Greenhouse Gas Emission from Dry Extraction of Mixed Palm Oil and Composting and Electricity Generation of By-products from Wet Extraction of Crude Palm Oil

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ชื่อวิทยานิพนธ์ การปล่อยก๊าซเรือนกระจกจากการสกัดน้ำมันปาล์มผสมแบบแห้งและการหมักปุ๋ยและการผลิตไฟฟ้าของวัสดุเศษเหลือจากการสกัดน้ำมันปาล์มดิบแบบเปียก

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บทคัดย่อ

งานวิจัยนี้พัฒนาวิธีการคำนวณค่าการปล่อยก๊าซเรือนกระจกจากกระบวนการสกัดน้ำมันปาล์มผสมแบบแห้ง และกระบวนการผลิตปุ๋ยหมักและกระบวนการผลิตกระแสไฟฟ้าของวัสดุเศษเหลือจากกระบวนการสกัดน้ำมันปาล์มดิบแบบเปียกเป็นวัตถุดิบหลัก การศึกษาได้เก็บข้อมูลโรงงานสกัดน้ำมันปาล์มผสมแบบแห้ง 3โรงงาน โรงงานหมักปุ๋ยชีวภาพ 1 โรงงาน โรงงานผลิตกระแสไฟฟ้าชีวมวล 1 โรงงาน ค่าการปล่อยก๊าซเรือนกระจกจากกระบวนการสกัดน้ำมันปาล์มผสมแบบแห้งโดยไม่มีการปันส่วนมีค่าเฉลี่ย 473 $kgCO_2e$/metric ton (Mt) mixed palm oil (MPO) ค่าการปล่อยก๊าซเรือนกระจกโดยใช้ค่าความร้อนปันส่วนมีค่าเฉลี่ย 290 $kgCO_2e$/Mt MPO, 190 $kgCO_2e$/Mt palm cake และ 172 $kgCO_2e$/Mt fine palm residues ส่วนค่าการปล่อยก๊าซเรือนกระจกโดยใช้ค่ามวลปันส่วนมีค่าเฉลี่ย 236 $kgCO_2e$/Mt of MPO, palm cake และ fine palm residues การได้มาซึ่งผลปาล์มก่อให้เกิดการปล่อยก๊าซเรือนกระจกสูงสุด กระบวนการสกัดน้ำมันปาล์มผสมแบบแห้งไม่มีการใช้น้ำจึงไม่ก่อให้เกิดมลพิษทางน้ำและไม่มีการปล่อยก๊าซเรือนกระจกจากกระบวนการบำบัดน้ำเสีย กระบวนการผลิตปุ๋ยหมักจากทะลายปาล์มเปล่าและกากตะกอนดีเคนเตอร์ปริมาณ 1 ตัน ก่อให้เกิดก๊าซเรือนกระจก 381 $kgCO_2e$ กระบวนการหมักในสภาวะไร้อากาศก่อให้เกิดค่าการปลดปล่อยก๊าซเรือนกระจกสูงสุด 188 kg CO_2e/Mt soil conditioner ส่วนอื่นในการหมักปุ๋ยที่ปล่อยก๊าซเรือนกระจกในปริมาณสูงได้แก่ การใช้สารเคมี และการใช้กระแสไฟฟ้า การเปลี่ยนกระบวนการหมักปุ๋ยและแหล่งจ่ายไฟฟ้าทำได้ยาก การลดการปล่อยก๊าซเรือนกระจกต้องลดการใช้สารยูเรียที่เติมในกระบวนการหมักเพื่อควบคุมอัตราส่วนคาร์บอนต่อไนโตรเจน และปริมาณไนโตรเจนในปุ๋ยหมัก กระบวนการผลิตกระแสไฟฟ้าจากทะลายปาล์มเปล่า เส้นใยปาล์ม และกะลาปาล์ม มีการปล่อยก๊าซเรือนกระจก 303 $kgCO_2e$/MWh ค่าการปล่อยก๊าซเรือนกระจกที่สำคัญเกิดจากการผลิตและขนส่งวัตถุดิบ และกระบวนการบำบัดน้ำเสีย ซึ่งมีค่า 228 และ 72 $kgCO_2e$/MWh ตามลำดับ ค่าการปล่อยก๊าซเรือนกระจกมีค่าสูงสุดจากกะลาปาล์มซึ่งมีค่าตัวคูณการปล่อยก๊าซเรือนกระจกสูง ดังนั้นการใช้เชื้อเพลิงชีวมวลสำหรับหม้อไอน้ำควรลดปริมาณการใช้กะลาปาล์มและเพิ่มปริมาณการใช้ทะลายปาล์มและเส้นใยปาล์ม

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ABTRACT

The calculation methodologies of greenhouse gas (GHG) emission from dry extraction of mixed palm oil and composting and electricity generation of by-products from wet extraction of crude palm oil as major input were developed in this study. Three dry extraction mill, one composting plant, and one electricity generation plant participated in the research. For dry extraction process, the average GHG emission value without allocation was 473 $kgCO_2e$/Mt MPO. The average GHG emission values allocated by lower heating value were 290 $kgCO_2e$/Mt MPO, 190 $kgCO_2e$/ton palm cake, and 172 $kgCO_2e$/Mt fine palm residues, while those of values allocated by mass were 236 $kgCO_2e$/Mt of MPO, palm cake, and fine palm residues. The palm fruits acquisition was defined as the GHG emission hot spot. The dry extraction process does not require water consumption, thus the water pollution is neglected and there is no GHG emission from the wastewater treatment process. The composting of empty fruit bunch (EFB) with decanter cake for producing 1 Mt soil conditioner emitted GHG of 381 $kgCO_2e$. The hot spot of GHG emission during composting process resulted from anaerobic decomposition which emitted GHG of 188 kg CO_2e/Mt soil conditioner. Other hot spots from composting were from chemical and electricity used. It is difficult to change the composting process and source of electricity, the GHG mitigation should be focused on the reduction of urea added to control C:N ratio and maintenance the amount of nitrogen in the soil conditioner. Total GHG emission of the electricity generation using EFB, fibers, and shells as biomass fuel was 303 $kgCO_2e$/MWh. The hot spots were raw material production and transportation and wastewater treatment process that emitted GHG of 228 and 72 $kgCO_2e$/MWh, respectively. The highest GHG emission was obtained from raw material acquisition, especially, from shells that have high EF value. Accordingly, the use of shells should be reduced instead, increasing usage of EFB and fibers as biomass fuel for the boiler.

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Anyanee Bunchai

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ABBREVATIONS AND SYMBOLS

BOD	Biochemical Oxygen Demand
C2G	Cradle to Gate
CH_4	Methane
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
CPO	Crude Palm Oil
DEDE	Best Practice Guide for Eco-Efficiency in Palm Oil Industry
EF	Emission Factor
EFB	Empty Fruit Bunch
EM	Effective Microorganism
FFB	Fresh Fruit Bunch
GHG	Greenhouse Gas Emission
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GWP	Global Warming Potential
H_2S	Hydrogen Sulfide
HFC	Hydro Fluorocarbon
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LHV	Lower Heating Value
MPO	Mixed Palm Oil
MPOB	Official Portal of Malaysian Palm Oil Board
Mt	Metric ton
N	Nitrogen
N_2O	Nitrous Oxide

ABBREVATIONS AND SYMBOLS (CONT.)

NEB	Net Energy Balance
NER	Net Energy Ratio
NEV	Net Energy Value
OER	Oil Extraction Rate
PDD	Project Design Document
PEA	Provincial Electricity Authority
PK	Palm Kernel
PKO	Palm Kernel Oil
PKS	Palm Kernel Shell
PME	Palm Methyl Ester
POME	Palm Oil Methyl Ester
RPO	Refined Palm Oil
SO_6	Sulfur Hexafluoride
SOPRC	Suratthani Oil Palm Research Center
SS	Suspended Solids
TGO	Thailand Greenhouse Gas Management Organization
TS	Total Solids
UNFCCC	United Nation Framework Convention on Climate Change
VFA	Volatile Fatty Acids
VS	Volatile Solids

CHAPTER I

INTRODUCTION

1.1 Background

The capacity of palm oil production in the South East Asia was approximately 38.2 million tons (Mt) in year 2007. This came from Indonesia of 19.3 million Mt Malaysia of 17.7 million Mt and Thailand of 1.17 million Mt (Henson *et al*, 2011). In Malaysia, the by-products from wet extraction process comprised empty fruit bunch (EFB) 22%, palm oil mill effluent (POME) 67%, fibers 13.5%, palm kernel (PK) 6.0% and shells 5.5% (Sulaiman *et al*, 2011). When using fresh fruit bunch (FFB) 6.07 Mt in the wet extraction process, it can produce EFB by mass 19.9%, and decanter cake 2.6% (Kaewmai *et al*, submitted). According to calculation, the palm oil mill in the South East Asia produced by-products in year 2007 including EFB of 7.65 million Mt, decanter cake of 1.15 million Mt and shells of 2.29 million Mt. The palm oil production capacity in Thailand was approximately 9.03 million Mt in year 2010. This lead to the generation of 0.54 million Mt of shells, 1.81 million Mt of EFB and 0.27 million Mt of decanter cake.

At present, the increasing in fossil fuel demand and price leads to development of the alternative energy. Biodiesel as one of the successful alternative energy is in use to mitigate this problem, since, it can be used to substitute diesel or mixed with diesel such as B3, B5 etc. The life cycle of biodiesel production system is oil palm cultivation, palm oil milling, crude palm oil (CPO) refining, biodiesel production, and all transport activities (Silalertruksa *et al*, 2012). In the biodiesel production, CPO or mixed palm oil (MPO) is used as the raw material. The extraction process of CPO and MPO in Thailand can be done by using wet and dry extraction process, respectively. The wet process could generate the greenhouse (GHG) emissions according to the activities such as FFB acquisition and transportation, electricity and fossil fuel production and use as well as the use of chemical and anaerobic process for wastewater treatment. Considering, the wet extraction process in Thailand, total capacity of wet extraction process was

8.16 million Mt FFB per year in year 2010 (Office of Agricultural Economics, OAE, 2010). Kaewmai *et al* (submitted), stated that the total GHG emission from palm oil mill with and without biogas capture system were 1,039 and 1,484 $kgCO_2e$/Mt CPO respectively. A wet extraction process could emit GHG approximately 2.8-19.7 $kgCO_2e$/kg palm oil (Reijnders and Huijbregts, 2008). For the dry extraction process, MPO is the main product where as the palm cake and fine palm residues are co-products. Palm cake and fine palm residues can be utilized in the feed stock production and composting process. Importantly, the dry extraction process does not use water. Thus, it does not produce the water pollution and there is no GHG emission due to the wastewater treatment process.

The utilization of by-products and waste from wet extraction process had a significant development. Currently, EFB can be used for many proposes such as mushroom cultivation, biomass fuel for electricity generation, raw material for composting, etc. Decanter cake also can be utilized in mushroom cultivation, soil conditioner material, feed stock production, composting, etc. However, the effective method for utilization of EFB in Thailand is to use EFB as biomass fuel in electricity generation plant. Presently, there are 2 electricity generation plants using biomass fuel with capacity of 9.5 MW and 9.9 MW (Project design document (PDD), Saraf Energy EFB to electricity project, 2006 and Surat Thani Biomass Power Generation Project in Thailand 2007). For decanter cake, it is successfully to be used as raw material in the composting plant. The utilization EFB with decanter cake in composting plant is considered as a part of palm oil chain.

In order to obtain sustainable palm oil development, environmental impacts from electricity generation process by EFB and composting process by EFB and decanter cake such as solid waste, wastewater, and greenhouse gas (GHG) emission must be determined and reduced. GHG including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbon (HFC), and sulfur hexafluoride (SO_6) has been considered worldwide as a prominent cause of global worming. Even though, the production of EFB and decanter cake can be considered as carbon neutral, however, the acquisition of other raw material, transportation, fossil fuel used, processing and waste disposal in the electricity generation plants by EFB and composting plant of EFB with decanter cake could emit GHG.

Presently, there are some methods that could be used to determine the GHG emission of the goods, products and the nation (International Organization for Standardization, ISO, 14040, and 14044, 2006, Intergovernmental Panel on Climate Change, IPCC, 2006). There are some previous studies on the GHG emission from palm oil industry, especially, for the wet extraction process (Reijnders and Huijbregts, 2008; Kaewmai *et al*, submitted article). However, there are no specific methods for calculating the GHG emissions and no GHG emission values for the dry extraction process of MPO, composting and electricity generation process. The objectives of this research, therefore, aimed to develop methodology of GHG calculation and to determine GHG emission values of dry extraction process, composting and electricity generation processes that use biomass from palm oil mill as a major raw material.

1.2 Objectives

1.2.1. To develop methodology of GHG calculation of dry extraction process, and composting and electricity generation processes that use waste and by-products from wet palm oil mill as a major raw material.

1.2.2. To determine GHG emission values of dry extraction process, composting and electricity generation processes that use waste and by-products from wet palm oil mill as a major raw material.

1.3 Scope of study

1.3.1. To develop methodology of GHG calculation and to determine the GHG emission value for the conversion of palm fruits to MPO by dry extraction process.

1.3.2. To develop methodology of GHG calculation and to determine the GHG emission value for the conversion of EFB and decanter cake from wet palm oil mill by anaerobic composting process to produce the soil conditioner.

1.3.3. To develop methodology of GHG calculation and to determine the GHG emission value for the electricity generation by using EFB, fibers, and shells from wet palm oil mill as raw material.

1.3.4. To use the concept of life cycle assessment (LCA) based on cradle to gate (C2G) evaluation.

1.3.5. To determine options for reducing the GHG from dry extraction process of MPO and composting process and electricity generation process from waste and by-products of wet palm oil mill.

1.4 Benefit of this study

1.4.1. To obtain the methodology of GHG calculation for dry extraction process of MPO and composting process and electricity generation process from waste and by-products of wet palm oil mill.

1.4.2. To establish the GHG emission values of dry extraction process of MPO and composting process and electricity generation process from waste and by-products of wet palm oil mill.

1.4.3. To obtain options for reduction of GHG emissions from dry extraction process of MPO and composting process and electricity generation process from waste and by-products of wet palm oil mill.

CHAPTER II

BACKGROUD AND LITERATURE REVIEWS

2.1 Life cycle of palm oil

The life cycle of palm oil from plantation to biodiesel production and use is show in figure 2.1. The production of palm oil composes of plantation and palm oil extraction. The major processes are palm oil plantation, crude palm oil (CPO) extraction and palm oil refinery, and transesterification into biodiesel. There are two kinds of extraction, wet and dry extraction processes. The extraction by wet process will get CPO, palm kernel (PK), and shells as products. The empty fruit bunch (EFB), fibers and decanter cake are wastes of wet extraction process. While the extraction by dry process will get mixed palm oil (MPO), palm cake, and fine palm residues as products. The biodiesel production includes refined palm oil transport, electricity production, catalyst production, methanol production, and transesterification into biodiesel (Wicke *et al*, 2008; Papong *et al*, 2010).

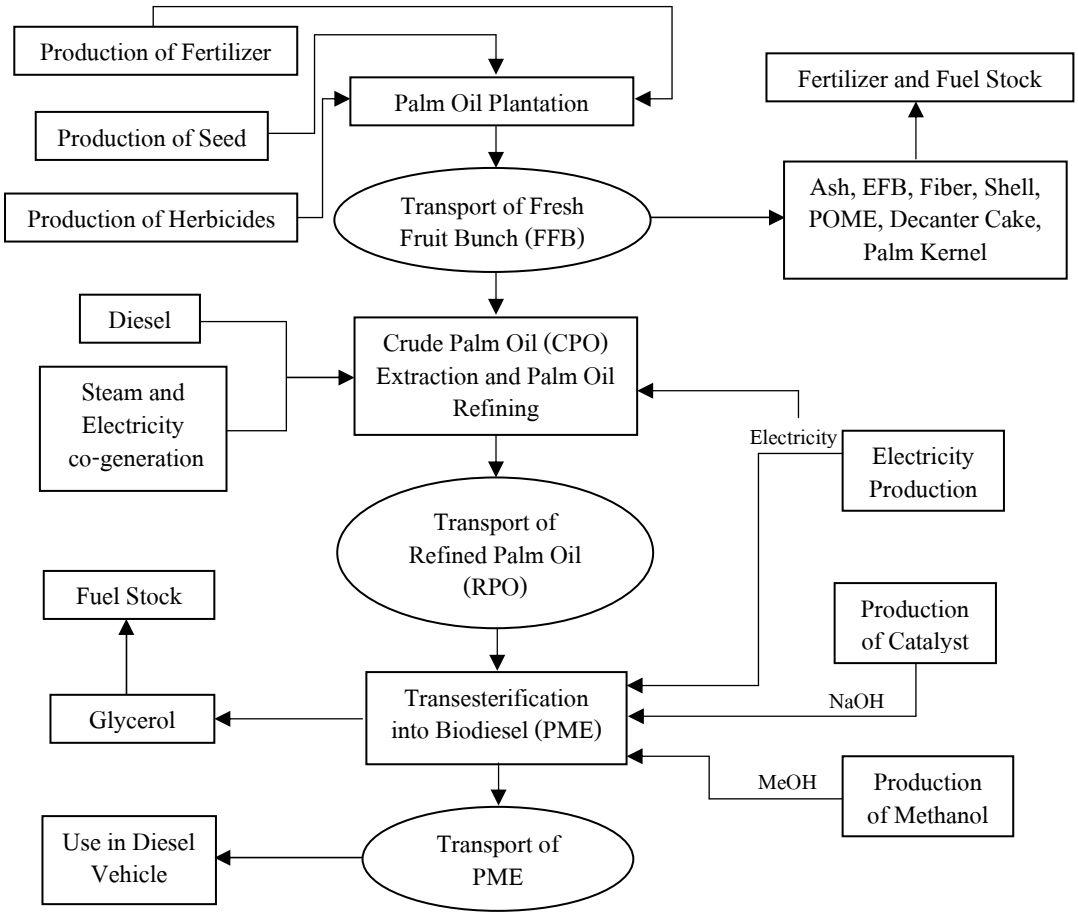

Figure 2.1 Life cycle of palm oil (Pleanjai *et al*, 2009).

2.2 Palm oil plantation

The life of palm oil trees have 25 years. The fresh fruit bunch (FFB) yield in Thailand was 17.5 tons (Mt) FFB/hectare. The greenhouse gas (GHG) emission from palm oil plantation and harvesting occurred from land conversion 60%, fossil fuel consumption 13%, and fertilizer use 13%. The GHG emission from palm oil cultivation associated diesel 1.0 gCO_2e/MJ, seed and nursery 0.1 gCO_2e/MJ, nitrogen fertilizer 15 gCO_2e/MJ, other fertilizer (P, K, Mg, B) 4.6 gCO_2e/MJ, pesticides and herbicides 4.6 gCO_2e/MJ (Pleanjai *et al*, 2009; Hassan *et al*, 2011). Souza *et al* (2010), studies GHG emission balance found that fertilizer 1,165.08 $kgCO_2e/ha$, pesticides 1,220.27 $kgCO_2e/ha$, and fuel 274.54 $kgCO_2e/ha\text{-}yr$ (Souza *et al*, 2010). The study on

GHG emission of palm oil cultivation in Thailand (Krabi, Chonburi, and Pattumthani) found that the hot spot occurred from fertilization. The fertilizer production and nitrogen fertilizer application results in nitrous oxide (N_2O) emissions (Sianjaeo *et al*, 2011).

2.3 Palm oil production

In general, the palm oil extraction consist wet and dry extraction processes. The raw material of wet extraction process is FFB. These products of wet extraction are CPO, PK, and shells. The raw material of dry extraction process is palm fruits. The product of dry extraction is MPO, while palm cake and fine palm residues are by-products. In 1996, outputs from the wet extraction process are CPO of 25-28%, EFB of 20-30%, palm press fibers (PPF) of 12-13%, and PK of 6.8-7.4% (Prasertsan. and Prasertsan, 1996). In 2008, the outputs from FFB processing included CPO of 15-18%, shells of 5-6%, kernel of 5-6%, palm fibers of 12-14%, and EFB of 25-17% (Department of Agriculture, DOA, 2008). Papong *et al* (2010), studied on palm oil production found that the main product was CPO, 0.18 kg/kg FFB and the co-product was palm kernel oil (PKO), 0.036 kg/kg FFB.

2.4 Palm oil extraction process

In Thailand, there are two extraction process of palm oil.

2.4.1 Wet extraction process; Most factories used the wet extraction. Figure 2.2 shows the diagram of wet extraction process. The wet extraction of palm oil from FFB involves five major sections:

(1) Primary production process: The FFB are harvested and transported to the palm oil mill by trucks. After that they were sterilized in an autoclave with the application of steam at 120 to140 °C at 3.0-3.5 bar, for about 75 to 90 min. The sterilized bunches are loaded into a rotary drum thresher where the fruits are separated from the bunch stalk EFB. The separated fruits are carried into digesters and mechanically converted into an extractable oily mash and fed into a continuous double screw press system where the oil is extracted. The

extracted crude palm oil is collected and flowed to the oil room section. The remaining press cake is transported to a dry section.

(2) Oil room: The crude palm oil from the presses is a mixture of palm oil 25 - 35%, water 45 - 55% and fibrous material varying in proportions. First screening, a small amount of hot water is added to the raw oil and passed through a vibrating screen to separate fibrous particles. The oil after sieving is separated sand from the oil by a sand cyclone to. Oil floats to the top of the tank and is collected by a funnel, and flows into the crude oil tank. The final purification step is done by centrifugation of the crude oil from the settling tank to remove water and fine suspended solids. After centrifugation the crude oil still contains water, which is removed by a vacuum evaporation system. The dried crude oil is kept in storage tanks before selling to on oil refinery. The sludge from the settling tank is collected in the sludge tank and subsequently treated to recover oil.

(3) Dry section: The remaining press cake is transported to a dry section. This section consists of fiber-nut separation, nut cracking, shell-kernel separation, and kernel drying processes. A fiber-nut separation system consists of air clarifiers and cyclones for drying and separating the nuts and fibers. Fiber is removed from the nut in the air cyclone. The fibers are then blown through a cyclone to the boiler house where it is used as fuel. The nut is cracked by a ripple mill and the kernel and the shells are separated by a clay water bath. The shells are by-products of this step. The produced kernel is dried to reduce its moisture to prevent molding, and subsequently stored in a silo. This kernel could be pressed inside the factory to produce CPKO or directly sold to other palm kernel mill plant.

