation is environmental friendly than fossil fuel power plants in terms of global warming potential and acidification potential. However, EFB utilization in Thailand is not be widespread. Due to EFB fuel is high moisture content and technologies used in Thailand is still in the experimental. Including the benefits of EFB will be used capital-intensive to investment. If such investments should be made in a factory manufacturing operations in the palm oil already, then it is reasonable and less investment in this business.

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