(4) Wastewater treatment system: Wastewater from the decanter/separator is discharged to wastewater treatment plant. The traditional practice uses waste stabilization ponds which consist of anaerobic ponds, aerobic ponds and retention ponds for treating the wastewater. The treated wastewater is discharged into palm oil plantation fields or stored in the retention ponds. Currently, the wastewater treatment is upgraded to biogas system and biogas is used to generate the electricity by gas engine. The produced electricity is used in the factory and the excess electricity is sold to Provincial Electricity Authority (PEA), Thailand by grid connection. The treated wastewater from biogas plant is flowed to the stabilization ponds. The treated

wastewater from stabilization ponds is discharged into palm oil plantation fields or stored in the retention ponds.

(5) Utility: In the utility section, it consists of the water supply process and electricity generation. The palm oil mill commonly uses river or reservoir water as raw water supply. Water supply is treated by the demineralization process before feeding to boiler. As mentioned earlier, fibers is used as the bio-fuel in the boiler to produce steam to generate electricity using in the mill and to sterilize FFB and to digest palm fruits in the digestion process. However, in some plants there is the diesel generator to generate the electricity for the start up of the process but some plants start up the process by electricity from PEA.

(6) Transport: Transport is another section that generates the GHG emission due to the use of fossil fuel. For palm oil mill, the transport of raw material (FFB) from plantation to the mill and the transport in the mill are counted.

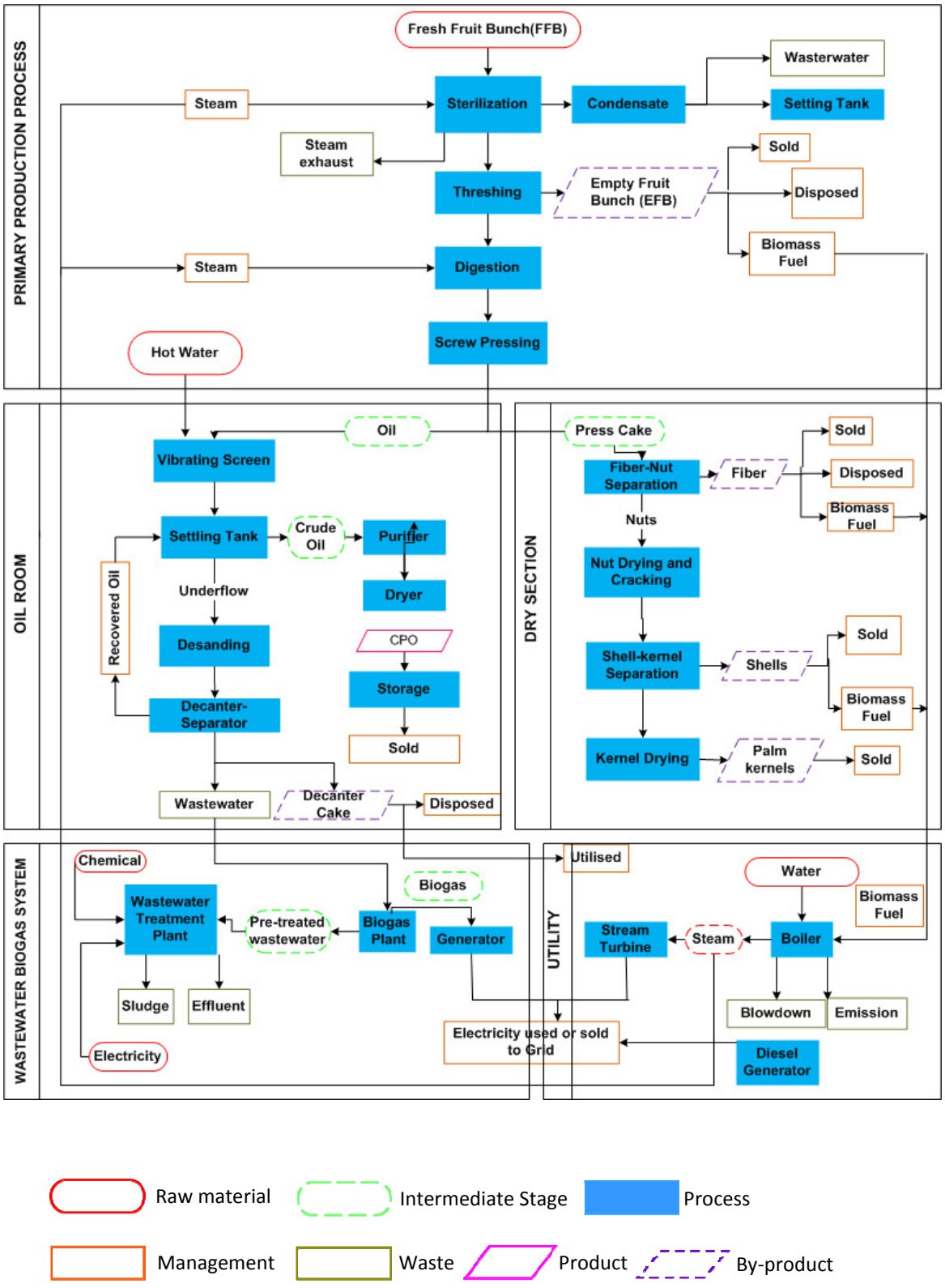

Figure 2.2 Wet extraction process

2.4.2 The dry extraction process. This system was developed for suitable to use in the community. According to this system steam is not used. The advantage of dry extraction process was easy maintenance system, saving energy, no wastewater, and can be applied at community. Developing dry extraction process could be helped reduce waste and pollution. Figure 2.3 shows the diagram of dry extraction process. The dry extraction process of FFB convert to MPO is described as following;

(1) Primary production process: The FEB are harvested and transported to the palm oil mill. FFB is fed to the chopper for cutting the FFB into small pieces. The chopped FFB is fed to the cutting process in order to separate between the fruits and EFB. Then, the fruits and EFB are fed into the coarse separation. Fine separation process is used to separate fruits from palm sepal. The fruits are brought through the hot air rotary drum and drying chamber.

(2) Oil room: The dry fruits are fed into a single screw press system where the oil is extracted. The press cake is a by-product from this process and is sold to animal feed mill. MPO is collected and flows to the filtration process. MPO is kept in storage tank prior to selling to an oil refinery.

(3) Utility: In the utility section of dry extraction process, the electricity is supplied from the PEA. The wood is use for drying.

(4) Transport: Transport is another section that could generate the GHG emission due to the use of fossil fuel. For dry extraction process, the transportation of raw material (FFB) to the mill and the internal transport are taken into accounted.

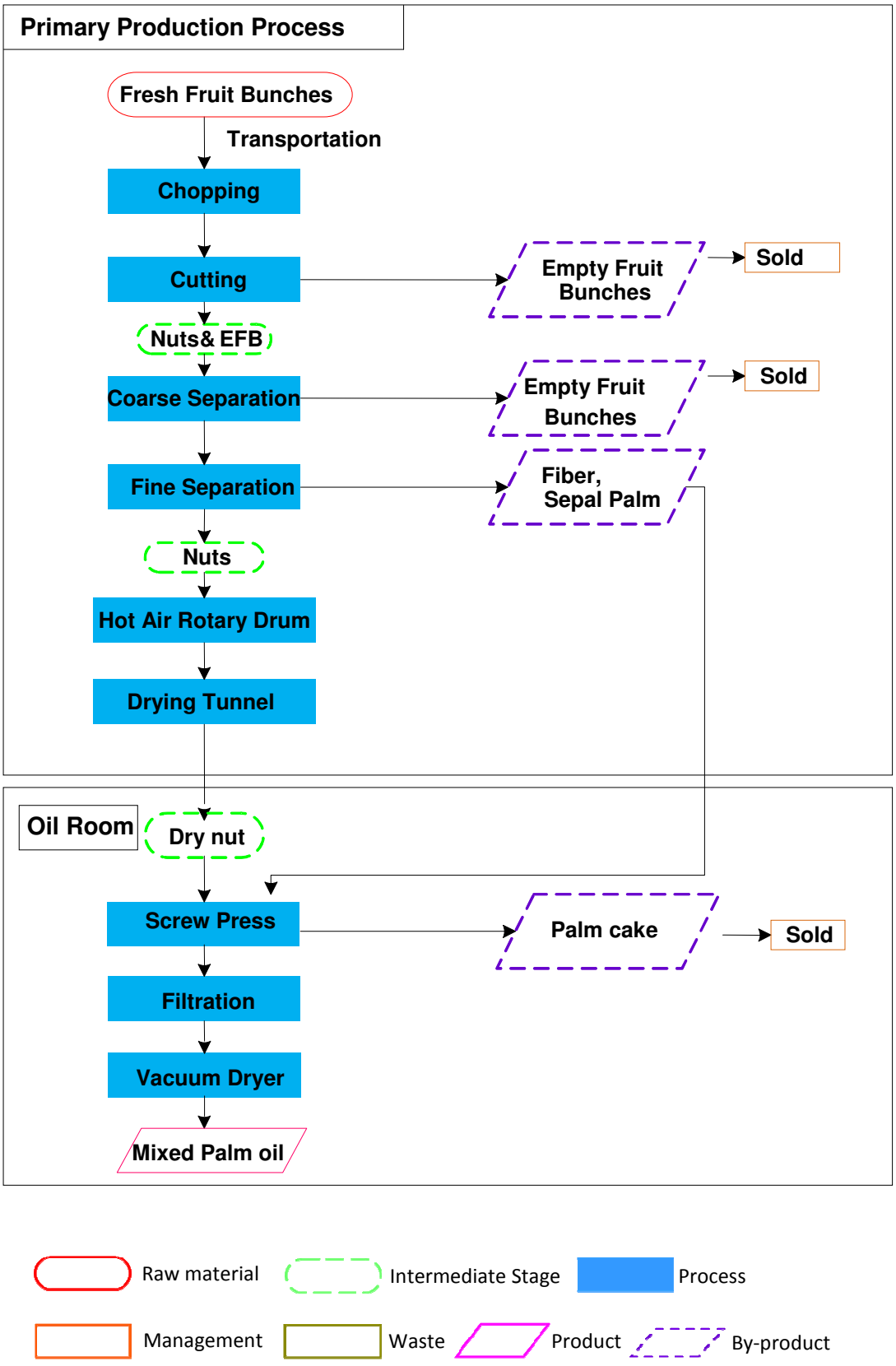

Figure 2.3 Dry extraction process

Table 2.1 Comparison between wet and dry palm oil extraction process.

Compare	**Wet extraction process**	**Dry extraction process**
Raw material	FFB	FFB
Product	CPO PKO Shells	MPO
Utility	Electricity Diesel Water	Electricity Diesel
By-products	EFB Fibers Decanter cake	Palm cake Fine palm residues
Wastewater	Have wastewater	Do not have wastewater

2.5 Utilization of by-products from crude palm oil extraction

The by-products from CPO extraction were EFB, fibers, decanter cake, shells and palm oil methyl ester (POME). The average percentage of output per Mt of FFB from wet extraction process in Thailand were CPO of 16.5%, PK of 3.3%, shells of 6.1%, fibers of 9.5%, EFB of 19.9%, and decanter cake of 2.6% (Kaewmai *et al*, submitted). In Malaysia, the by-products from wet extraction process comprised EFB of 22%, fibers of 13.5%, PK of 6.0%, and shells of 5.5% (Sulaiman *et al*, 2011). EFB contains 42% C, 0.8% N, 0.06% P, 2.4% K, and 0.2% Mg (Krause *et al*, 1994). The biomass from palm oil extraction could be used as fuel to produce electricity (bio-power) and heat (Sumathi *et al*, 2008).

The EFB and decanter cake can be used as fertilizer due to high nutrient content, high moisture content (60%) and easy degradation. (Prasertsan. and Prasertsan, 1996; Pleanjai *et al*, 2009). EFB can be used as biomass fuel for electricity generation as well (Papong *et al*, 2010).

EFB is biodegradable in open windrows at 75 ^{O}C; it converted to methane (CH_4) 50% and N_2O 49% (Stichnothe and Schuchardt, 2011).

Figure 2.4 shows the composting production process from EFB and decanter cake. The composting production process is described as following:

(1) Primary production process: The EFB and decanter cake are transported to composting plant. EFB is brought into shearing and cutting process in order to turn EFB into EFB fiber. For decanter cake, it is mixed with nutrient and effective microorganisms. Subsequently, the decanter cake and EFB fiber are mixed in ratio of 1:5.

(2) Composting: The mixed decanter cake and fiber is mixed with urea and composted under anaerobic condition. The composting pile is turned every 15 days. After two months, the compost is drying at 70-80 ^{O}C.

(3) Sieving: The dried compost is fed to sieving process to separate the organic soil conditioner from the unhydrolyzed material. The organic soil conditioner is packed and kept prior to selling to the clients whereas unhydrolyzed material is brought back to the primary process as the raw material.

(4) Utility: The electricity is supplied from the PEA. The mechanical used in composting process include cutter, mixer, dryer, and sieve.

(5) Transport: Transport is another section that generates the GHG emission due to the use of fossil fuel. For composting process, the transport of raw materials to the plant and the internal transport are taken into accounted.

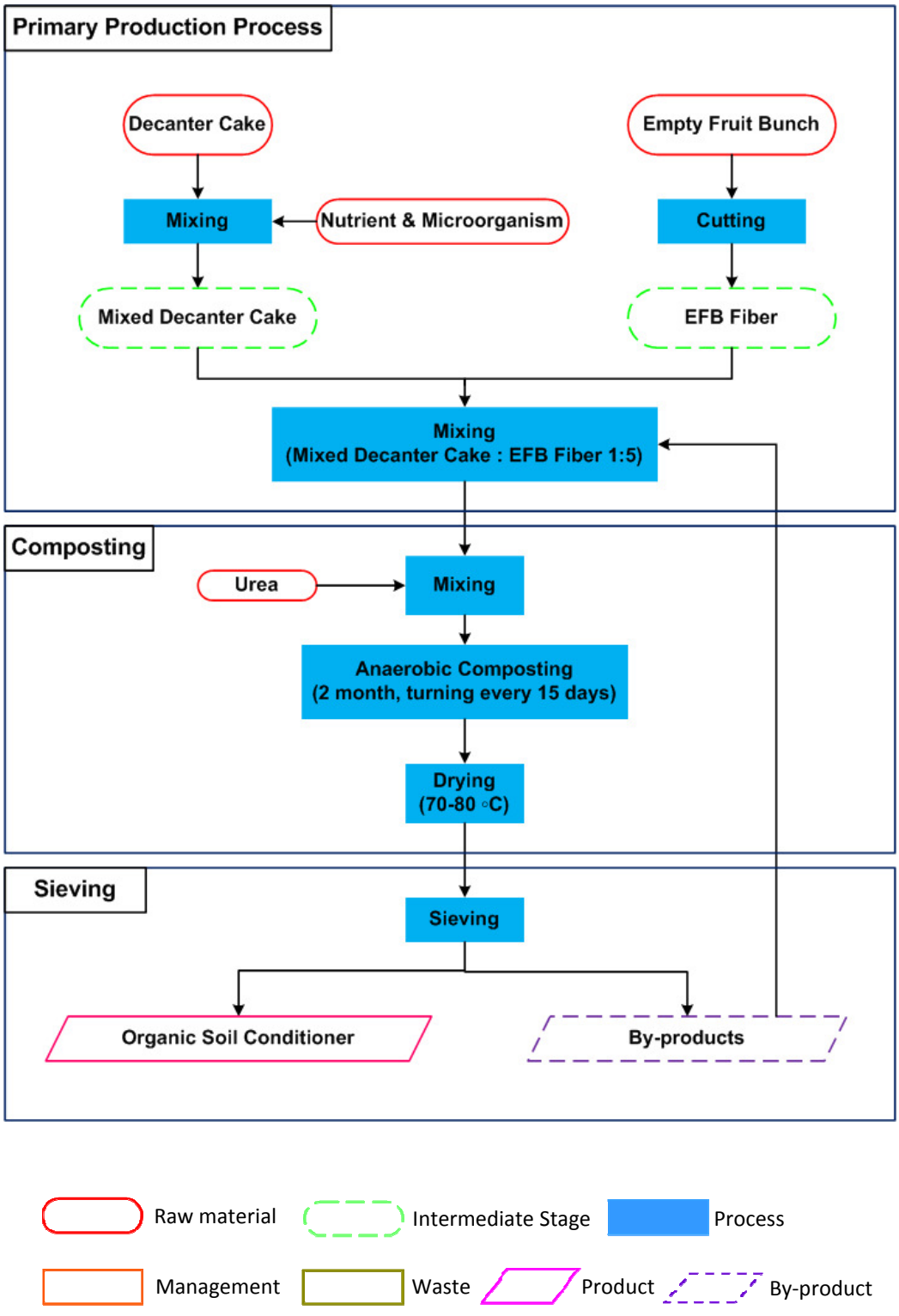

Figure 2.4 Composting production process

The biomass fuel to electricity project in Thailand consisted of two electricity generation plants namely Surat Thani Biomass Power Generation Project and Saraff Energy EFB to Electricity Project. The EFB was used as the major biomass fuel of these two projects. Surat Thani Biomass Power Generation project operated 9.9 MW electricity power generating unit. The biomass power plant of 9.5 MW gross was operated in the Saraff Energy EFB to Electricity Project. The operation of a grid-connected power plant operated mainly on EFB. That consists of a 60 Mt/hour boiler. Boiler was supplied the temperature of 450 °C for steam and steam turbine supplied a rated capacity of 9.5 MW for turbine. The synchronous generator adopts the state of art technology of a microcomputer based excitation system. The main power circuit was a full-bridge thyristor converter with over-voltage protection, together with field discharge circuitry. The system was equipped with generator voltage regulating, field current regulating, constant power factor regulating, and constant reactive power regulating modes. Besides all mentioned equipment and systems, in order to operate the plant at the designed performance with EFB, a new feeding system and dryer were installed (Project design document (PDD), Saraf Energy EFB to electricity project, 2009 and Surat Thani Biomass Power Generation Project in Thailand 2007).

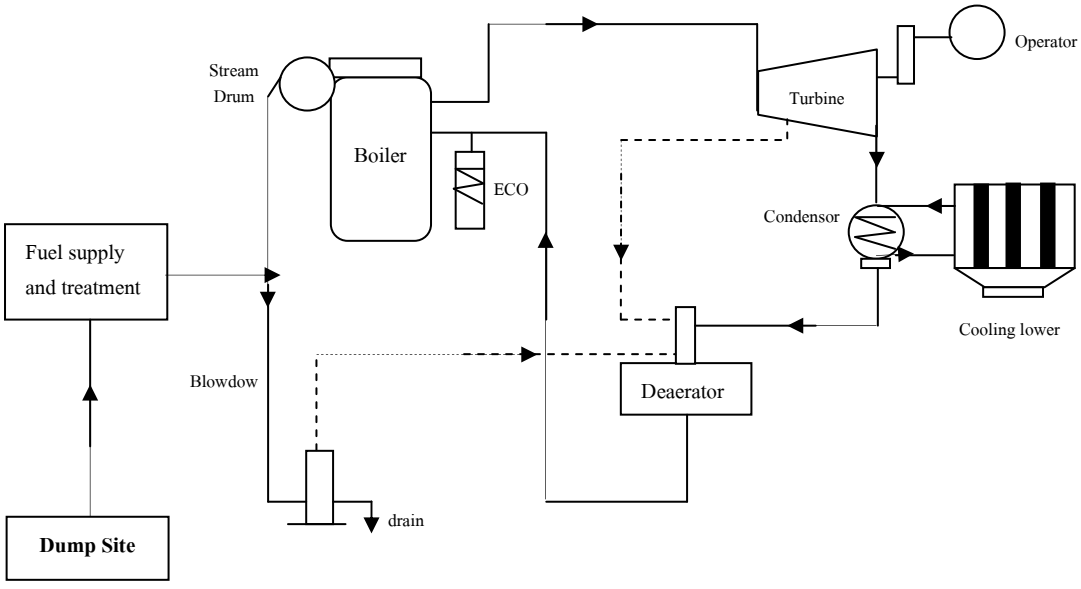

Figure 2.5 Biomass electricity generation process

Figure 2.6 presents the biomass electricity generation process. The biomass electricity generation process described as following: The EFB is transported to electricity generation plant. EFB is pressed by screw press in order to separate water from EFB. Subsequently, pressed EFB is cut by a woodchopper into EFB fiber for feeding to boiler. In the boiler process, the steam is produced and flow to steam turbine, generator for generating electricity. The produced electricity is used in the factory and the excess electricity is sold to PEA.

The wastewater from EFB pressing is collected in the settling tank for separating the oil from wastewater. For the first plant, the wastewater is treated by the biogas system and the biogas is collected and utilized to generate the electricity by the gas engine whereas aerobic treatment system (aerated lagoon) is applied in the second plant. The treated wastewater from biogas plant is flowed to stabilization ponds and later is stored in the retention ponds.

For the by-products, the fly and bottom ash are obtained from combustion process and the sludge is produced from wastewater treatment plant. In near future, ash and wastewater sludge will be used to produce soil conditioner.

In the utility section of electricity generation, it consists of the water supply process and electricity generation. For the water supply process, they used water from river as raw water supply. The water supply plant commonly uses coagulation, sedimentation, and filtration process for water treatment. Water supply is treated by the demineralization process prior to feed to boiler. The electricity is generated from the electricity generation plant and biogas plant.

Transport is another section that could generate the GHG emission due to the use of fossil fuel. For electricity generation process, the transport of raw material is taken into accounted.

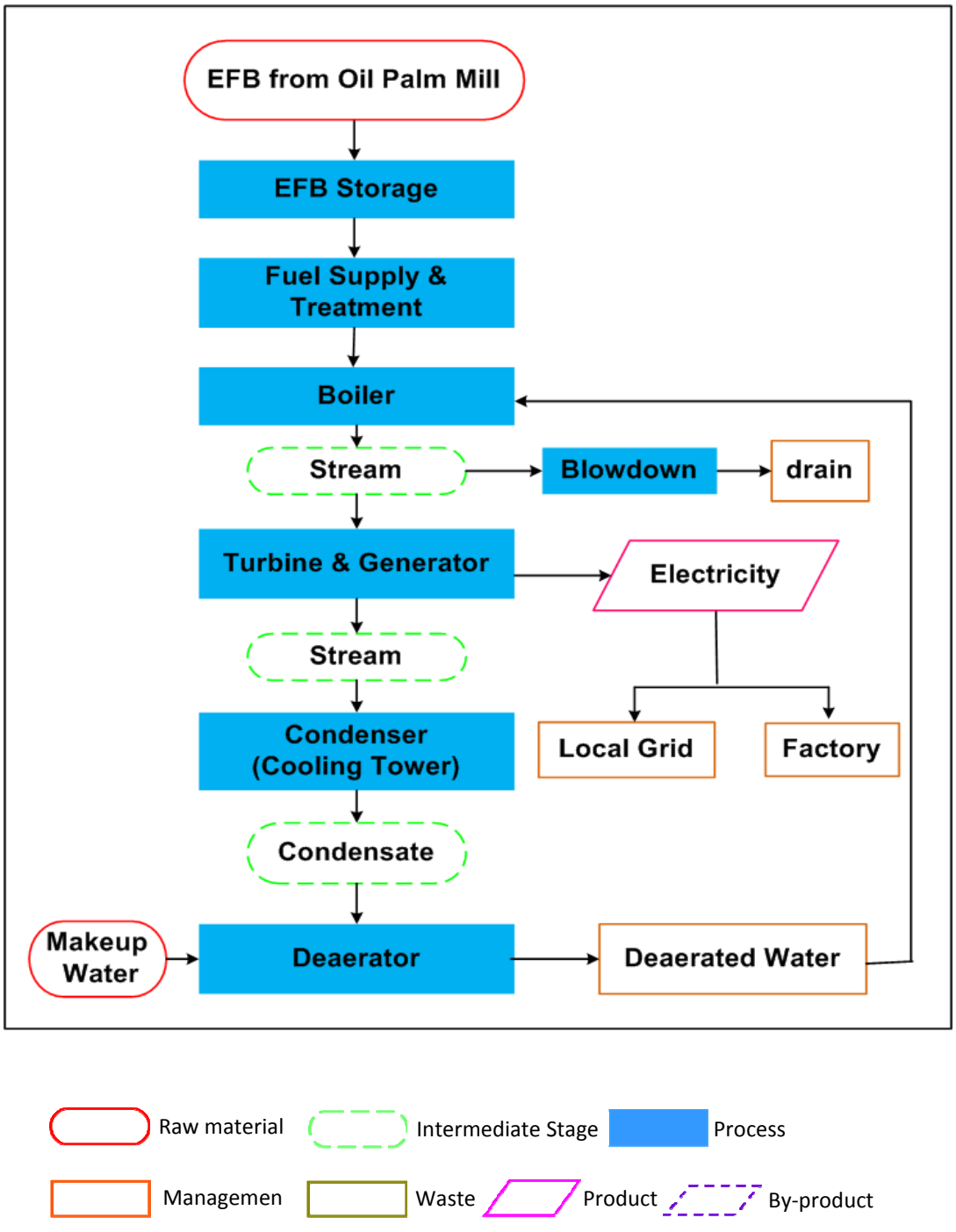

Figure 2.6 Biomass electricity generation process

The fibers ash composed of 1.7-6.6% P, 17-25% K, and 7% Ca (Krause *et al*, 1994). Fibers can be used as biomass fuel in the CPO extraction process and electricity generation (Pleanjai *et al*, 2009).

Shells can be used as fuel in the co-generation, in boiler in-house steam and power generation (Silalertruksa *et al*, 2012).

Palm oil mill effluent (POME) has high organic contents in terms of biochemical oxygen demand (BOD) and chemical oxygen demand (COD). POME was converted into organic fertilizers and used in the nearby oil palm cultivation area and biogas from the anaerobic treatment of mill effluents was used to produce electricity (Papong *et al*, 2010).

2.6 Energy change in product and waste from palm oil mill

The energy output of palm oil mill extraction (PME) was 38.7-40.2 MJ/kg. Energy output from co-products of glycerol, PK, and shells were 3.42, 6.36, and 8.45 MJ/kg PME, respectively (Pleanjai *et al*, 2009; Papong *et al*, 2010). The net energy value (NEV) and net energy ration (NER) of PME system was 20.4 MJ/kg and 2.0 respectively. The energy outputs that were allocation by low heating value (LHV) were 84.4%PME and 15.6% glycerin. The NEV and NER of life cycle PME production were 24.03 MJ/kg and 2.48 respectively. Pleanjai *et al* (2009), found that net energy balance (NEB), NER of PME, and co-production were 100.84 GJ/ha and 3.58 respectively. The NER of PME without co-products was 2.42.

The energy outputs from biodiesel production of the co-production were biodiesel of 147.15 GJ/ha, fibers of 21.16 GJ/ha, shells of 14.54 GJ/ha, biogas of 1.85 GJ/ha, and electricity from the power plant of 11.03 GJ/ha. The heat content of fibers and shells were 8 MJ/kg and 12 MJ/kg respectively. NER of biodiesel plus electricity surplus was 5.4. The NER of only biofuel production was 5.0 (Souza *et al*, 2010).

2.7 Greenhouse gas (GHG) emissions

The GHG emissions of carbon containing gas linked to palm oil life cycle in south Asia with an emission of about 2.8-19.7 $kgCO_2e/kg$ of palm oil. A GHG emission was calculated from carbon emission related to the fossil fuel use during the production of palm oil, and the transport of palm oil, carbon emission related to the reduction of biomass above ground and below ground on palm oil plantations compared to topical forests, methane emission from processing residues originating in the yield of FFB. The carbon emission from the fossil fuel used during the production of palm oil was 0.88 Mt C/ha. The value for carbon emission from the fossil fuel use during the transport of palm oil was 0.43 Mt C/ha. The carbon emission related to the reduction of biomass below ground on palm oil plantations compared to tropical forests amounts was 7.5 Mt C/ha. The estimate carbon emission related to the reduction of biomass above ground on palm oil plantations compared to tropical forests was between 10 and 15 Mt/ha. Methane emission from processing residues originating in the yield of FFB was between 32 and 48 kg of CH_4/ha (Reijnders and Huijbregts, 2008).

Keawmai *et al* (submitted), determined GHG emission value for wet extraction process from 14 mills in Thailand. The total GHG emission from palm oil mill with and without biogas capture system were 1,039 and 1,484 $kgCO_2e$/Mt CPO respectively. The average value of GHG emission from wet extraction process was 1,198 $kgCO_2e$/Mt CPO. The average value of GHG emission allocated by LHV was 871 $kgCO_2e$/Mt CPO.

The GHG emission was a potential environmental disadvantage of home composting because of a lack of reliable GHG emission. The system for GHG emission tested consists of six composting units. A static flux chamber method was used to measure and calculate the value of the GHG emissions for one year composting of organic household waste. The average organic household waste input in the six composting units was 2.6 to 3.5 kg/week and the temperature inside was higher than the ambient temperature only a few degrees (2 to 10 °C). The emissions of CH_4 and N_2O were quantified as 0.4 to 4.2 $kgCH_4$/megagrams (Mg) and 0.30 to 0.55 kgN_2O/Mg, respectively. These depended on frequency of mixing. Composting units exposed to weekly mixing had the highest emission, whereas the units without mixing during the entire year had the lowest emission. In addition to the higher emission from the often mixing units, there was

also an instant release of methane during mixing which was estimated to 8 to12% of the total CH_4 emissions. The experiment with higher loads of organic household waste (up to 20 kg every fortnight) showed a higher emission and significantly increased overall emission (in kg substance per Mg wet waste). The GHG emissions (in kg CO_2eq/Mg wet waste) from home composting of organic household waste were found to be in the same order of magnitude as for centralized composting plants (Andersen *et al*, 2010).

The total life cycle GHG emission of palm oil biodiesel in Brazil with allocation by mass was 1,437 kg CO_2e/ha, without allocation was1,900 kg CO_2e/ha. The GHG emission from agricultural phase was 1,220 kg CO_2e/ha including GHG emission from fertilizer of 1,165 kg CO_2e/ha and pesticides of 55 kg CO_2e/ha. The GHG emission from fuel was 274 kg CO_2e/ha. The GHG emission from industry phase was 406 kg CO_2e/ha including oil extraction of 65 kg CO_2e/ha and transesterification of 341 kg CO_2e/ha (Souza *et al*, 2010).

2.8 Equations

2.8.1 The calculation of greenhouse gas emission from life cycle for the production of palm oil in the following equation (Reijnders and Huijbregts, 2008):

$$IS_{palm\ oil} = \frac{(C_{prod} + C_{trans} + C_{above} + C_{below})\frac{MOL_{CO2}}{MOL_c}GWP_{CO2} + CH4_{waste}GWP_{CH4}}{M_{fruit}\frac{MOL_{palm\ oil}}{MOL_c}F_{fruit \rightarrow oil}} \quad (2\text{-}1)$$

Where:

$IS_{palm\ oil}$: the life cycle global warming impact score for the production of palm oil (Mt CO_2 equivalent per Mt of palm oil)

C_{prod} : the C emission related to the fossil fuel use during the production of palm oil (Mt C/ha/year)

C_{trans} : the C emission related to the fossil fuel use during the transport of palm oil to Europe (Mt C/ha/year)

C_{above} : the C emission related to the reduction of biomass above ground on palm oil plantations compared to tropical forests (Mt C/ha/year)

C_{below} : the C emission related to the reduction of biomass belowground on palm oil plantations compared to tropical forests (Mt C/ha/year)

MOL_{CO2} is the molecular weight of CO_2 (g/mol)

MOL_C : the molecular weight of C (g/mol)

$MOL_{palm\ oil}$: the average molecular weight of palm oil (g/mol)

GWP_{CO2} : the global warming potential of CO_2 (CO_2-eq.)

$CH4_{waste}$: the CH_4 emission from processing residues originating in the yield of FFB/ha/year

GWP_{CH4} : the global warming potential of CH_4 (24.5 CO_2eq.)

M_{fruit} : the yearly production of fresh fruit bunches (Mt C/ha/year)

$F_{fruit/oil}$: the oil fraction extractable from fruit bunches

2.8.2 The GHG emission equation from organization of Intergovernmental Panel on Climate Change (IPCC), United Nation Framework Convention on Climate Change (UNFCCC) the following as:

(1) The equation of GHG emission from grid connected renewable electricity generation (AMS-I.D., Version 15)

$$BE_y = EG_{BL,y} \times EF_{CO2} \quad (2\text{-}2)$$

Where:

BE_y = Baseline Emissions in year y; t CO_2

$EG_{BL,y}$ = Energy baseline in year y; kWh

EF_{CO2} = CO_2 Emission Factor in year y; t CO_2e/kWh

(2) The equation of GHG emission from composting (AM0025, version 11)

$$E_{compost} = E_{compost,N2O} + E_{compost,\ CH4} \quad (2\text{-}3)$$

Where:

$E_{compost}$: The GHG emission from composting during the year ($kgCO_2e$)

$E_{compost,N2O}$: N_2O emission from composting process ($kgCO_2$ e)

$$E_{compost,\ N2O} = Q_{compost} \times EF_{N2O,compost} \times GWP_{N2O} \quad (2\text{-}3.1)$$

Where:

$Q_{compost}$: Total organic soil conditioner during the year (Mt)

$EF_{N2O,compost}$: emission factor of N_2O from composting (Mt N_2O/Mt of compost)

GWP_{N2O} : Global warming potential of N_2O, default value 310

$E_{compost,\ CH4}$: CH_4 emission from composting process ($kgCO_2$ e).

$$E_{composy,\ CH4} = E_{CH4,Anaerobic,y} \times S_{a,y} \quad (2\text{-}3.2)$$

Where:

$S_{a,y}$: The share of waste that degrades under anaerobic conditions in the composting plant during the year *y* (%)

$E_{CH4,Anaerobic,y}$: The quantity of methane that would be generated from anaerobic pockets in the composting process during the year *y* (Mt CH_4)

$$E_{CH4,Anaerobic,y} = \Psi(16/12)FxDOC_f xMCFxGWP_{CH4} x \sum \sum A_{project,j,x} xDOC_j \cdot e^{-kj(y-x)}(1-e^{-kj}) \quad (2\text{-}3.3)$$

Where:

Ψ : Model correction factor to account for model uncertainties

F : Fraction of methane in the SWDS gas

DOC_f : Fraction of degradable organic carbon that can decompose

MCF : Methane correction factor

GWP_{CH4} : Global warming potential of CH_4, default value 25

$A_{project,j}$: Amount of organic waste type j prevented from disposal in the SWDS

DOC_j : Fraction of degradable organic carbon (by weight) in the waste type j (Table 2.2)

k_j : Decay rate for the waste type j (Table 2.3)

x : Year during the crediting period

y : Year for which methane emissions are calculated

Table 2.2 Faction of degradable organic carbon in the waste type j (DOC_j)

Waste type j	**DOC_j (% wet waste)**	**DOC_j (%dry waste)**
- Wood and wood products	43	50
- Pulp, paper and carboard (other than sludge)	40	44
- Food, food waste, beverages and tobacco (other than sludge)	15	38
- Textiles	24	30
- Garden, yard and park waste	20	49
- Glass, plastic, metal, other inther inert waste	0	0

Source: UNFCCC, 2010

Table 2.3 Decay rate for the waste type j

Waste type j		Boreal and Temperate (MAT≤20 ∘C		Tropical (MAT > 20 ∘C)	
		Dry (MAP/PET<1)	Wet (MAP/PET>1)	Dry (MAP<1000 mm)	Wet (MAP>1000 mm)
- Slowly degrading	- Pulp, paper, cardboard (otherthan sludge), textiles	0.04	0.06	0.045	0.07
	- Wood, wood products and straw	0.02	0.03	0.025	0.035
-Moderately degrading	- Other (non-food) organic putrescible garden and park waste	0.05	0.1	0.065	0.17
- Rapidly degrading	- Food, food waste, sewage sludge, beverages and tobacco	0.06	0.185	0.085	0.4

Source: UNFCCC, 2010

(3) The equation of GHG emission from wastewater treatment with biogas system (ACM-III.H, Version 15)

$$PE_y = PE_{power,y} + PE_{ww,\ treatment,y} + PE_{s,\ treatment,y} + PE_{ww,\ discharge,y} + PE_{s,\ final,y} + PE_{Fugitive,y} + PE_{Biomass,y} + PE_{Flaring,y} \quad (2\text{-}4)$$

Where:

PE : Project activity emissions in the year y (Mt CO_2e)

$PE_{power,y}$: Emissions from electricity or fuel consumption in the year y (Mt CO_2e)

$PE_{ww,treatment,y}$: Methane emissions from wastewater treatment systems affected by the project activity, and not equipped with biogas recovery, in year y (Mt CO_2e)

$PE_{s,treatment,y}$: Methane emissions from sludge treatment systems affected by the project activity, and not equipped with biogas recovery, in year y (Mt CO_2e)

$PE_{ww,\ discharge,y}$: Methane emissions from degradable organic carbon in treated wastewater in year y (Mt CO_2e)

$PE_{s,\ final,y}$: Methane emissions from anaerobic decay of the final sludge produced in year y (Mt CO_2e)

$PE_{Fugitive,y}$: Methane emissions from biogas release in capture systems in year y (Mt CO_2e)

$PE_{Biomass,y}$: Methane emissions from biomass stored under anaerobic conditions in year y (Mt CO_2e)

$PE_{Flaring,y}$: Methane emissions due to incomplete flaring in year y (Mt CO_2e)

CHAPTER III

GREENHOUSE GAS EMISSION FROM MIXED PALM OIL EXTRACTION WITH DRY PROCESS IN THAILAND

3.1. Introduction

The palm oil industry is one of the important economic sectors in Southern Thailand. The total economic value of palm oil products in year 2010 accounted for 216 Million U.S. dollar (Institute of data and information services, IDIS, 2010). The total palm plantation area in the southern Thailand reported by the Suratthani oil palm research center (SOPRC) was approximately 515,354 hectares (SOPRC, 2010). A life cycle of palm oil consists of the palm oil plantation, transportation of fresh fruit bunch (FFB), extraction of the crude palm oil (CPO) and its by-products management, refinery of oil palm, and biodiesel production.

At present, the increasing in fossil fuel demand and price leads to development of the alternative energy. Biodiesel as one of the successful alternative energy is in use to mitigate the increasing of fossil fuel demand problem, since it can be used to substitute diesel or mixed with diesel such as B3, B5 etc. The life cycle of biodiesel production system from palm oil consisted of oil palm cultivation, palm oil milling, CPO refining, biodiesel production and all transport activities (Silalertruksa *et al*, 2012). In the biodiesel production, CPO or mixed palm oil (MPO) is used as the raw material. The extraction process of CPO and MPO in Thailand can be done by using wet or dry extraction processes, respectively.

The wet process could generate the greenhouse (GHG) emission according to the activities such as FFB acquisition and transportation, fossil fuel production, transportation, and use, electricity production and use, chemical production, transportation and used as well as anaerobic process for wastewater treatment. Considering, the wet extraction process in Thailand, an approximate total capacity of wet extraction process was approximately 8.16 million metric tons (Mt) FFB per year in year 2010 (Office of Agricultural Economics, OAE, 2010). Kaewmai *et*

al (submitted), stated that the average GHG emission from palm oil mill with and without biogas capture system without allocation was 1,198 $kgCO_2e$/Mt CPO respectively. For the dry extraction process, MPO is the main product where as the palm cake and fine palm residues are co-products. Palm cake and fine palm residues can be utilized in the feed stock production and composting process. Importantly, the dry extraction process does not use water. Thus, it does not produce the water pollution and there is no GHG emission due to the wastewater treatment process.

In order to develop the sustainable palm oil industry, there are serious concerned for reducing the environmental impact, especially global warming which caused by an increase in the level of GHG such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). There are some previous studies on the GHG emission from palm oil industry, especially, for the wet extraction process (Reijnders and Huijbregts, 2008; Kaewmai *et al*, submitted). However, there are no specific methods for calculating the GHG emission and no GHG emission values for the dry extraction process of MPO. The objectives of this research, therefore, aimed to develop methodology of GHG calculation and to determine GHG emission value of dry extraction process.

3.2. Methods

3.2.1 Goal and scope

The goal of this work is to develop methodology of GHG calculation and to determine the GHG emission value for the conversion of palm fruits to MPO by dry extraction process. The concept of life cycle assessment (LCA) based on cradle to gate (C2G) evaluation was used in this study. The functional unit of dry extraction process was 1 Mt of MPO.

3.2.2 System boundary

Figure 3.1 presents system boundary of dry extraction process. Raw material is palm fruits. Emission factor (EF) of palm fruits acquisition was obtained from the study on GHG emission from palm oil industry of Thailand project: oil palm for cultivation section by Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) (Thailand Greenhouse Gas Management Organization, TGO, 2011).

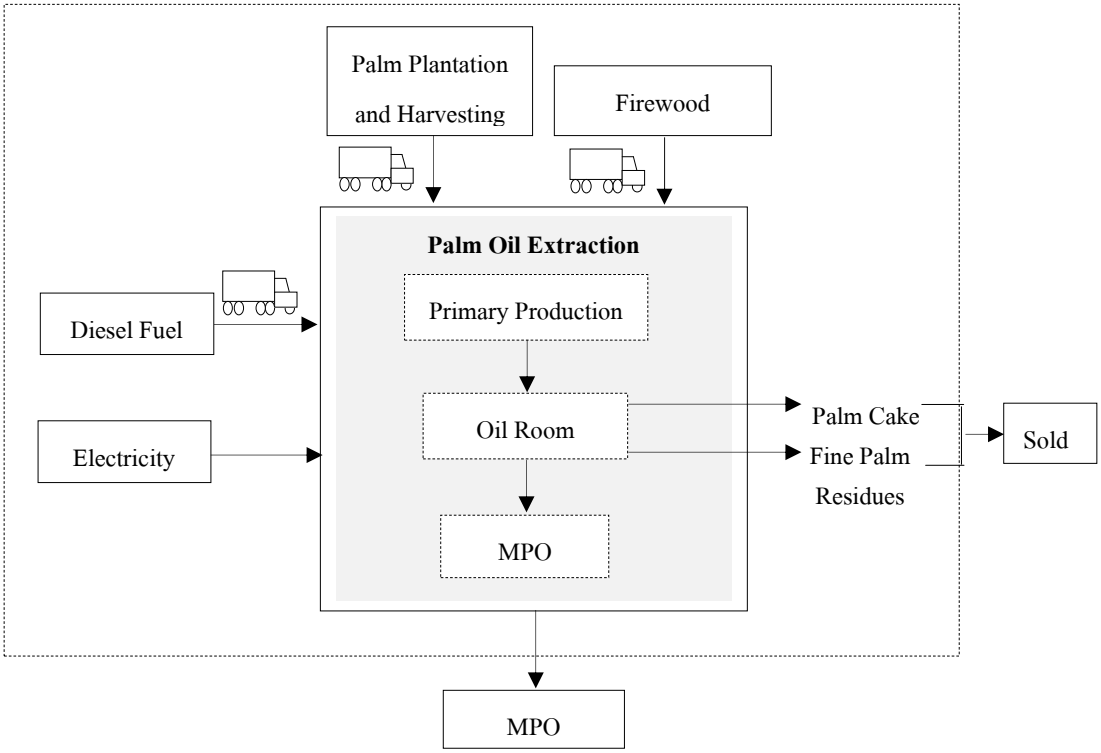

Figure 3.1 Simplify system boundary of dry extraction process for LCA study

The data that were used in the GHG emission calculation of oil palm cultivation included all input data and output data such as electricity consumption, fuel consumption, N-fertilizer, P-fertilizer, K-fertilizer, agro-chemical, organic fertilizer, empty fruit bunch (EFB), and FFB. The transportation of inputs to oil palm plantation, germinated seed production, nursery, immature plantation that caused GHG emission were taken into accounted. GHG emission resulting from oil palm cultivation consists CO_2, CH_4, N_2O. (GIZ, 2011).

For utility section of the dry extraction process, it utilizes firewood, diesel, and electricity. The firewood is used for drying palm fruits. The emission from transportation of firewood into mill was included in calculation. However, EF of firewood production was considered to be zero. The GHG emission of production, transportation and combustion of diesel was considered. Diesel has been used by truck for moving products and wastes in production process. The GHG emission from electricity consumption supplied from Provincial Electricity Authority (PEA) was included in the calculation.

The transport is another section that can generate the GHG emission due to the use of diesel fuel. For dry extraction process, the transportation of raw material (palm fruits) to the mill and the internal transport are taken into the GHG calculation.

3.2.3 Production process

The conversion of palm fruits to MPO is shown in Figure 3.2. Primary production; the palm fruits are harvested and transported to the palm oil mill by trucks for an immediate processing. Palm fruits are fed to the chamber for cleaning. The palm fruits are brought through the drying chamber by firewood at temperature of 100-120 ^{o}C. Oil room; the dry palm fruits are fed into a single screw press system where the oil is extracted. The MPO including CPO and palm kernel oil (PKO) is collected and flows to the filtration process. MPO is kept in storage tank prior to selling to an oil refinery. The press cake and fine palm residues are co-products from this process and are sold to an animal feed mill.

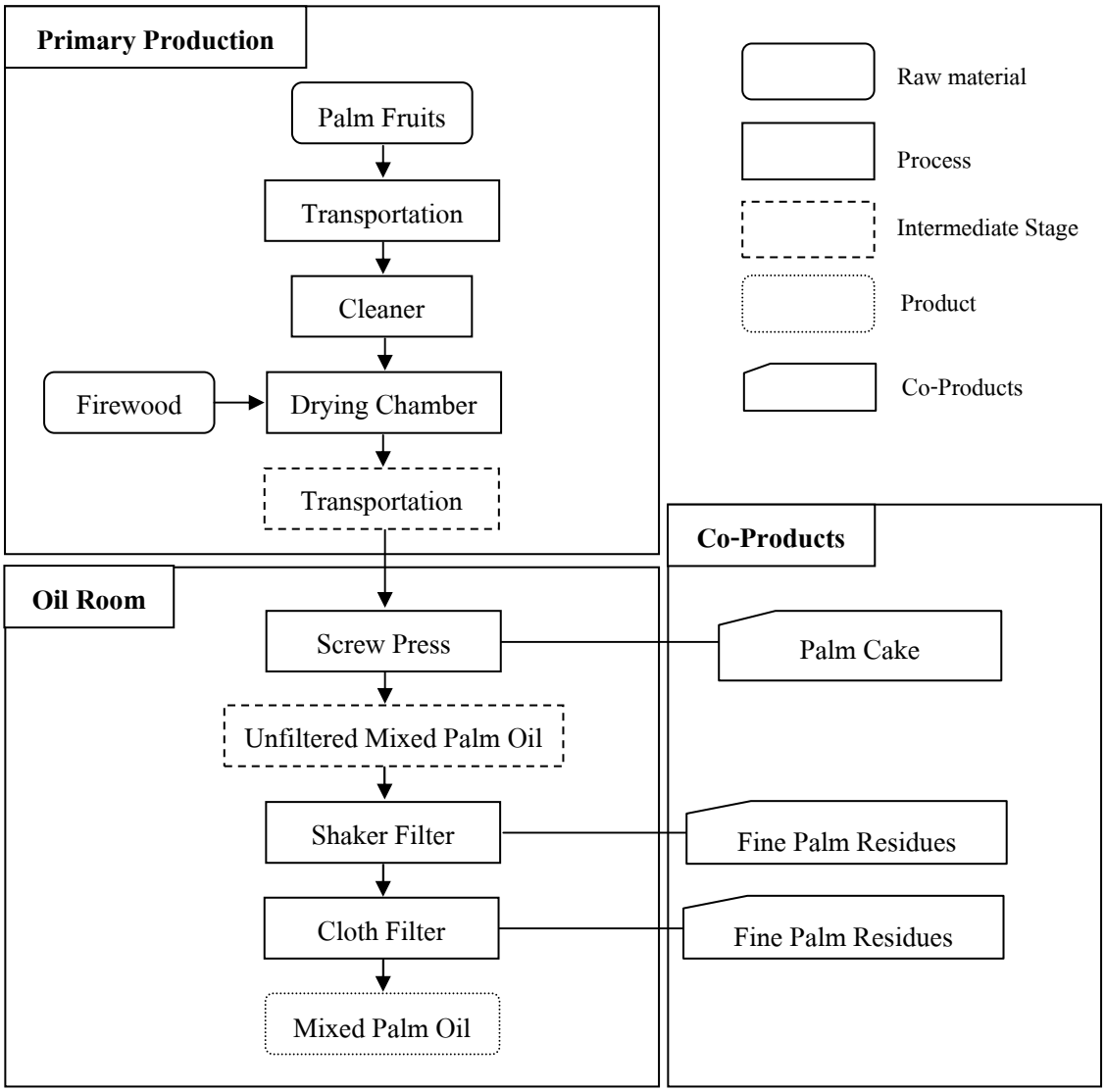

Figure 3.2 Mixed palm oil production by dry extraction process of palm fruits

3.2.4 Developing a methodology for GHG calculation

The GHG calculation and GHG emissions from dry extraction process using LCA approach were developed according to Intergovernmental Panel on Climate Change (IPCC, 2006) and United Nation Framework Convention on Climate Change (UNFCCC, 2010) methods. The EFs from TGO (TGO, 2011) and IPCC were used. The GHG emission calculation methodologies were reviewed to set up the Thai GHG calculation methodology for the conversion of palm fruits to MPO by dry extraction process. Since, the further production process can be the food and energy supply chain. The total GHG emission value from dry extraction process was

determined and allocated by energy and mass to MPO as a main product and to palm cake and fine palm residues as co-products.

3.2.5 Data collection

Three dry extraction plants located in the south of Thailand were participated in this study. All of relevant data related to the calculation were continuously collected. In order to establish reliability of GHG emission result, the actual related data must be gathered as much as possible. Several methods for data collection were used in this study such as on-site interviews, surveys and questionnaires. One year period data was applied for the GHG emission calculation. In addition, EFs to convert quantities of palm fruits, firewood, electricity, diesel, and transportation into resulting GHG emission were obtained from scientifically recognized literatures such as IPCC and TGO. These factors are expressed as the amount of GHG emitted per unit. In addition, MPO, palm cake and fine palm residues were collected and analyzed for their lower heating value (LHV) on wet basis by Automatic Calorimeter (Leco, AC-500).

3.3. Results and discussion

3.3.1 Dry extraction process

The inventory list of dry extraction process for producing 1 Mt of MPO from three mills is presented in Table 3.1. The average palm fruits of 4.1 Mt was required for producing 1 Mt of MPO. The range of oil extraction rate (OER) was between 21.9 and 29.5% with the average value of 24.3%. The average OER of 18% was obtained from the mill with the wet extraction process in Thailand (Development of Alternative Energy and Development Energy, DEDE, 2006). Keawmai *et al*. (submitted) studies GHG emission from wet extraction processe in Thailand. It produced CPO of about 16.5% of FFB by mass, shells of 6%, fibers of 10%, and PK of 5%. While the OER of wet extraction process in Malaysia was 20.45%. (Malaysia Palm Oil Board, MPOB, 2011).The OER of the dry extraction process was higher than that of wet extraction process. Since, only palm fruits were used as raw material where as the wet extraction process used FFB which mainly composed of palm fruits and empty fruit bunch (EFB).

Therefore, the high OER was obtained for dry extraction process. In addition, the dry extraction process produced MPO which composed of CPO and PKO, whereas the wet extraction process produced only CPO. This could be lead to the high OER the dry extraction process in comparison with that of wet extraction process. The co-products outputs from 1 Mt of MPO extraction were palm cake of 0.75 Mt and fine palm residues of 0.36 Mt.

Table 3.1 Inventory list of three dry extraction processes for producing one Mt MPO

Data	Unit	Value			
		Mill 1	**Mill 2**	**Mill 3**	**Average**
Palm fruits	Mt	4.55	4.36	3.38	4.10±0.63
Electricity used	kWh	98.2	84.0	93.5	91.9±7.23
Firewood	Mt	0.27	1.04	0.34	0.55±0.43
Diesel fuel	L	3.41	2.44	0.50	2.12±1.48
MPO	Mt	1.00	1.00	1.00	1.00
Palm cake	Mt	0.54	0.81	0.90	0.75±0.19
Fine palm residues	Mt	0.38	0.35	0.35	0.36±0.02

The average values of firewood of 91.9 Mt, diesel fuel of 2.1 L, and electricity of 91.9 kWh were employed in the production of 1 Mt MPO. The percentage of outputs per one Mt MPO from dry extraction process were MPO of 22 to 30% of palm fruits by mass on wet basis, palm cake 12 to 26%, and fine palm residues of 8 to 10%. The raw material was transported by several types of truck including 7- Mt four-wheel truck, 16 – Mt six-wheel truck, 16 - Mt ten-wheel truck, and 32- Mt eighteen-wheel truck to the mill. For the utility section, the electricity was supplied from the PEA. In the GHG calculation, the production of firewood and combustion of firewood in palm fruits drying process could be defined as carbon neutral. The diesel fuel was the major fossil fuel that was used for transportation of raw materials in the mills.

The LHV on wet basis of MPO, palm cake, and fine palm residues from dry extraction process are shown in Table 3.2. The average LHV of MPO, palm cake and fine palm residues was 39,060, 21,485, and 19,142 MJ/Mt, respectively. The LHV on wet basis of MPO of mill 1, 2 and 3 were comparable, whereas their LHV of palm cake and fine palm residues were significantly difference. This may due to the performance of the production process for extracting the oil from the palm fruits. In general, the LHV of palm cake and fine palm residues should be low for the mill with high performance. However, in the case of high percentage of oil loss, the LHV of co-products must be increased. The LHV of product and co-products was used in the allocation procedure of GHG emission to the product and co-products.

Table 3.2 Lower heating value of MPO, palm cake and fine palm residues

Product and co-products	LHV* (MJ/Mt)			
	Mil 1	Mill 2	Mill 3	Average
MPO	39,212	38,883	39,084	39,060±166
Palm Cake	18,915	19,414	26,127	21,485±4,028
Fine Palm Residues	37,736	27,998	19,142	19,142±9,300

Remake: *the LHV was analyzed on wet basis

3.3.2 GHG emitted sources and calculation

For dry extraction process, the GHG emissions from raw material (palm fruits), diesel fuel, firewood, electricity used and transport are counted to calculate the GHG emission as shown in the following equation:

$$E_{\text{Dry extraction}} = E_{PF} + E_{\text{Fuel}} + E_{\text{Firewood}} + E_{\text{Electricity}} \quad (3\text{-}1)$$

Where:

$E_{\text{Dry extraction}}$ is the total GHG emissions from dry extraction process ($kgCO_2e$)

E_{PF} is the GHG emission from palm fruits production and transportation ($kgCO_2e$). Since, there are no EF of palm fruits production. The GHG emission from palm fruits production can be calculated by using EFs of FFB production. According to study of Keawmai *et al*, (sudmitted), the palm fruits 1 Mt was produced from 1.25 Mt of FFB. The amount of palm fruits that was used in production was converted to amount of FFB and multiple by EFs of FFB to get the GHG emission of palm fruits production.

E_{Fuel} is the GHG emission from diesel fuel production, transport and combustion ($kgCO_2e$)

$E_{Firewood}$ is the GHG emission from firewood transport ($kgCO_2e$)

$E_{Electricity}$ is the GHG emission from electricity consumption ($kgCO_2e$)

The calculation of each section is the result of multiplying the activity data (e.g. Mt of palm fruits, L of diesel fuel used, Mt of firewood, kWh of electricity used) by EFs. The EFs of FFB production, diesel fuel production, diesel fuel combustion, electricity used, and transportation were collected from TGO (TGO, 2011) as shown in Table 3.3.

Table 3.3 Emission Factors (EFs) for GHG calculation.

Subject	Values	Unit	Data Source
FFB (Southern West)	71.00	$kgCO_2e$/Mt FFB	GHG emission from palm oil industry of Thailand project (TGO,2011)
FFB (Southern East)	82.00	$kgCO_2e$/Mt FFB	GHG emission from palm oil industry of Thailand project (TGO, 2011)
Firewood	0.000	$kgCO_2e$/Mt firewood	IPCC 2006 vol. 5
Electricity	0.561	$kgCO_2e$/kWh	TC Common data
Diesel Production	0.4293	$kgCO_2e$/L	IPCC 2007, DEDE*
Diesel Used	2.7080	$kgCO_2e$/L	IPCC 2007, DEDE*
Transportation (Cont.)			
- Truck 4 wheel, 7 Mt (No load)	0.3105	$kgCO_2e$/km	Thai LCI data
- Truck 4 wheel, 7 Mt (Full load)	0.1399	$kgCO_2e$/Mt-km	Thai LCI data
- Truck 6 wheel, 11 Mt (No load)	0.4882	$kgCO_2e$/km	Thai LCI data
- Truck 6 wheel, 11 Mt (Full load)	0.0609	$kgCO_2e$/Mt-km	Thai LCI data
- Truck 10 wheel, 16 Mt (No load)	0.5851	$kgCO_2e$/km	Thai LCI data
- Truck 10 wheel, 16 Mt (Full load)	0.0529	$kgCO_2e$/Mt-km	Thai LCI data
-Truck 18 wheel, 32 Mt (No load)	0.8612	$kgCO_2e$/km	Thai LCI data
-Truck 18 wheel, 32 Mt (Full load)	0.0441	$kgCO_2e$/Mt-km	Thai LCI data
- Truck 22 wheel, 32 Mt (No load)	1.0122	$kgCO_2e$/km	Thai LCI data
- Truck 22 wheel, 32 Mt (Full load)	0.0456	$kgCO_2e$/Mt-km	Thai LCI data

* DEDE = Development of Alternative Energy and Development Energy

3.3.3 GHG emissions and hot spots

The GHG emission of dry extraction process without allocation is presented in Figure 3.3. The average value of total GHG emission without allocation for extraction of 1 Mt of MPO was equal to 473 $kgCO_2e$/Mt MPO. The acquisition of palm fruits was the primary GHG emission source. It emitted GHG between 387 and 497 $kgCO_2e$/Mt MPO or between 88 and 90% of total GHG emission. The second GHG emission source was electricity from PEA of between 47 and 55 $kgCO_2e$/Mt MPO or between 8 and 12% of total GHG emission. The summation of GHG emission from diesel fuel and firewood was less than 2% of total GHG emission. The average values of GHG emission from acquisition of palm fruits, electricity, diesel fuel, and firewood were 429, 52, 7, and 1 $kgCO_2e$/Mt MPO, respectively.

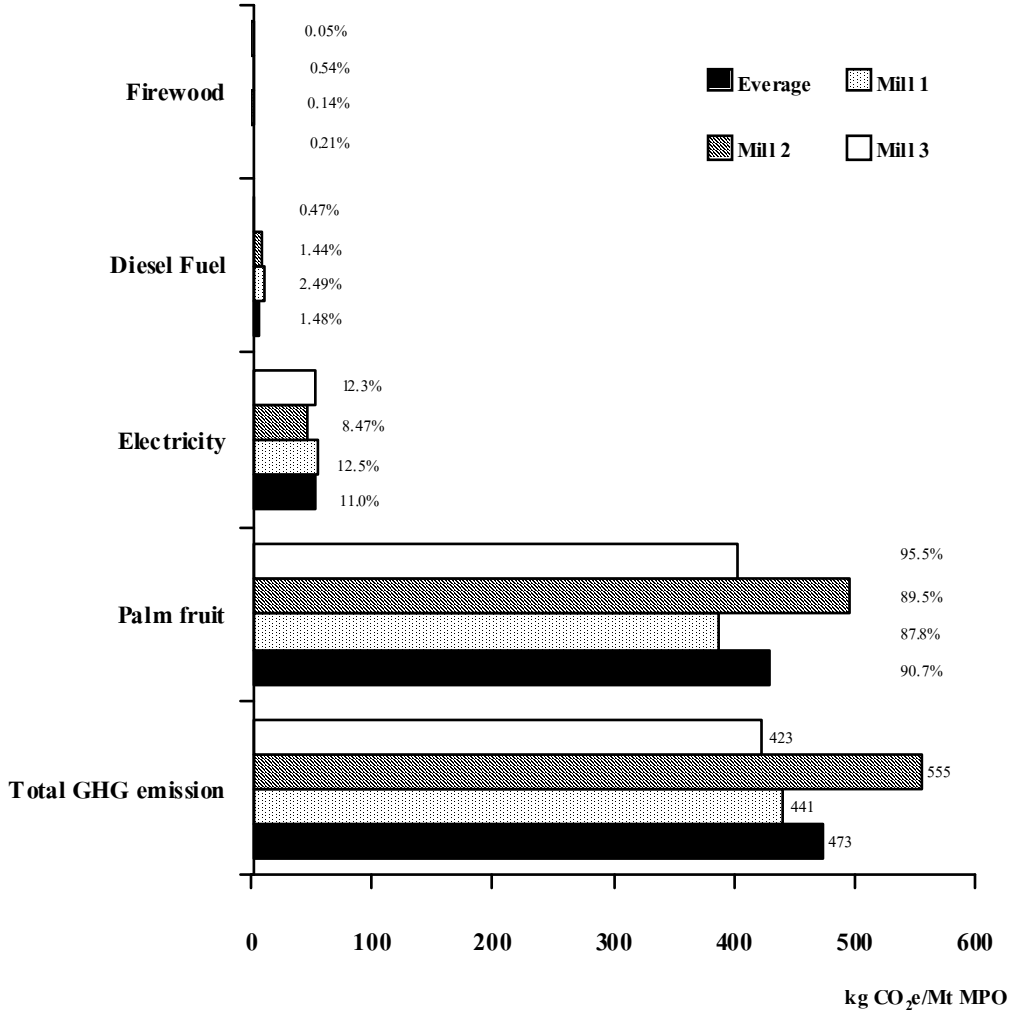

Figure 3.3 GHG emissions for dry extraction process without allocation

Considering GHG emission from wet extraction process, the average GHG emission from wet extraction process with biogas capture without allocation was 1,039 $kgCO_2e$/Mt CPO. The GHG emission hot spots of wet extraction process with biogas capture were wastewater treatment plant and FFB acquisition. Their GHG emissions accounted for 49.4 and 48.7% of total GHG emission, respectively (Keawmai *et al*, submitted). When compared GHG emission from dry extraction process with that of wet extraction process, it was found that the GHG emission from dry extraction process was 2.5 times or 61% lower than GHG emission from wet extraction process.

The allocation by LHV is generally used for the product or co-products that are used in the energy section such as bio-diesel, bio-ethanol and bio-hydrogen. In the case of allocation by mass, it is suitable for the product or co-products that are used as eligible oils, cosmetics, and others. In this study, the MPO can be used for bio-diesel, eligible oils and cosmetics. The allocation by LHV and mass were conducted. The average GHG emission value with allocation by LHV was 290 $kgCO_2e$/Mt MPO, 190 $kgCO_2e$/Mt palm cake, and 172 $kgCO_2e$/Mt fine palm residues (Figure 3.4). Figure 3.5 presents GHG emission by mass allocation. The average GHG emission value with allocation by mass was 236 $kgCO_2e$/Mt MPO, palm cake, and fine palm residues.

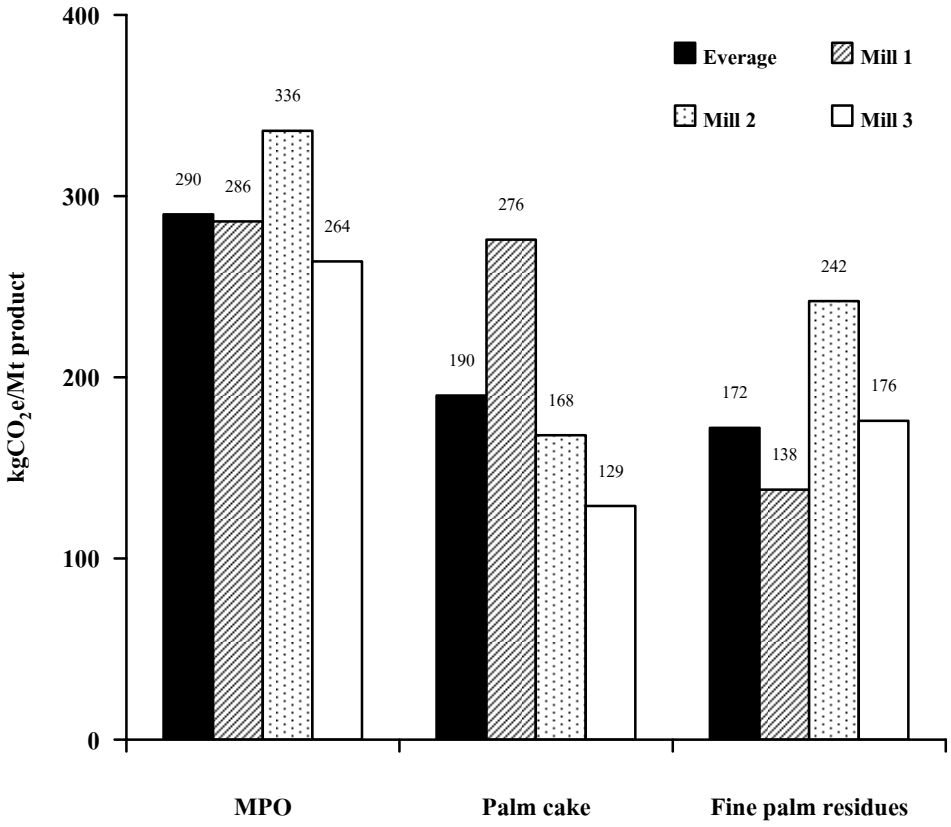

Figure 3.4 GHG emissions for dry extraction process by energy allocation

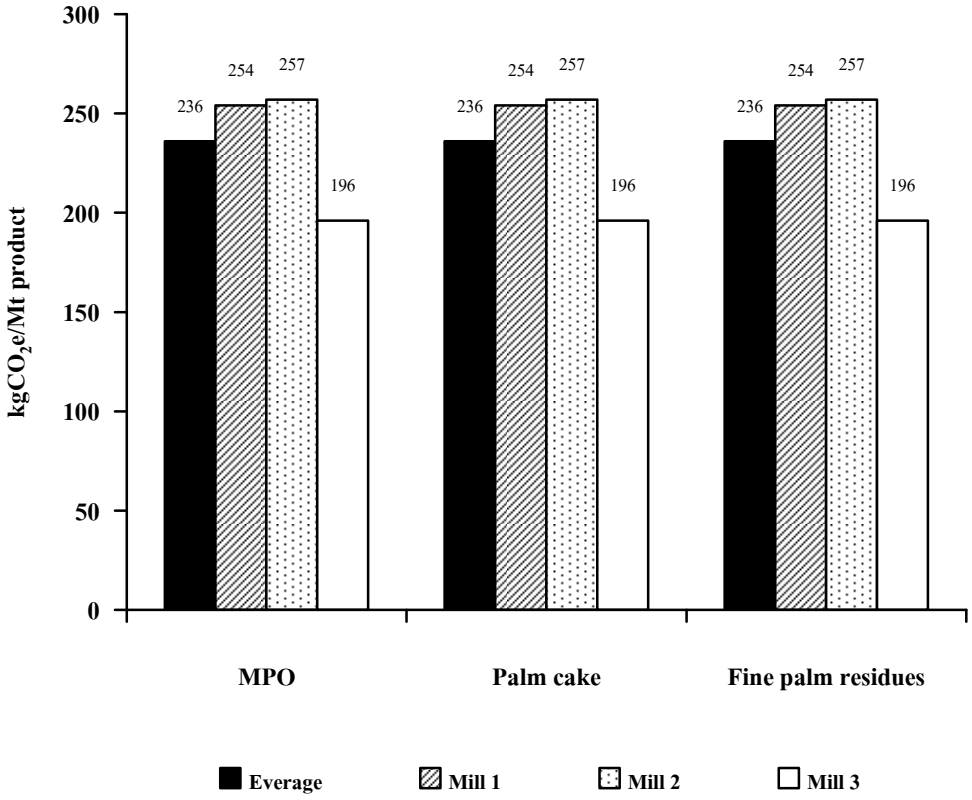

Figure 3.5 GHG emissions for dry extraction process by mass allocation

In comparison to wet extraction process with biogas capture, the average value of GHG emissions in Thailand allocated by LHV was 750 $kgCO_2e$/Mt CPO (Keawmai *et al*, submitted), whereas GHG emissions of 3 dry extraction process in Thailand allocated by LHV was 290 $kgCO_2e$/Mt MPO. The production of 1 Mt MPO by dry extraction process, therefore, emitted less GHG emission than production of 1 Mt CPO by wet extraction process.

3.3.4 Recommendation on GHG mitigation of palm oil mills

The GHG emission of dry extraction process accounted from 4 sections including palm fruits acquisition, electricity, firewood, and diesel fuel. The major GHG emission hot spots for dry extraction process were palm fruits acquisition and electricity. For the wet extraction processes, GHG emission generated from 5 sections including raw material such as FFB acquisition and chemical productions, chemical used, energy used, transportation, and

wastewater management. The GHG emission hot spots of wet extraction process were wastewater treatment process and FFB acquisition.

According to this result, it can be stated that the FFB and palm fruits acquisition were the main GHG emission hot spots of both wet and dry extraction processes. The GHG mitigation option on FFB and palm fruits acquisition should be promptly developed and used. In addition, the environmental policy maker should set the national policy to support the palm oil plantation that employed the GHG mitigation options. Considering the GHG emission from palm oil plantation, GIZ developed the GHG calculation and optimization guidelines for palm oil plantation in Thailand. The GHG emission from chemical fertilizer production, transportation, and utilization accounted for 80 % of total GHG emission in the plantation. The reduction of GHG emission for palm oil plantation could be done by increasing quantity and quality of palm fruits production based on the principles of Good Agricultural Practice (GAP) by the Department of Agriculture (DOA). In GAP, the appropriate fertilizer and a soil analysis were recommended to be used in palm oil plantation. The main cause of GHG emission from palm oil plantation was N-fertilizer to approximately 80%. Therefore, the organic fertilizer or the chemical fertilizer with the application of EFB instead of using only chemical fertilizer was recommended. The soil analysis must be done before and during plantation in order to apply appropriate fertilizers. In practical, this should be used to educate the small and large scale oil palm growers.

For specific GHG emission hot spots in dry extraction process, electricity supplied from PEA was considered as important GHG emission source. The further development should be focused on the technology for using fine palm residue as biomass fuel to generate electricity for using in the mill. Considering palm oil industry, According to the GHG organization plan in 2012-2015 of TGO, Thailand should reduce GHG emission of 1.5 million Mt CO_2e in year 2012.

The advantage of dry extraction process is not only emitted low GHG but, can be established by using low investment cost in the small scale at community level and easily operated. The palm oil productivity data of Office of Agricultural Economic (OAE) in 2011 was 10.7 million Mt FFB. By using OER of 16.5%, the CPO of 1.766 million Mt could be produced. In 2011, the wet extraction process has GHG emission values of approximately 1,835 million

$kgCO_2e$. In 2012, palm oil productivity will be increased to 11.6 million Mt FFB or 1.914 million Mt CPO (OAE, 2012) that will emit approximately 1,989 million $kgCO_2e$. It can be seen that the CPO production of 0.15 million Mt will be increased in 2012. In year 2012, Thailand has a target for decreasing GHG emission of 1.5 million Mt CO_2e By expansion of dry extraction process based on this capacity, GHG reduction of 83 million kg CO_2e or 4.17% of target will be achieved.

3.4. Conclusions

The GHG emission calculation methodology from dry extraction of MPO was developed. Three dry extraction mills in Thailand were participated in this research. The average GHG emission value allocated by LHV was 290 $kgCO_2e$/Mt MPO, 190 $kgCO_2e$/Mt palm cake, and 172 $kgCO_2e$/Mt fine palm residues while those of values allocated by mass was 236 $kgCO_2e$/Mt MPO, palm cake, and fine palm residues. The palm fruits acquisition was defined as the GHG emission hot spot. It accounted of about 90% of total GHG emission. The GHG emission from dry extraction process was 61% lower than that of wet extraction process. In addition, dry extraction process can be established using low investment cost in the small scale at community level. By expansion of dry extraction process of 0.15 million Mt CO_2e, GHG reduction of 83 million kg CO_2e or 4.17% of a target of GHG reduction in Thailand in year 2012 will be achieved.

CHAPTER IV

GREENHOUSE GAS EMISSION OF COMPOSTING USING EMPTY FRUIT BUNCH AND DECANTER CAKE FROM WET PALM OIL EXTRACTION IN THAILAND

4.1. Introduction

The capacity of palm oil in the South East Asia was approximately 38.2 million metric ton (Mt) in year 2007. This came from Indonesia of 19.3 million Mt, Malaysia of 17.7 million Mt and Thailand of 1.17 million Mt (Henson *et al*, 2011). In Malaysia, the by-products from wet extraction process comprised empty fruit bunch (EFB) 22%, palm oil mill effluent (POME) 67%, fibers 13.5%, palm kernel (PK) 6% and shells 5.5% (Sulaiman *et al*, 2011). When using fresh fruit bunch (FFB) 6.07 Mt on wet basis in the wet extraction process, it produced EFB 20% by mass, and decanter cake 3% (Keawmai *et al*, submitted). According to calculation, the palm oil mill in the South East Asia produced by-products in year 2007 including EFB of 7.65 million Mt, decanter cake of 1.15 million Mt and shells of 2.29 million Mt. The palm oil production in Thailand of about 9.03 million Mt in year 2010 produced shells of 0.54 million Mt, EFB of 1.81 million Mt, and decanter cake of 0.27 million Mt.

The utilization of by-products and waste from wet extraction process had a significant development. Presently, EFB can be used for many proposes such as mushroom cultivation, biomass fuel for electricity generation, raw material for composting, etc. Decanter cake also can be utilized in mushroom cultivation, soil conditioner material, feed stock production, composting, etc. For decanter cake, it is successfully to be used as raw material in the composting plant. The utilization of EFB with decanter cake in composting plant is considered as a part of palm oil chain.

In order to obtain sustainable palm oil development, environmental impacts from composting process by EFB and decanter cake such as solid waste, wastewater, and greenhouse gas (GHG) emissions must be determined and reduced. GHG including carbon dioxide (CO_2),

methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbon (HFC), and sulfur hexafluoride (SO_6) has been considered worldwide as a prominent cause of global warming. Even though, the calculation of GHG emissions of wet palm oil extraction in Thailand did not allocate GHG emissions to EFB and decanter cake because they were defined as waste (Keawmai *et al*, submitted), however, the acquisition of other inputs, transportation, fossil fuel used, and processing of composting plant of EFB with decanter cake can emitt GHG.

The methodology of GHG emission calculation and GHG emission values for wet was developed and determined (Kaewmai *et al*, submitted). The methodology of GHG calculation and GHG emission value of dry extraction process was presented in Chapter III. However, there are no specific methods for calculating the GHG emission and no GHG emission value for the composting process using EFB and decanter cake as raw material. The objectives of this research, therefore, aimed to develop GHG calculation methodology and to determine GHG emission value of composting process that use EFB and decanter cake from wet palm oil mill as a major raw material.

4.2. Methods

4.2.1 Goal and scope

The goal of this work is to develop methodology of GHG calculation and to determine the GHG emission value for the conversion of EFB and decanter cake by anaerobic composting process to produce the soil conditioner. The concept of life cycle assessment (LCA) based on cradle to gate (C2G) evaluation was used in this study. The functional unit of composting was 1 Mt soil conditioner.

4.2.2 System boundary

The system boundary of GHG emission of composting of EFB and decanter cake from wet palm oil extraction is illustrated in Figure 4.1.

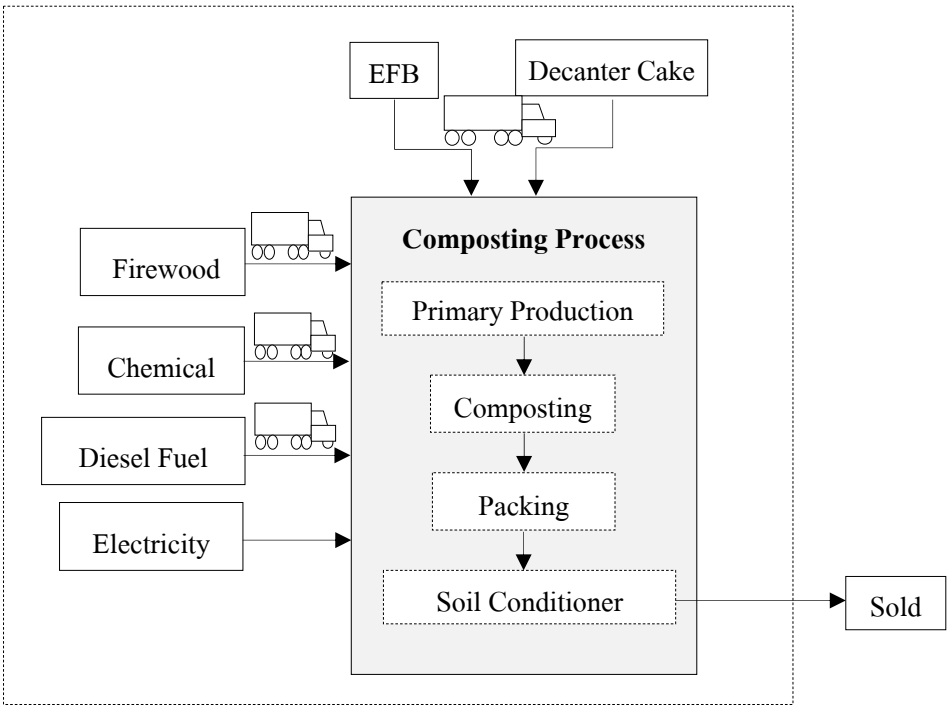

Figure 4.1 System boundary of composting process for LCA study

The major input consists of EFB and decanter cake from wet palm oil extraction. In addition, the chemical including nutrients, effective microorganisms (EM), urea, molasses, and dolomite were counted as inputs. The GHG emission of EFB and decanter cake production was considered to be zero.

In utility section, it utilizes firewood, diesel, and electricity. The GHG emission of transportation of firewood into mill was included in calculation. GHG emission of firewood production and combustion was considered to be zero. Diesel consumption was considered emission from production, transportation and combustion. Diesel has been used by truck for moving products and wastes in production process. The GHG emission from electricity consumption that was supplied from Provincial Electricity Authority (PEA) was included in the calculation.

For composting process, its GHG emission consists of CO_2, CH_4, and N_2O. They caused by anaerobic composting. The global warming potential of CH_4 and N_2O are 25 and 310 times higher than CO_2e respectively (IPCC, 2007).

The transport of inputs to the composting plant consists of decanter cake, EFB, and chemical transportation.

4.2.3 Production process

The composting production process is shown in Figure 4.2. Primary production; the EFB and decanter cake are transported to composting plant. EFB is brought into shearing and cutting process in order to turn EFB into EFB fibers. For decanter cake, it is mixed with nutrient and effective microorganism. Subsequently, the decanter cake and EFB fibers are mixed. After that they are mixed with nutrient and EM. Composting; the mixture of decanter cake and EFB fibers is mixed with urea and composted under anaerobic condition with blanket covering. The composting pile is turned every 15 days. After two months, the compost is drying at 70-80 $^{\circ}$C. Sieving; the dried compost is fed to sieving process to separate the soil conditioner from the unhydrolyzed material. The soil conditioner is packed and kept prior to selling to the clients whereas unhydrolyzed material is brought back to the primary process as the raw material.

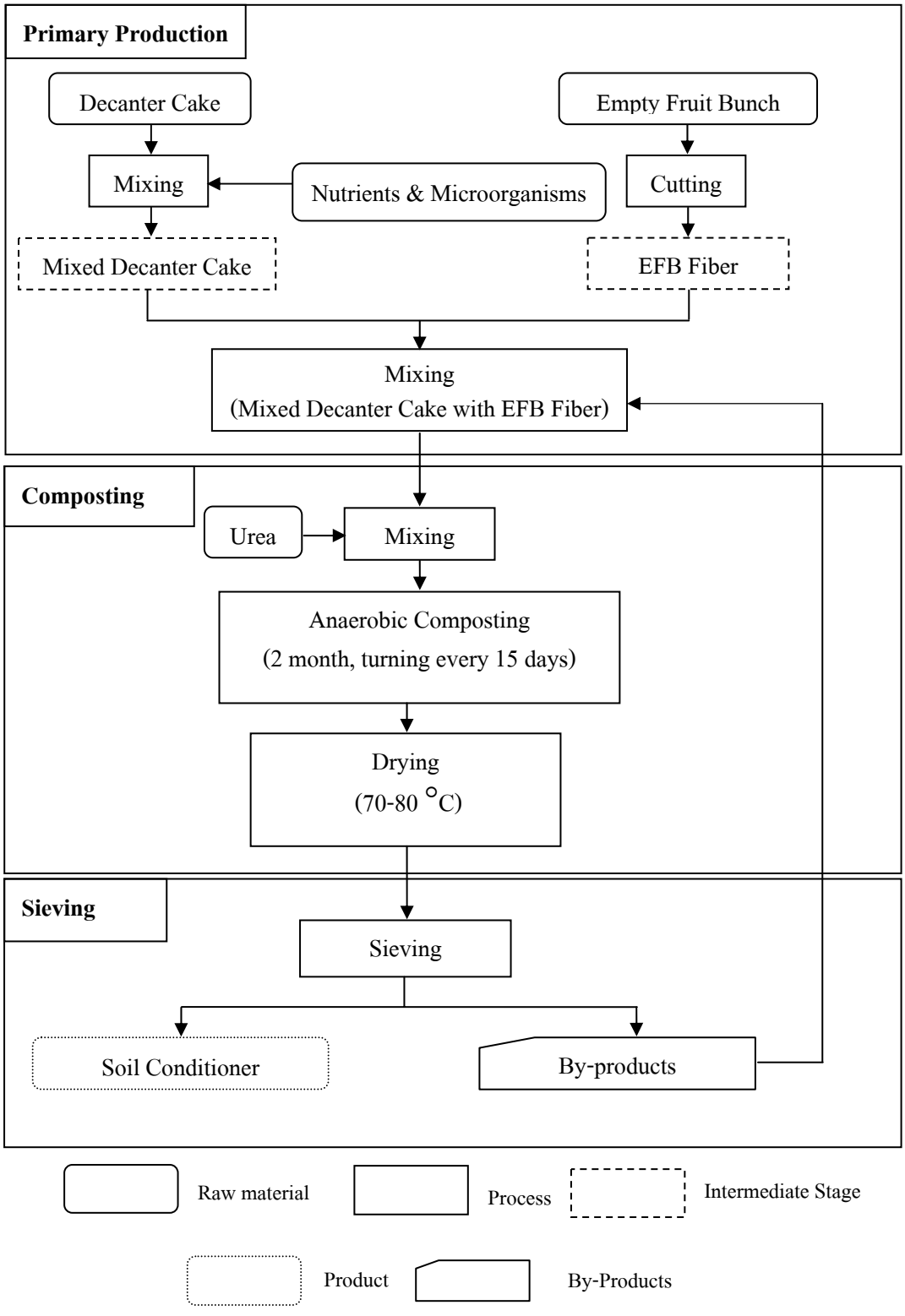

Figure 4.2 Diagram of composting process from by-products of wet palm oil extraction

4.2.4 Developing a methodology for GHG calculation

The GHG calculation and GHG emissions from composting process using LCA approach was developed according to IPCC (IPCC, 2006) and United Nation Framework Convention on Climate Change (UNFCCC, 2010) method. The emission factors (EFs) from Thailand Greenhouse Gas Management Organization (TGO, 2011) and IPCC were used. The GHG emissions calculation methodologies were reviewed to set up the Thai methodology of GHG calculation for the conversion of EFB and decanter cake to soil conditioner by anaerobic composting process. When the manufacturing process produce more than one products, GHG emissions must be allocated to all products. However, there is only single product from composting process. Total GHG emissions, therefore, is belonged to soil conditioner.

4.2.5 Data collection

Single composting plant was participated in this study. The study plant is located in the southern of Thailand. All of relevant data related to the calculation was continuously collected. In order to establish reliability of GHG emission result, the actual related data must be gathered as much as possible. Several methods for data collection were used in this study such as on-site interviews, surveys, and questionnaires. One year period data was applied for the GHG emission calculation. In addition, EFs values to convert the quantity of inputs into the resulting GHG emission were obtained from scientifically recognized literatures. These factors are expressed as the amount of GHG emitted per unit. In addition, the sampling of raw major input including EFB, decanter cake was conducted for theirs moisture content analysis.

4.3. Results and discussion

4.3.1 Production process analysis

The production of 1 Mt soil conditioner was utilized 2 Mt of EFB, 1.67 Mt of decanter cake, 112.1 kWh of electricity, 8.0 L of diesel fuel, 10.0 kg of urea, 20.0 kg of molasses, 266.7 kg of dolomite, and 4.0 kg of EM (Table 4.1). The EFB, decanter cake, firewood, and diesel fuel were transported to the mill using several types of truck including 7- Mt four -wheels

truck, 10- Mt six -wheels truck, 16 -Mt ten -wheels truck, and 32- Mt twenty two-wheels truck. For the utility section, the electricity was supplied from the PEA. Diesel fuel was major fossil fuel in use. The soil conditioner was only one output. The analysis of moisture constant found that EFB and decanter cake had moisture content of 38 and 76%, respectively. The range of moisture content that suitable for composting was between 50 to 80% (Sun *et al*, 2009; Abdullah and Chin, 2010; Andersen *et al*, 2010). When composting was conducted under anaerobic condition, the raw material with high moisture content could be easily degraded (Prasertsan S. and Prasertsan P, 1996).

Table 4.1 Inventory list for composting process of 1 Mt soil conditioner.

Data	Unit	Value
EFB	Mt	2.00
Decanter Cake	Mt	1.67
Electricity used	kWh	112.1
Firewood	Mt	0.54
Diesel Fuel	L	8.00
Urea	kg	10.0
Molasses	kg	20.0
Dolomite	kg	266.7
EM	kg	4.00
Soil Conditioner	Mt	1.00

4.3.2 GHG emitted sources and calculation

The GHG emission from inputs including EFB and decanter cake, firewood, chemical, diesel fuel, electricity used, composting process, and transport are counted to calculate the GHG emission as presented in the following equation:

$$E_{Compost} = E_{Input} + E_{Firewood} + E_{Chemical} + E_{Fuel} + E_{Electricity} + E_{Composting} \quad (4\text{-}1)$$

Where:

$E_{Compost}$ is the total GHG emission from composting process from waste of palm oil extraction ($kgCO_2e$)

E_{Input} is the GHG emission from input (EFB and decanter cake) transport ($kgCO_2e$)

$E_{Firewood}$ is the GHG emission from firewood transport (kgCO2e)

$E_{Chelmical}$ is the GHG emission from chemicals production, and transport ($kgCO_2e$)

E_{Fuel} is the GHG emission from diesel fuel production, transport and combustion ($kgCO_2e$)

$E_{Electricity}$ is the GHG emission from electricity consumption ($kgCO_2e$)

$E_{Composting}$ is the nitrous oxide and methane emission from composting process ($kgCO_2e$). GHG emission calculation of organic waste and bioorganic solid waste using co-composting methodology (UNFCCC, 2010) was used in this study is shown in following:

$$E_{Compost} = E_{Compost,N2O} + E_{Compost, CH4} \quad (4\text{-}2)$$

Where:

$E_{Compost}$: The GHG emission from composting process in the period of compost ($kgCO_2e$)

$E_{Compost,N2O}$: Nitrous oxide emission from composting process ($kgCO_2e$)

$$E_{Compost, N2O} = Q_{Compost} \times EF_{Compost, N2O} \times GWP_{N2O} \quad (4\text{-}3)$$

Where: $Q_{Compost}$ is nitrous oxide emission from composting process that can be calculated from total soil conditioner (Mt), $EF_{Compost, N2O}$ is EFs of nitrous oxide from composting (tN_2O/Mt of compost) of 0.043 tN_2O/Mt of compost-yr (UNFCCC, 2010), and GWP_{N2O} is global warming potential of N_2O (310 $kgCO_2e/kgN_2O$).

$E_{Compost, CH4}$: methane emission from composting process ($kgCO_2e$)

$$E_{Composy, CH4} = S_{a,y} \times E_{CH4,Anaerobic} \quad (4\text{-}4)$$

Where: $S_{a,y}$ is share of waste that degrades under anaerobic conditions in the composting plant (%). According to the composting process, the operating condition was conducted under complete anaerobic composting, therefore, the $S_{a,y}$ of 100% was used in the calculation. $E_{CH4,Anaerobic,y}$ is quantity of methane that would be generated from anaerobic process (Mt CH_4).

It must be noted that the production, transportation and disposal of soil conditioner packing were not taken into the accounted.

The EFs for chemical production, diesel production, diesel combustion, electricity, and transportation were collected from TGO (TGO, 2011) (Table 4.2). The emission of CH_4 was converted to carbon dioxide equivalent (CO_2e) value by using the global warming potential (GWP) over 100 years timeframe of 25 kg CO_2e/kg CH_4.

Table 4.2 Emission Factors (EFs) for GHG calculation.

Subject	**Values**	**Unit**	**Data Source**
Electricity	0.561	$kgCO_2e$/kWh	TC Common data
Diesel Production	0.4293	$kgCO_2e$/L	IPCC 2007, DEDE
Diesel Used	2.7080	$kgCO_2e$/L	IPCC 2007, DEDE
Urea	5.5300	$kgCO_2e$/kg urea	JEMAI Pro using Thai Electricity Grid
Dolomite	0.0265	$kgCO_2e$/kg dolomite	Ecoinvent 2.0
Transportation			
- Truck 4 wheel, 7 Mt (No load)	0.3105	$kgCO_2e$/km	Thai LCI data
- Truck 4 wheel, 7 Mt (Full load)	0.1399	$kgCO_2e$/Mt-km	Thai LCI data
- Truck 6 wheel, 11 Mt (No load)	0.4882	$kgCO_2e$/km	Thai LCI data
- Truck 6 wheel, 11 Mt (Full load)	0.0609	$kgCO_2e$/Mt-km	Thai LCI data
- Truck 10 wheel, 16 Mt (No load)	0.5851	$kgCO_2e$/km	Thai LCI data
- Truck 10 wheel, 16 Mt (Full load)	0.0529	$kgCO_2e$/Mt-km	Thai LCI data

Table 4.2 Emission Factors (EFs) for GHG calculation (Cont.).

Subject	Values	Unit	Data Source
Transportation (Cont.)			
-Truck 18 wheel, 32 Mt (No load)	0.8612	$kgCO_2e/km$	Thai LCI data
-Truck 18 wheel, 32 Mt (Full load)	0.0441	$kgCO_2e/Mt\text{-}km$	Thai LCI data
- Truck 22 wheel, 32 Mt (No load)	1.0122	$kgCO_2e/km$	Thai LCI data
- Truck 22 wheel, 32 Mt (Full load)	0.0456	$kgCO_2e/Mt\text{-}km$	Thai LCI data

4.3.3 The GHG emissions and hot spot

The GHG emission for producing 1 Mt of soil conditioner was 381 $kgCO_2e/Mt$ soil conditioner (Figure 4.3). The highest GHG emission value was due to composting process of about 188 kg CO_2e/Mt soil conditioner or 49% of total GHG emission. It was not surprising, since, the composting was conducted under anaerobic condition; the CH_4 emission could be generated under anaerobic condition. In addition, the applied nitrogen could be converted to N_2O. The CH_4 and N_2O have GWP of 25 and 310 times higher than CO_2 (IPCC, 2006). The second GHG emission source came from chemical used in the production process of 91 kg CO_2e/Mt soil conditioner. GHG emission from electricity used of 63 kg CO_2e/Mt soil conditioner was found. Others sources emitted GHG in the low level. Andersen *et al* (2010), directly measured the GHG emission from home composting of organic waste by close flux chamber. The GHG emission ranged between 177 to 252 $kgCO_2/Mg$ wet organic waste. The GHG emission for producing the soil conditioner in this work was slightly higher than that of Andersen study. It may due to the utilization of chemical in the composting process in this study.

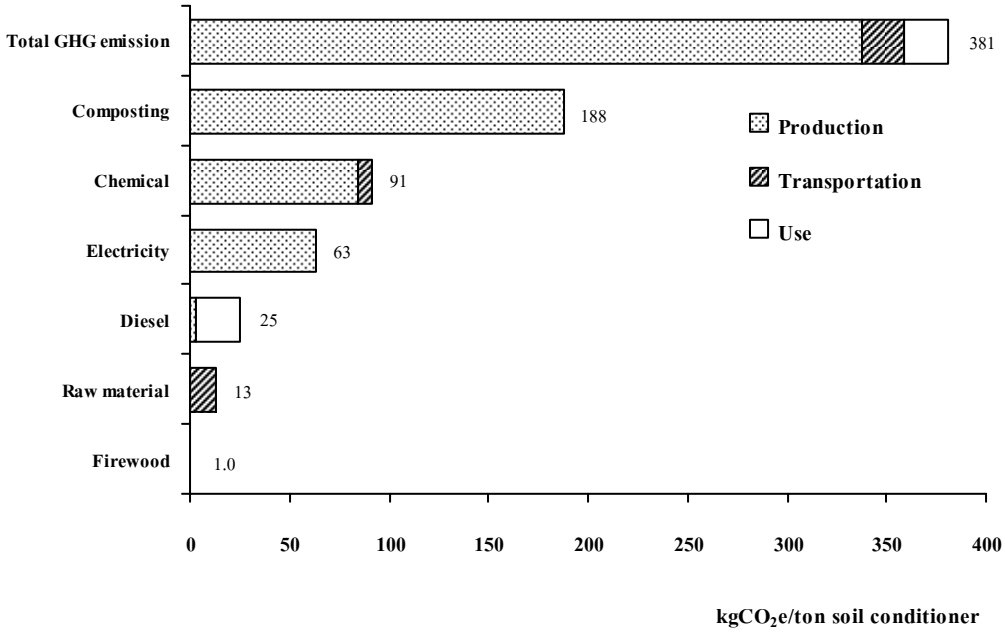

Figure 4.3 GHG emissions for composting process

The hot spots of GHG emission from composting process were the processing under anaerobic condition, chemical and electricity used. However, it was difficult to change the process and electricity source. The GHG mitigation, therefore, should focused on the reduction of urea that was added into the process for control of carbon: nitrogen (C:N) ratio and keeping the suitable amount of nitrogen in the soil conditioner. The C:N ratio in the mixed material must be determined. The addition amount of urea should be applied for keeping optimal C:N ratio and amount of nitrogen in the soil conditioner only. The excess urea should be reduced as much as possible.

The chemical fertilizer (N:P:K; 15:5:15) had GHG due to production process of 2.050 $kgCO_2$/kg fertilizer (TGO, 2011). From this study, the soil conditioner (summation of N, P, K is less than 3% by mass) production emitted GHG without allocation of 0.3810 $kgCO_2$/kg soil conditioner. The production of organic soil conditioner emitted GHG less than that of chemical fertilizers. This observation should lead to the use of organic soil conditioner instead of chemical fertilizer.

4.4. Conclusions

The methodology of GHG emissions for composting of EFB and decanter cake was developed in this research. The GHG emission for producing 1 Mt of soil conditioner was 381 kgCO_2e. The GHG emission hot spot was due to the anaerobic condition during composting process of about 188 kg CO_2e/Mt soil conditioner. Other GHG emission sources from high to low were electricity consumption, chemical production, transportation, and used, diesel fuel production, transportation, and used, raw material (EFB and decanter cake) production and transportation, and firewood transportation, respectively. The hot spot of GHG emission from composting process were from anaerobic condition, chemical and electricity used. It was difficult to change the process, the GHG mitigation, therefore, should be focused on the reduction of chemical that was added into the process for control of C:N ratio and keeping the suitable amount of nitrogen in the soil conditioner. Since, composting should help to add up value of waste from wet palm oil extraction and they emitted low amount of GHG in compared with chemical fertilizer. Policy makers should utilized these advantages as the supporting information to draw the environmental policy to sustain the composting production industry that utilized the wastes from palm oil mill as raw materials.

CHAPTER V

GREENHOUSE GAS EMISSION OF ELECTRICITY GENERATION USING BIOMASS FUEL FROM WET PALM OIL EXTRACTION IN THAILAND

5.1. Introduction

Electricity is one of the most extensively used for human life and for economic development. Presently, quantity fossil fuel use for electricity production has limited and it is costly. In addition, the fossil fuel caused greenhouse gas (GHG) emission as pollution to environment. The alternative energy for electricity generation has interested increased by many organizations. Biomass is alternative biofuel, it can be used as a raw material in electricity production, especially, biomass fuel from wet extraction of crude palm oil (CPO). Therefore, the utilization of by-products and waste from wet extraction process had a significant development. The outputs from wet palm oil extraction were crude palm oil (CPO), fibers, shells, kernels, decanter cake, empty fruit bunches (EFB), ash, and palm oil mill effluent (POME) or wastewater (Yusoff, 2006; Silalertruksa *et al*, 2012). POME could be used extensively as mulch and organic fertilizer. Fibers and shells were used as biomass fuel. The wet palm oil extraction process, produced EFB 22% of total fresh fruit bunch (FFB) by mass, fibers 13.5%, and shells 5.5% (Yusoff, 2006).

Presently, one of the effective method for utilization of EFB in Thailand is to use EFB as biomass fuel in electricity generation plant. There are two electricity generation plants using biomass fuel from wet palm oil extraction with capacity of 9.5 MW and 9.9 MW (Project design document (PDD), Saraf Energy EFB to electricity project, 2006 and Surat Thani Biomass Power Generation Project in Thailand, 2007). The electricity generation plant using EFB, shells and fibers is considered as a part of palm oil chain. In order to obtain sustainable palm oil development, environmental impacts from electricity generation process using EFB, fibers and shells such as solid waste, wastewater, and air pollutant emission or GHG emission must be reduced GHGs including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydro fluorocarbon (HFC), and sulfur hexafluoride (SO_6) (Silalertruksa *et al*, 2012) have been considered worldwide as a prominent cause of global warming. The electricity generation plant can emit GHG due to by biomass fuel from wet

palm oil extraction, the acquisition of raw material, transportation, fossil fuel used, processing and waste disposal.

The GHG emission calculation methodology and GHG emission values for wet and dry palm oil extraction processes were developed and determined (Kaewmai *et al*, submitted). The methodology of GHG calculation and GHG emission value of dry extraction process, and composting process were presented in Chapter III, IV, respectively. However, there are no specific methods for calculating the GHG emission and no GHG emission values for electricity generation process using biomass fuel from wet palm oil extraction as major inputs. The objectives of this research, therefore, aimed to develop methodology of GHG calculation and to determine GHG emission values of electricity generation process by using EFB, fibers, and shells as biomass fuel.

5.2. Methods

5.2.1 Goal and scope

The goal of this work is to develop methodology of GHG calculation and to determine the GHG emission values for the electricity generation by using EFB, fibers, and shells as major inputs. The concept of life cycle assessment (LCA) based on cradle to gate (C2G) evaluation was used in this study. The functional unit of electricity generation process was 1 MWh.

5.2.2 System boundary

The system boundary of GHG emission of electricity generation from EFB, fibers, and shells of wet palm oil extraction is presented in figure 5.1.

The major inputs included EFB, fibers and shells. The GHG emission from transportation of inputs from wet palm oil extraction mill to the electricity generation plant was counted. The EFs of EFB and fibers production were considered to be zero (Keawmai *et al*, submitted).

For utility section of electricity generation, diesel has been used by truck for moving wastes in production process and using in diesel generator. Alum, sodium dioxide, and anionic polymer were used in water supply production process. For the water supply process, the water from

a river was used as raw water supply. The water supply plant commonly used coagulation, sedimentation, and filtration process for water treatment. The water was treated by the demineralization process prior to feed to boiler. The electricity was generated from the electricity generation plant and biogas plant. Wastewater was treated by anaerobic pond, biogas recovery plant, and aerated lagoon.

The transport of raw material consists of EFB, fibers, shells, and chemicals to electricity generation plant were counted in the calculation.

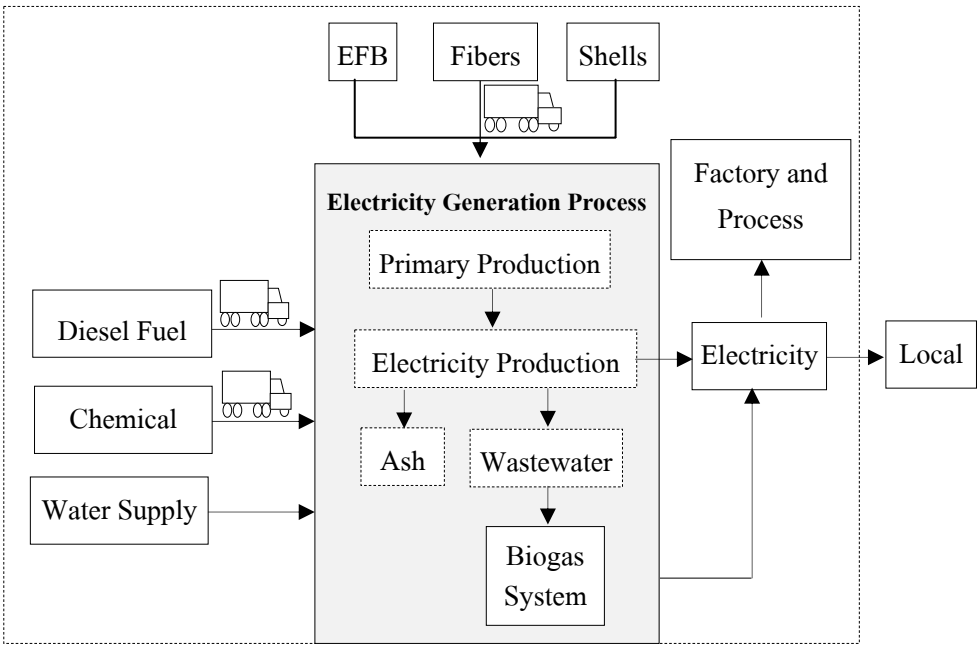

Figure 5.1 System boundary of electricity generation process for LCA study

5.2.3 Production process

The electricity generation process is presented in Figure 5.2. Primary production; the EFB, fibers and shells were transported to electricity generation plant and kept in storage area. EFB was pressed by screw press to separate oil and water. Subsequently, pressed EFB was cut by a wood chopper into EFB fibers. After that, EFB, fibers and shells were mixed together. Electricity production; the electricity was mainly generated from boiler and steam turbine process; however,

there was some electricity that can be generated by the biogas recovery plant. For boiler and steam turbine process, EFB fibers, fibers, and shells were fed to combustion chamber in the boiler system. In the boiler process, the steam was produced and flow to steam turbine generator for producing electricity. The produced electricity was used in the factory and the excess electricity is sold to Provincial Electricity Authority (PEA), Thailand by grid connection. In the biogas recovery plant, the wastewater from EFB pressing was collected by the settling tank for separating the oil from wastewater. After that, the wastewater was pumped to the biogas plant where the biogas is collected and utilized to generate the electricity by the gas engine. The electricity was utilized in the plant and excess electricity was sold to PEA. The treated wastewater from biogas recovery plant in fed to treat in aerated lagoon and later treated wastewater was stored in the retention ponds. By-products; the fly and bottom ash are obtained from combustion process. Ash could be utilized as raw material in light weight brick and to produce compost.

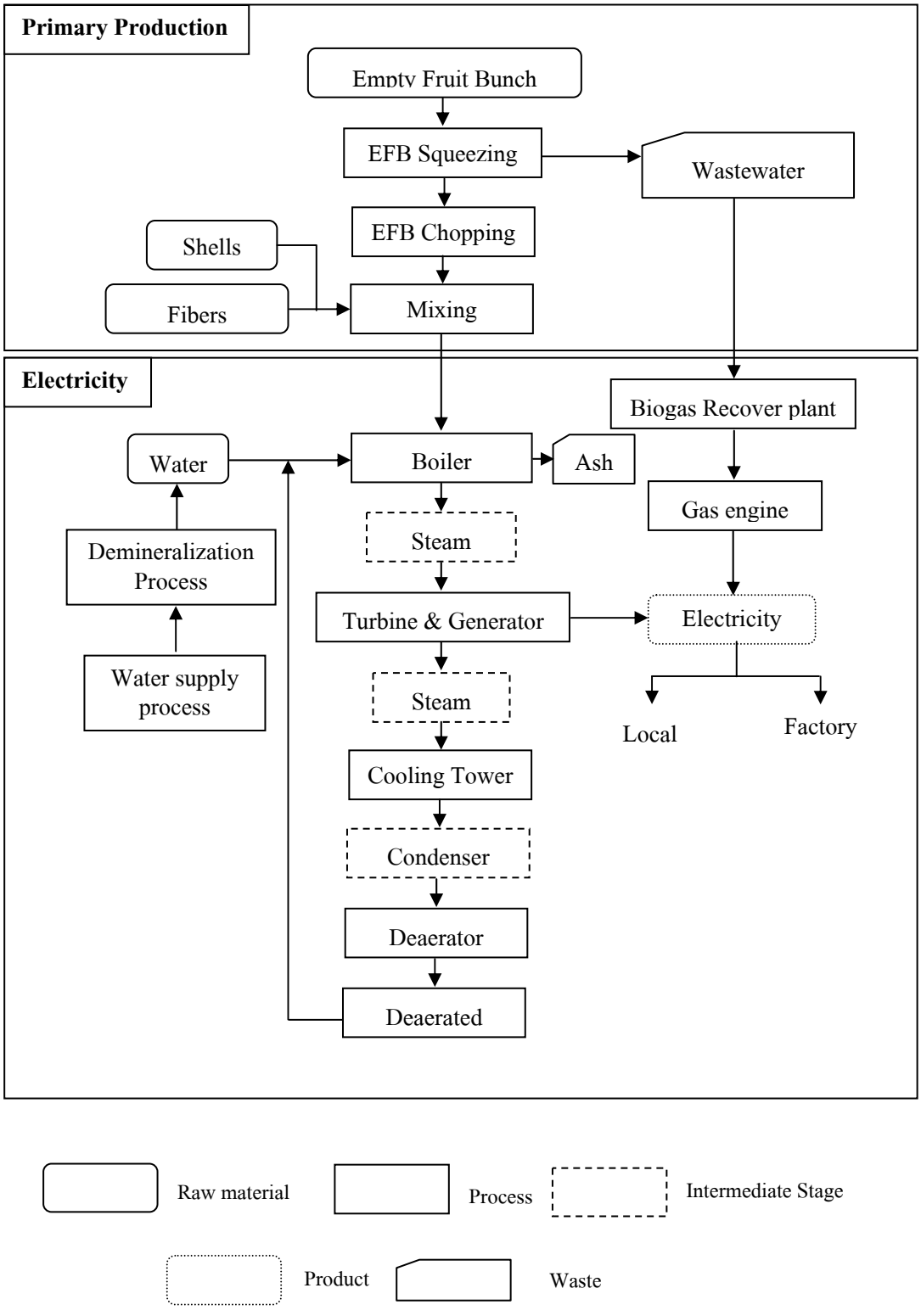

Figure 5.2 Diagram of electricity generation process from by-product of palm oil extraction

5.2.4 Developing a methodology for GHG calculation

The GHG calculation and GHG emissions from electricity generation process using LCA approach was developed according to IPCC (IPCC, 2006) and United Nation Framework Convention on Climate Change (UNFCCC, 2010) method. The emission factors (EFs) from Thailand Greenhouse Gas Management Organization (TGO, 2011) and IPCC were used. The GHG emissions calculation methodologies were reviewed to set up the Thai GHG calculation methodology for the conversion of EFB, fibers and shells to electricity by electricity generation. When the manufacturing process produce more than one product GHG emissions must be allocated to all products. However, there is only single product from electricity generation. Total GHG emissions was belonged to generated electricity.

5.2.5 **Data collection**

Single electricity generation plant was participated in this study. The study plant was located in the Southern of Thailand. All of relevant data related to the calculation was continuously collected. In order to establish reliability of GHG emission result, the actual related data was gathered as much as possible. Several methods for data collection were utilized in this study such as on-site interviews, surveys, and questionnaires. One year period data was applied for the GHG emission calculation. In addition, EFs for converting the quantity of inputs into the resulting GHG emission were obtained from scientifically recognized literatures. These factors were expressed as the amount of GHG emitted per unit. For, wastewater treatment plant, water samples were collected at outlet from production process, inlet to biogas system, outlet from biogas system, and final detention pond. They were kept and storage in 4 $^{\circ}$C prior to analysis of their total solids (TS), volatile solids (VS), suspended solids (SS), oil and greases, chemical oxygen demand (COD), volatile fatty acids (VFA). Gas sampling was collected from outlet from scrubber prior to gas engine for analysis of %CH_4, %CO_2, and %N composition.

5.3. Results and discussion

5.3.1 Production process analysis

The materials for generation of 1 MWh included 0.46 metric ton (Mt) of EFB, fibers of 0.62 Mt, shells of 0.58 Mt, 0.65 L of diesel fuel, 0.54 kg of sodium hydroxide (NaOH), 0.09 kg of anionic polymer, and 0.01 kg of alum as shown in Table 5.1. These raw materials and chemicals were transported from the production sources to the mill by several types of truck including 11- Mt six-wheels truck, 16- Mt ten-wheels truck, and 32-Mt eighteen-wheels truck. In utility section, diesel fuel was used for start up the generator for producing the electricity. The product from electricity generation process was electricity whereas the ash and wastewater were considered as waste.

Table 5.1 Inventory list for electricity generation process of 1 MWh.

Data	Unit	Value
EFB	Mt	0.46
Fibers	Mt	0.62
Shells	Mt	0.58
Electricity used	kWh	-
Diesel Fuel	L	0.65
Sodium Hydroxide	kg	0.54
Anionic Polymer	kg	0.09
Alum	kg	0.01
Electricity	MWh	1.00
Ash	Mt	N.A
Wastewater	m^3	0.0014

Remark N.A. = not available

The wastewater of 0.0014 m^3/MWh or 0.003 m^3/Mt EFB from electricity production was treated by wastewater treatment plant with biogas recovery system. The wastewater characteristic is presented in Table 5.2**.** The COD value of 63,920 mg/L was detected in wastewater; it was slightly

reduced to 61,440 mg/L in the wastewater inlet to biogas system. The reduction of COD could be converted to methane and carbon dioxide GHG. After biogas system, the COD of 1,613 mg/L was detected in treated wastewater. The COD reduction could be converted to CH_4 and CO_2 and captured to be used in the gas engine for generating electricity. The outlet treated wastewater from biogas system was treated by aerated lagoon and stabilization pond system and COD was reduced to 438 mg/L. The performance of wastewater treatment plant for reducing the COD of about 99% was obtained. Considering the quality of treated wastewater in final pond TS of 10.0 mg/L, VS of 1,290 mg/L, SS of 0.29 mg/L, COD of 438 mg/L were determined. This treated wastewater was applied to palm oil plantation by using land treatment technique or stored in detention pond.

Table 5.2 Wastewater characteristic in the wastewater treatment process of electricity generation plant.

Detail analysis	**Outlet from production process**	**Inlet to biogas system**	**Outlet from biogas system**	**Final pond**
TS (mg/L)	126,520	18,680	16,040	14,180
VS (mg/L)	101,180	13,140	3,500	1,290
SS (mg/L)	121,300	9,700	0.35	0.29
Oil & Greases(mg/L)	6	5	N.A.	N.A.
COD (mg/L)	63,920	61,440	1,613	438
VFA (mg/L)	N.A.	361	289	N.A.

Remark N.A. = not available

The percentage of CH_4 in biogas could affect the performance of the gas engine in the biogas recovery plant. The CO_2 of 30.2%, CH_4 of 74.2%, and N of 2.4% were detected in the biogas after bio-scrubber. When POME was treated by anaerobic digestion CH_4 of 65%, CO_2 of 35% and traces of hydrogen sulfide (H_2S) were detected in biogas (Yacob *et al*, 2005). Pipatmanomai *et al* (2009) proposed that the CH_4 of 60% in biogas was suitable for electricity generation. The percentage of biogas from the biogas recovery plant in this study was comparable with this range. It can be stated that the wastewater from biomass electricity generation plant can be treated by anaerobic treatment process for production biogas to generate electricity.

5.3.2 GHG emitted sources and calculation

For electricity generation process, the emission from production of EFB, fibers, and shells acquisition, chemical, diesel fuel, wastewater treatment system, and transport are counted to calculate the GHG emission as summarized in the following equation:

$$E_{Total} = E_{Input} + E_{Chemical} + E_{Fuel} + E_{Wastewater} \quad (5\text{-}1)$$

Where:

E_{Total} is the total GHG emission from electricity generation process ($kgCO_2e$)

E_{Input} is the GHG emission from EFB and fibers transport and production and transport of shells ($kgCO_2e$)

The GHG emission of fibers production from wet extraction process was considered to be zero because in the process fibers was internal used in the boiler. Only few amount of fibers was sold to outside. Therefore, the calculation of GHG emission from wet extraction process did not allocation GHG emission to fibers. The GHG emission of EFB, fibers, and shells combustion could be consider as carbon neutral.

$E_{Chemical}$ is the GHG emissions from chemicals production and transport ($kgCO_2e$)

E_{Fuel} is the GHG emission from diesel fuel production, transport and combustion ($kgCO_2e$)

$E_{Wastewater}$ is the GHG emission from wastewater treatment system ($kgCO_2e$)

The components of the GHG emission equation from anaerobic conversion of wastewater treatment system in detail are shown in the following (UNFCCC, 2010);

$$\begin{aligned} E_{wastewater}(kgCO_2e) = {} & E_{Wastewater,\ treatment}\ (kgCO_2e) + E_{Sludge,\ treatment}\ (kgCO_2e) + \\ & E_{Wastewater,\ discharge}\ (kgCO_2e) + E_{Sludge,\ final}\ (kgCO_2e) + E_{Fugitive}\ (kgCO_2e) \\ & + E_{Biomass}\ (kgCO_2e) + E_{Flaring}\ (kgCO_2e) \end{aligned} \quad (5\text{-}2)$$

The GHG emission from wastewater system including; $E_{wastewater\ ,treatment}$ is the GHG emission from wastewater treatment system ($kgCO_2e$), $E_{Sludge,treatment}$ is the GHG emission from sludge treatment system (kg CO_2e), $E_{Wastewater,discharge}$ is the GHG emission from degradable organic carbon in treated wastewater ($kgCO_2e$), $E_{Sludge,final}$ is the GHG emission from anaerobic decay of the final sludge ($kgCO_2e$), $E_{Fugitive}$ is methane emission from biogas release in capture systems ($kgCO_2e$), $E_{Biomass}$ is methane emission from biomass stored under anaerobic conditions ($kgCO_2e$), $E_{Flare,y}$ is methane emission due to incomplete flaring ($kgCO_2e$). For this study, there appeared no sludge treatments; therefore, $E_{Sludge,\ treatment}$, $E_{Sludge,\ final,}$ and $E_{Biomass}$ are considered to be zero. GHG emission from degradable organic carbon in treated wastewater ($E_{Wastewater,\ discharge}$) was considered to be zero, since, treated wastewater did not discharge to the natural water source. Methane emission due to incomplete flaring ($E_{Flaring}$) in wastewater treatment system was considered to be zero regard to no flaring of methane. The GHG emission from $E_{wastewater\ ,treatment}$ and $E_{Fugitive}$ were counted to calculate the GHG emission as presented in the following equation:

$$E_{Wastewater,\ treatment}\ (kgCO_2e) = \sum Q_{ww}\ x\ COD_{removed}\ x\ MCF_{ww,treatment}\ x\ B_{o,ww}\ x\ UF_{BL}\ x\ GWP_{CH4} \quad (5\text{-}3)$$

And

$$E_{fugitive,ww} = (1 - CFE_{ww})\ x\ MEP_{ww,treatment}\ x\ GWP_{CH4} \quad (5\text{-}4)$$

Where: Q_{ww} is volume of treated wastewater discharged, $COD_{removed}$ is the chemical oxygen demand removed by the treatment of the project activity equipped with biogas, $MCF_{ww,treatment}$ is methane correction factor for the project wastewater treatment equipped with biogas recovery, $B_{o,ww}$ is methane producing capacity of the wastewater (0.25 kg CH_4/kg COD, IPCC, 2006), UF_{BL} is model correction factor to account for model uncertainties (0.89, UNFCCC, 2003), CEF_{ww} is capture efficiency of the biogas recovery equipment in the sludge treatment systems, GWP_{CH4} is global warming potential for methane of 25 $kgCO_2e$/kg CH_4 (IPCC, 2007).

The GHG emission was calculated by conversion of the activities data with EFs to be GHG emissions. The EFs of shells, chemical production, diesel production, diesel combustion and transportation were collected from TGO (TGO, 2011) as shown in Table 5.3.

Table 5.3 Emission Factors (EFs) for GHG calculation.

Subject	**Values**	**Unit**	**Data Source**
Shells	373.00	$kgCO_2e$/Mt shells	TGO, 2011
Electricity	0.561	$kgCO_2e$/kWh	TC Common data
Diesel Production	0.4293	$kgCO_2e$/L	IPCC 2007, DEDE
Diesel Used	2.7080	$kgCO_2e$/L	IPCC 2007, DEDE
NaOH	1.0377	$kgCO_2$/kg NaOH	Thai Electricity Grid
Anionic polymer	0.3500	$kgCO_2$/kg anionic polymer	Ecoinvent 2.0
Alum	0.2770	$kgCO_2$/kg alum	Ecoinvent 2.0
Transportation			
- Truck 4 wheel, 7 Mt (No load)	0.3105	$kgCO_2e$/km	Thai LCI data
- Truck 4 wheel, 7 Mt (Full load)	0.1399	$kgCO_2e$/Mt-km	Thai LCI data
- Truck 6 wheel, 11 Mt (No load)	0.4882	$kgCO_2e$/km	Thai LCI data
- Truck 6 wheel, 11 Mt (Full load)	0.0609	$kgCO_2e$/Mt-km	Thai LCI data
- Truck 10 wheel, 16 Mt (No load)	0.5851	$kgCO_2e$/km	Thai LCI data
- Truck 10 wheel, 16 Mt (Full load)	0.0529	$kgCO_2e$/Mt-km	Thai LCI data
-Truck 18 wheel, 32 Mt (No load)	0.8612	$kgCO_2e$/km	Thai LCI data
-Truck 18 wheel, 32 Mt (Full load)	0.0441	$kgCO_2e$/Mt-km	Thai LCI data
- Truck 22 wheel, 32 Mt (No load)	1.0122	$kgCO_2e$/km	Thai LCI data
- Truck 22 wheel, 32 Mt (Full load)	0.0456	$kgCO_2e$/Mt-km	Thai LCI data

5.3.3 The GHG emissions and hot spot

The result of GHG emission calculation from electricity generation process from by-products of palm oil mill is present in Figure 5.3, the highest GHG emission from raw material acquisition was 228 $kgCO_2e$/MWh or 75%. This came from the summation of GHG emission of shells of 218 $kgCO_2e$/MWh, EFB of 6 $kgCO_2e$/MWh, and fibers of 4 $kgCO_2e$/MWh. The second GHG emission source was from wastewater treatment system with biogas capture of 72 $kgCO_2e$/MWh or 24%. The GHG emission from other sources was found in the level of as low as 1%. The GHG emission of EFB and fibers were due to transportation. Finally, total GHG emission value of the electricity generation process was 303 $kgCO_2e$/MWh. The electricity generation process had the highest GHG emission from raw material. Most of them occurred from shells, which had high EF value. The amount of shells for combustion therefore must be reduced.

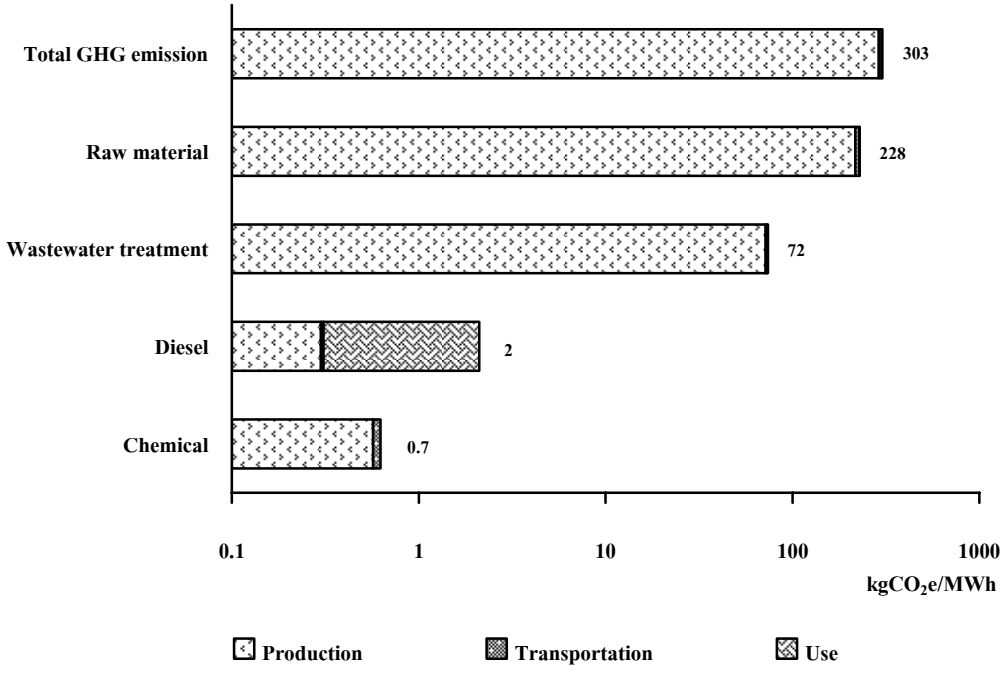

Figure 5.3 GHG emissions for electricity generation process

The GHG emission for electricity generation by using EFB, fibers and shells was 0.303 $kgCO_2e$/kWh, where as GHG emission of electricity generation by using fossil fuel and other

fuel sources in Thailand was 0.5610 $kgCO_2e/kWh$ (TGO, 2011). The production 1 kWh electricity generation by biomass fuel emitted GHG emission less than that of by fossil electricity generation.

5.4. Conclusions

GHG emission methodology for electricity generation process by biomass fuel was developed in this research. For the electricity generation process, GHG emission was 303 $kgCO_2e/MWh$. The GHG emission hot spots were from raw material and wastewater treatment plant of 228 and 72 $kgCO_2e/MWh$, respectively. In the electricity generation process, the highest GHG emission was due to raw material acquisition. It was mainly occurred from shells which had high EF values. The amount of shells in combustion process must be reduced. Since, electricity generation process should help to add up values of by-products and waste of wet palm oil extraction they emitted low amount of GHG, policy makers should be utilized these advantages as the sustain information to draw the environmental policy to support the electricity production industries that utilized the by-products and waste from wet palm oil mill in Thailand.

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APPENDIX A

DATA COLLECTION

APPENDIX A

DATA COLLECTION

A.1 Data collection

Table A.1 Data collection of dry extraction process during in the year

Detail	Unit	Mill 1	Mill 2	Mill 3
Quantity of palm fruits	Ton/year	24,024	11,200	12,350
Quantity of firewood	Ton/year	1,425	2,680	1,230
Quantity of electricity used	kWh/year	518,390	216,000	341,635
Quantity of diesel fuel used	L/year	18,000	6,267	1,825
Quantity of mixed palm oil	Ton/year	5,280	2,570	3,652
Quantity of palm cake	Ton/year	2,880	2,080	3,270
Quantity of fine palm residue	Ton/year	2,024	890	1,280

Table A.2 Data collection of composting process during in the year

Detail	Unit	Data
Quantity of EFB	ton/year	3,600
Quantity of decanter cake	ton/year	3,000
Quantity of firewood used	ton/year	972
Quantity of electricity used	kWh/year	201,780
Quantity of diesel fuel used	L/year	14,400
Quantity of urea	ton/year	18
Quantity of dolomite	ton/year	480
Quantity of EM	ton/year	7.2
Quantity of molasses	ton/year	36
Quantity of organic composting	ton/year	1,800

Table A.3 Data collection of electricity generation process during in the year

Detail	Unit	Data
Quantity of empty fruit bunch (EFB)	ton/year	68,065
Quantity of fibers	ton/year	24,732
Quantity of shells	ton/year	23,100
Quantity of sodium dioxide (NaOH)	kg/year	20,475
Quantity of anionic polymer	kg/year	4,790
Quantity of alum	kg/year	4,257
Quantity of diesel fuel	L/year	25,920
Quantity of electricity production	MWh/year	39,765
Quantity of ash	ton/year	N.A
Quantity of wastewater	L/year	67,151

APPENDIX B

GREENHOUSE GAS EMISSION CALCULATION

APPENDIX B

GREENHOUSE GAS EMISSION CALCULATION

B.1. GHG emission calculation for dry extraction process

B.1.1. GHG emission calculation for dry extraction process of mill 1

(1) GHG emissions from palm fruits in the production process

GHG emissions ($kgCO_2e$) = [GHG emissions from production palm fruits] + [GHG emissions from transportation palm fruits]

- GHG emissions from plantation and harvesting palm fruits

Equation

GHG emissions ($kgCO_2$) = Quantity of FFB (ton) x Emission Factor ($kgCO_2$/ton FFB)

Determine

Quantity of FFB	=	5.69	ton FFB/ton MPO
Emission factor of palm fruit production	=	71.00	kg CO_2e/ton FFB

GHG Emission from plantation and harvesting of palm fruits

= (5.69 tons FFB/ton MPO) x (71.00 kg CO_2e/ton FFB)

= 403.99 $kgCO_2e$/ton MPO

- GHG emissions from transportation palm fruits into plant

Equation

GHG emissions ($kgCO_2$) = Quantity of palm fruits (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of palm fruits (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of palm fruits (tons) / Quantity of palm fruit in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of palm fruits into plant = 4.55 ton PF/ton MPO

Detail of transportation following:

- 40% PF transportation by truck 4 wheel, 7 ton, distance 20 km
- 40% PF transportation by truck 10 wheel, 16 ton, distance 50 km
- 20% PF transportation by truck 18 wheel, 32 ton, distance 70 km

GHG emission from transportation of palm fruits into plant

= [(40%*4.55 tons *20 km*0.1399 $kgCO_2e$/ton-km) + (((40%*4.55 ton)/7 tons)*20 km*0.3105 $kgCO_2e$/km)] + [(40%*4.55 tons*50 km*0.0529 $kgCO_2e$/ton-km) + (((40%*4.55tons) /16 tons)*50 km*0.5851 $kgCO_2e$/km)] + [(20%*4.55 tons *70 km*0.0441 $kgCO_2e$/ton-km) + (((20%*4.55 tons /32 tons)*70 km*0.8612 $kgCO_2e$/km)]

= [5.0924 + 1.6146] + [4.8139 + 3.3277] + [2.8092 + 1.7143]

= 19.3721 $kgCO_2e$/ton MPO

Thus;

GHG emissions from palm fruits in production process

= 403.99 + 19.3721 $kgCO_2e$/ton MPO

= 423.3621 $kgCO_2e$/ton MPO

(2) GHG emissions from firewood into plant

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from firewood production] + [GHG emissions from firewood transportation] + [GHG emission from firewood combustion]

- GHG emissions from firewood production

Equation

GHG emissions ($kgCO_2$) = Quantity of firewood (ton) x Emission Factor ($kgCO_2e$/ton)

Determine

Quantity of firewood used = 0.27 tons bio-fuel/ton MPO

Emission Factor of firewood production = 0.000 $kgCO_2e$/ ton bio-fuel

Thus;

GHG emission from firewood production

= (0.27 tons bio-fuel/ton MPO) x (0.000 kg CO_2e/ton bio-fuel)

= 0.0000 kgCO_2e/ton MPO

- GHG emissions from firewood combustion

Equation

GHG emission (kgCO_2) = Quantity of firewood (ton) x Emission Factor(kgCO_2e/ton)

Determine

Quantity of firewood used	=	0.27	tons bio-fuel/ton MPO
Emission factor of firewood combustion	=	0.000	kgCO_2e/ton bio-fuel

GHG emissions from firewood combustion

= (0.27 tons bio-fuel/ton MPO) x (0.000 kg CO_2e/ton)

= 0.0000 kgCO_2e/ton MPO

- GHG emissions from firewood transportation

Equation

GHG emissions (kgCO_2) = Quantity of firewood (tons) x Average one-way distance (km) x Emission Factor from transportation (kgCO_2e/ton-km)

GHG Emissions (kgCO_2) = [Quantity of firewood (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load (kgCO_2e/ton-km)] + [(Quantity of firewood (tons) / Quantity of firewood in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload (kgCO_2e/ton-km)]

Determine

Quantity of firewood	=	0.27	tons bio-fuel/ton MPO

Detail transportation following as:

- 50% firewood transportation by truck 4 wheel, 7 ton, distance 10 km
- 50% firewood transportation by truck 10 wheel, 16 ton, distance 30 km

GHG emissions from firewood transportation

= [(50%* 0.27 tons*10 km*0.1399 $kgCO_2e$/ton-km) + (((50%*0.27 tons) /7 tons)*10 km*0.3105 $kgCO_2e$/km)] + [(50%* 0.27 tons*30 km*0.0529 $kgCO_2e$/ton-km) + (((50%*0.27 tons) /16 tons)*30 km*0.5851 $kgCO_2e$/km)]

= [0.1889 + 0.0599] + [0.2142 + 0.1481] kg CO_2e/ton MPO

= 0.6111 $kgCO_2e$/ton MPO

Thus;

GHG emissions from firewood in the production process

= 0.000 + 0.000 + 0.6111 $kgCO_2e$/ton MPO

= 0.6111 $kgCO_2e$/ton MPO

(3) GHG emissions from grid electricity used

Equation

GHG emissions ($kgCO_2$) = Quantity of electricity used (kWh) x Emission Factor ($kgCO_2e$/kWh)

Determine

Quantity of grid electricity used	=	98.18	kWh/ton MPO
Emission factor of grid electricity	=	0.5610	$kgCO_2e$/kWh

Thus;

GHG emissions from grid electricity in the production process

= (98.18 kWh/ ton MPO) x (0.5610 $kgCO_2e$/kWh)

= 55.0790 $kgCO_2e$/ton MPO

(4) GHG emissions from diesel fuel in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from diesel fuel production] + [GHG emissions from diesel fuel transportation] + [GHG emission from diesel fuel combustion]

GHG emission ($kgCO_2$) = Quantity of diesel fuel (L) x Emission Factor ($kgCO_2e$/L)

Determine

Quantity of diesel fuel used	=	3.41	L/ton MPO
Emission factor of diesel fuel production	=	0.4293	kg CO_2e/L
Emission factor of diesel fuel combustion	=	2.7080	$kgCO_2e$/L
Density of diesel fuel	=	0.85	g/cm^3
Quantity of diesel fuel	=	0.0029	ton diesel/ton MPO

Detail transportation following as:

- 100% diesel, transportation by boat bulk distance 823 km
- 100% diesel, transportation by truck 6 wheel, 8.5 ton distance 211 km

GHG emissions from diesel fuel production = (3.41 L/ton MPO) x (0.4293 kg CO_2e/L)

= 1.4639 kgCO_2e/ton MPO

GHG emissions from diesel fuel transportation

= [(0.0029 tons diesel x 823 km x 0.002 kgCO_2e/ton-km) +((0.0029/1,700,000 tons) x 823 km x 0.002 kgCO_2e/ton-km)] + [(0.0029 tons diesel x 211 km x0.0672 kgCO_2e/ton-km) + ((0.0029 tons diesel/8.5 tons) x 211 km x 0.4238 kgCO_2e/ton-km)]

= 0.0048 + 0.0000 + 0.0411 + 0.0305 kgCO_2e/ton MPO

= 0.0764 kgCO_2e/ton MPO

GHG emissions from fossil fuel combustion = (3.41 L/ton MPO) x (2.7080 kgCO_2e/L)

= 9.2342 kgCO_2e/ton MPO

Thus;

GHG emissions from diesel fuel in the production process

= 1.4639+ 0.0764 + 9.2342 kgCO_2e/ton MPO

= 10.7746 kgCO_2e/ton MPO

Therefore:

GHG emissions without allocation from dry extraction process production of mill 1

= 423.3621 + 0.6111+ 55.0790 + 10.7746 kgCO_2e/ton MPO

= 489.8270 kgCO_2e/ton MPO

GHG emission calculation allocation of mill 1

- Allocation by energy

% Energy distribution $_{MPO}$ = [39,212 (MJ/ton) x 5,280 (ton)] / [$\sum$ (39,212 (MJ/ton) x 5,280 (ton) + $\sum$ (37,736 (MJ/ ton) x 2,880 (ton)) + $\sum$ (18,915 (MJ/ton) x 2,024 (ton))]

= 0.5848

Emission $_{MPO, allocated}$ = [(489.8270 (kg CO_2e) x 5,280 (ton)) x 0.5848] / 5,280 (ton)

= 286.4508 kg CO_2e/ton MPO

% Energy distribution $_{palm\ cake}$ = [37,736 (MJ/ton) x 2,880 (ton)] / [$\sum$ (39,212 (MJ/ton) x 5,280 (ton) + $\sum$ (37,736 (MJ/ ton) x 2,880 (ton)) + $\sum$ (18,915 (MJ/ton) x 2,024 (ton))]

= 0.3070

Emission $_{\text{palm cake, allocated}}$ = [(489.8270 (kg CO_2e) x 5,280 (ton)) x 0.3070] / 2,880 (ton)

= 275.6910 kg CO_2e/ton palm cake

% Energy distribution $_{\text{fine palm residue}}$ = [18,915 (MJ/ton) x 2,024 (ton)] / [$\sum$ (39,212 (MJ/ton) x 5,280 (ton) + $\sum$ (37,736 (MJ/ ton) x 2,880 (ton)) + $\sum$ (18,915 (MJ/ton) x 2,024 (ton))]

= 0.1081

Emission $_{\text{fine palm residue}}$ = [(489.8270 (kg CO_2e) x 5,280 (ton)) x 0.1081] / 2,024 (ton)

= 138.1312 kg CO_2e/ton fine palm residues

Therefore:

GHG emission with allocation by energy for dry extraction process of mill 1

MPO	=	286.45	kg CO_2e/ton MPO
Palm cake	=	275.69	kg CO_2e/ton palm cake
Fine palm residues	=	138.13	kg CO_2e/ton fine palm residues

- Allocation by mass

% Energy distribution $_{\text{MPO}}$ = [5,280 (ton)] / [$\sum$ (5,280 (ton) + 2,880 (ton) + 2,024 (ton))]

= 0.5185

Emission $_{\text{MPO, allocated}}$ = [(489.8270 (kg CO_2e) x 5,280 (ton)) x 0.5185] / 5,280 (ton)

= 253.9559 kg CO_2e/ton MPO

% Energy distribution $_{\text{palm cake}}$ = [2,880 (ton)] / [$\sum$ (5,280 (ton) + 2,880 (ton) + 2,024 (ton))]

= 0.2828

Emission $_{\text{palm cake, allocated}}$ = [(489.8270 (kg CO_2e) x 5,280 (ton)) x 0.2828] / 2,880 (ton)

= 253.9559 kg CO_2e/ton palm cake

% Energy distribution $_{\text{fine palm residue}}$ = [2,024 (ton)] / [$\sum$ (5,280 (ton) + 2,880 (ton) + 2,024 (ton))]

= 0.1987

Emission $_{\text{fine palm residue}}$ = [(489.8270 (kg CO_2e) x 5,280 (ton)) x 0.1987] /2,024 (ton)

= 253.9559 kg CO_2e/ton fine palm residues

Therefore:

GHG emission with allocation by mass for dry extraction process of mill 1

MPO	=	253.9559	kg CO_2e/ton MPO
Palm cake	=	253.9559	kg CO_2e/ton palm cake
Fine palm residues	=	253.9559	kg CO_2e/ton fine palm residues

B.1.2 GHG emission calculation for dry extraction process of Mill 2

(1) GHG emissions from palm fruits in the production process

GHG emissions ($kgCO_2e$) = [GHG emissions from production palm fruits] + [GHG emissions from transportation palm fruits]

- GHG emissions from plantation and harvesting palm fruits

Equation

GHG emissions ($kgCO_2$) = Quantity of FFB (ton) x Emission Factor ($kgCO_2$/ton FFB)

Determine

Quantity of FFB	=	5.45	ton FFB/ton MPO
Emission factor of FFB production	=	82.00	kg CO_2e/ton FFB

GHG Emission from plantation and harvesting of palm fruits

= (5.45 tons FFB/ton MPO) x (82.00 kg CO_2e/ton FFB)

= 446.90 $kgCO_2e$/ton MPO

- GHG emissions from transportation palm fruits into plant

Equation

GHG emissions ($kgCO_2$) = Quantity of palm fruits (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of palm fruits (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of palm fruits (tons) / Quantity of palm fruits in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of palm fruits into plant = 4.36 ton PF/ton MPO

Detail of transportation following:

- 15% PF transportation by truck 6 wheel, 11 ton, distance 30 km
- 25% PF transportation by truck 18 wheel, 32 ton, distance 150 km
- 32% PF transportation by truck 18 wheel, 32 ton, distance 180 km
- 28% PF transportation by truck 18 wheel, 32 ton, distance 220 km

GHG emission from transportation of palm fruits into plant

= [(15%*4.36 tons *30 km*0.0609 $kgCO_2e$/ton-km) +

(((15%*4.36 ton)/11 tons) *30 km*0.4882 $kgCO_2e$/km)] +

[(25%*4.36 tons*150 km*0.0441 $kgCO_2e$/ton-km) +

(((25%*4.36 tons) /32 tons)*150 km*0.8612 $kgCO_2e$/km)] +

[(32%*4.36 tons *180km*0.0441 $kgCO_2e$/ton-km) +

(((32%*4.36 tons /32 tons)*180 km *0.8612 $kgCO_2e$/km)] +

[(28%*4.36 tons*220 km*0.0441 $kgCO_2e$/ton-km) +

(((28%*4.36 tons)/32 tons)*220 km*0.8612 $kgCO_2e$/km)]

= [1.1948 + 0.8708] + [7.2103 + 4.4002] + [11.0751 + 6.7587] + [11.8442 + 7.2280] $kgCO_2e$/ton MPO

= 50.5821 $kgCO_2e$/ton MPO

Thus;

GHG emissions from palm fruits in production process

= 446.90 + 50.5821 $kgCO_2e$/ton MPO

= 497.482 $kgCO_2e$/ton MPO

(2) GHG emissions from firewood into plant

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from firewood production] + [GHG emissions from firewood transportation] + [GHG emission from firewood combustion]

- GHG emissions from firewood production

Equation

GHG emissions ($kgCO_2$) = Quantity of firewood (ton) x Emission Factor ($kgCO_2e$/ton)

Determine

Quantity of firewood used	=	1.04	tons bio-fuel/ton MPO
Emission Factor of firewood production	=	0.000	$kgCO_2e$/ ton bio-fuel

GHG emission from firewood production

= (1.04 tons bio-fuel/ton MPO) x (0.000 kg CO_2e/ton bio-fuel)

= 0.0000 $kgCO_2e$/ton MPO

- GHG emissions from firewood combustion

Equation

GHG emission ($kgCO_2$) = Quantity of firewood (ton) x Emission Factor($kgCO_2e$/ton)

Determine

Quantity of firewood used = 1.04 tons bio-fuel/ton MPO

Emission factor of firewood combustion = 0.000 $kgCO_2e$/ton bio-fuel

GHG emissions from firewood combustion

= (1.04 tons bio-fuel/ton MPO) x (0.000 kg CO_2e/ton)

= 0.0000 $kgCO_2e$/ton MPO

- GHG emissions from firewood transportation

Equation

GHG emissions ($kgCO_2$) = Quantity of firewood (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of firewood (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of firewood (tons) / Quantity of firewood in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of firewood = 1.04 tons bio-fuel/ton MPO

Detail transportation following as:

- 100% firewood transportation by truck 10 wheel, 16 ton, distance 28 km

GHG emissions from firewood transportation

= [(100%x1.04 tonsx28 kmx0.0529 $kgCO_2e$/ton-km) + (((100%x1.04 tons) /16 tons)x28 kmx0.5851 $kgCO_2e$/km)]

= [1.5404 + 1.0649] kg CO_2e/ton MPO

= 2.6053 $kgCO_2e$/ton MPO

Thus;

GHG emissions from firewood in the production process

= 0.000 + 0.000 + 2.6053 $kgCO_2e$/ton MPO

= 2.6053 $kgCO_2e$/ton MPO

(3) GHG emissions from grid electricity used

Equation

GHG emissions ($kgCO_2$) = Quantity of electricity used (kWh) x Emission Factor ($kgCO_2e$/kWh)

Determine

Quantity of grid electricity used	=	84.03	kWh/ton MPO
Emission factor of grid electricity	=	0.5610	$kgCO_2e$/kWh

Thus;

GHG emissions from grid electricity in the production process

= (84.03 kWh/ton MPO) x (0.5610 $kgCO_2e$/kWh)

= 47.1408 $kgCO_2e$/ton MPO

(4) GHG emissions from diesel fuel in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from diesel fuel production] + [GHG emissions from diesel fuel transportation] + [GHG emission from diesel fuel combustion]

GHG emission ($kgCO_2$) = Quantity of diesel fuel (L) x Emission Factor ($kgCO_2e$/L)

Determine

Quantity of diesel fuel used	=	2.44	L/ton MPO
Emission factor of diesel fuel production	=	0.4293	kg CO_2e/L
Emission factor of diesel fuel combustion	=	2.7080	$kgCO_2e$/L
Density of diesel fuel	=	0.85	g/cm^3
Quantity of diesel fuel	=	0.0021	ton diesel/ton MPO

Detail transportation following as:

- 100% diesel, transportation by boat bulk distance 1129 km
- 100% diesel, transportation by truck 6 wheel, 8.5 ton distance 70 km

GHG emissions from diesel fuel production = (2.44 L/ton MPO) x (0.4293 kg CO_2e/L)

= 1.0475 $kgCO_2e$/ton MPO

GHG emissions from diesel fuel transportation

= [(0.0021 tons dieselx1129 kmx0.002 $kgCO_2e$/ton-km)

+ ((0.0021/1,700,000 tons)x1129 kmx0.002 $kgCO_2e$/ton-km)]

+[(0.0021 tons diesel x 70 km x0.0672 $kgCO_2e$/ton-km)

+ ((0.0021 tons diesel/8.5 tons) x 70 km x 0.4238 $kgCO_2e$/ton-km)]

= 0.0047 + 0.0000 + 0.0099 + 0.0070 $kgCO_2e$/ton MPO

= 0.0216 $kgCO_2e$/ton MPO

GHG emissions from diesel fuel combustion = (2.44 L/ton MPO) x (2.7080 $kgCO_2e$/L)

= 6.6075 $kgCO_2e$/ton MPO

Thus;

GHG emissions from diesel fuel used in the production process

= 1.0475 + 0.0216 + 6.6075 $kgCO_2e$/ton MPO

= 7.6766 $kgCO_2e$/ton MPO

Therefore:

GHG emissions without allocation from dry extraction process production of mill 2

= 497.482 + 2.6053 + 47.1408 + 7.6766 $kgCO_2e$/ton MPO

= 554.905 $kgCO_2e$/ton MPO

GHG emission calculation allocation of mill 2

- By energy

% Energy distribution $_{MPO}$ = [38,883 (MJ/ton) x 2,570 (ton)] / [$\sum$ (38,883 (MJ/ton) x 2,570 (ton) + $\sum$ (19,414 (MJ/ ton) x 2,080 (ton)) + $\sum$ (27,998 (MJ/ton) x 890 (ton))]

= 0.6048

Emission $_{MPO, allocated}$ = [(554.905 (kg CO_2e) x 2,570 (ton)) x 0.6048] / 2,570 (ton)

= 335.6065 kg CO_2e/ton MPO

% Energy distribution $_{palm\ cake}$ = [19,414 (MJ/ton) x 2,080 (ton)] / [$\sum$ (38,883 (MJ/ton) x 2,570 (ton) + $\sum$ (19,414 (MJ/ ton) x 2,080 (ton)) +$\sum$ (27,998 (MJ/ton) x 890 (ton))]

= 0.2444

Emission $_{palm\ cake, allocated}$ = [(554.905 (kg CO_2e) x 2,570 (ton)) x 0.2444] / 2,080 (ton)

= 167.5674 kg CO_2e/ton palm cake

% Energy distribution $_{fine\ palm\ residue}$ = [27,998 (MJ/ton) x 890 (ton)] / [$\sum$ (38,883 (MJ/ton) x 2,570 (ton) + $\sum$ (19,414 (MJ/ ton) x 2,080 (ton)) + $\sum$ (27,998 (MJ/ton) x 890 (ton))]

= 0.1508

Emission $_{MPO, allocated}$ = [(554.905 (kg CO_2e) x 2,570 (ton)) x 0.1508] / 890 (ton)

= 241.6368 kg CO_2e/ton fine palm residues

Therefore;

GHG emission with allocation by energy for dry extraction process of mill 2

MPO	=	335.62	kg CO_2e/ton MPO
Palm cake	=	167.57	kg CO_2e/ton palm cake
Fine palm residues	=	241.64	kg CO_2e/ton fine palm residues

- Allocation by mass

% Energy distribution $_{MPO}$ = [2,570 (ton)] / [$\sum$ (2,570 (ton) + 2,080 (ton) + 890 (ton))]

= 0.4639

Emission $_{MPO, allocated}$ = [(554.905 (kg CO_2e) x 2,570 (ton)) x 0.4639] / 2,570 (ton)

= 257.4198 kg CO_2e/ton MPO

% Energy distribution $_{palm\ cake}$ = [2,080 (ton)] / [$\sum$ (2,570 (ton) + 2,080 (ton) + 890 (ton))]

= 0.3755

Emission $_{palm\ cake, allocated}$ = [(554.905 (kg CO_2e) x 2,570 (ton)) x 0.3755] / 2,080 (ton)

= 257.4198 kg CO_2e/ton palm cake

% Energy distribution $_{fine\ palm\ residue}$ = [890 (ton)] / [$\sum$ (2,570 (ton) + 2,080 (ton) + 890 (ton))]

= 0.1606

Emission $_{MPO, allocated}$ = [(554.905 (kg CO_2e) x 2,570 (ton)) x 0.1606] / 890 (ton)

= 257.4198 kg CO_2e/ton fine palm residues

Therefore;

GHG emission with allocation by mass for dry extraction process of mill 2

MPO	=	257.42	kg CO_2e/ton MPO
Palm cake	=	257.42	kg CO_2e/ton palm cake
Fine palm residues	=	257.42	kg CO_2e/ton fine palm

B.1.3 GHG emission calculation for dry extraction process of mill 3

(1) GHG emissions from palm fruits in the production process

GHG emissions (kgCO_2e) = [GHG emissions from production palm fruits] +

[GHG emissions from transportation palm fruits]

- GHG emissions from plantation and harvesting palm fruits

Equation

GHG emissions (kgCO_2) = Quantity of FFB (ton) x Emission Factor (kgCO_2/ton PF)

Determine

Quantity of FFB = 4.23 ton FFB/ton MPO

Emission factor of FFB production = 82.00 kg CO_2e/ton FFB

GHG Emission from plantation and harvesting of palm fruits

= (4.23 tons FFB/ton MPO) x (82.00 kg CO_2e/ton FFB)

= 346.86 kgCO_2e/ton MPO

- GHG emissions from transportation palm fruits into plant

Equation

GHG emissions (kgCO_2) = Quantity of palm fruits (tons) x Average one-way distance (km) x Emission Factor from transportation (kgCO_2e/ton-km)

GHG Emissions (kgCO_2) = [Quantity of palm fruits (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load (kgCO_2e/ton-km)] + [(Quantity of palm fruits (tons) / Quantity of palm fruit in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload (kgCO_2e/ton-km)]

Determine

Quantity of palm fruits into plant = 3.38 ton PF/ton MPO

Detail of transportation following:

- 50% PF transportation by truck 4 wheel, 7 ton, distance 20 km
- 20% PF transportation by truck 6 wheel, 11 ton, distance 100 km
- 30% PF transportation by truck 6 wheel, 11 ton, distance 250 km

GHG emission from transportation of palm fruits into plant

= [(50%*3.38 tons *20 km*0.1399 kgCO_2e/ton-km) + (((50%*3.38 ton)/7 tons)*20 km *0.3150 kgCO_2e/km)] + [(20%*3.38 tons*100 km*0.0609 kgCO_2e/ton-km) + (((20%*3.38 tons) /11 tons)*100 km*0.4882 kgCO_2e/km)] + [(30%*3.38 tons*250 km *0.0609 kgCO_2e/ton-km) +(((30%*3.38 tons /11 tons)*250 km*0.4882 kgCO_2e/km)]

= [4.7286 + 1.5210] + [4.1168 + 3.0002] + [15.4381 + 11.2508] kgCO_2e/ton MPO

= 40.0555 kgCO_2e/ton MPO

Thus;

GHG emissions from palm fruits in production process

= 346.86 + 40.0555 kgCO_2e/ton MPO

= 386.9155 kgCO_2e/ton MPO

(2) GHG emissions from firewood into plant

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from firewood production] + [GHG emissions from firewood transportation] + [GHG emission from firewood combustion]

- GHG emissions from firewood production

Equation

GHG emissions ($kgCO_2$) = Quantity of firewood (ton) x Emission Factor ($kgCO_2e$/ton)

Determine

Quantity of firewood used = 0.34 tons bio-fuel/ton MPO

Emission Factor of firewood production = 0.000 $kgCO_2e$/ ton bio-fuel

GHG emission from firewood production

= (0.34 tons bio-fuel/ton MPO) x (0.000 kg CO_2e/ton bio-fuel)

= 0.0000 $kgCO_2e$/ton MPO

- GHG emissions from firewood combustion

Equation

GHG emission ($kgCO_2$) = Quantity of firewood (ton) x Emission Factor($kgCO_2e$/ton)

Determine

Quantity of firewood used = 0.34 tons bio-fuel/ton MPO

Emission factor of firewood combustion = 0.000 $kgCO_2e$/ton bio-fuel

GHG emissions from firewood combustion

= (0.34 tons bio-fuel/ton MPO) x (0.000 kg CO_2e/ton)

= 0.0000 $kgCO_2e$/ton MPO

- GHG emissions from firewood transportation

Equation

GHG emissions ($kgCO_2$) = Quantity of firewood (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of firewood (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of firewood (tons) / Quantity of firewood in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of firewood = 0.34 tons bio-fuel/ton MPO

Detail transportation following as:

- 100% firewood transportation by truck 6 wheel, 11 ton, distance 5 km

GHG emissions from firewood transportation

= [(100%* 0.34 tons*5 km*0.0609 $kgCO_2e$/ton-km)] + [((100%*0.34 tons) /11 tons)*5 km*0.4882 $kgCO_2e$/km)]

= [0.1035 + 0.0754] kg CO_2e/ton MPO

= 0.1789 $kgCO_2e$/ton MPO

Thus;

GHG emissions from firewood in the production process

= 0.000 + 0.000 + 0.1789 $kgCO_2e$/ton MPO

= 0.1789 $kgCO_2e$/ton MPO

(3) GHG emissions from grid electricity used

Equation

GHG emissions ($kgCO_2$) = Quantity of electricity used (kWh) x Emission Factor ($kgCO_2e$/kWh)

Determine

Quantity of grid electricity used = 93.54 kWh/ton MPO

Emission factor of grid electricity = 0.5610 $kgCO_2e$/kWh

Thus;

GHG emissions from grid electricity in the production process

= (93.54 kWh/ ton MPO) x (0.5610 $kgCO_2e$/kWh)

= 52.4759 $kgCO_2e$/ton MPO

(4) GHG emissions from diesel fuel in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from diesel fuel production] + [GHG emissions from diesel fuel transportation] + [GHG emission from diesel fuel combustion]

GHG emission ($kgCO_2$) = Quantity of diesel fuel (L) x Emission Factor ($kgCO_2e$/L)

Determine

Quantity of diesel fuel used	=	0.50	L/ton MPO
Emission factor of diesel fuel production	=	0.4293	kg CO_2e/L
Emission factor of diesel fuel combustion	=	2.7080	kgCO_2e/L
Density of diesel fuel	=	0.85	g/cm^3
Quantity of diesel fuel	=	0.0004	ton diesel/ton MPO

Detail transportation following as:

- 100% diesel, transportation by boat bulk distance 1129 km
- 100% diesel, transportation by truck 6 wheel, 8.5 ton distance 180 km

GHG emissions from diesel fuel production = (0.50 L/ton MPO) x (0.4293 kg CO_2e/L)

= 0.2147 kgCO_2e/ton MPO

GHG emissions from diesel fuel transportation

= [(0.0004 tons diesel x 1129 km x 0.002 kgCO_2e/ton-km) + ((0.0004/1,700,000 tons) x 1129 km x 0.002 kgCO_2e/ton-km)]

+ [(0.0004 tons diesel x 150 km x0.0672 kgCO_2e/ton-km)+ ((0.0004 tons diesel/8.5 tons) x 150 km x 0.4238 kgCO_2e/ton-km)]

= 0.0009 + 0.0000 + 0.0040 + 0.0030 kgCO_2e/ton MPO

= 0.0079 kgCO_2e/ton MPO

GHG emissions from diesel fuel combustion = (0.50 L/ton MPO) x (2.7080 kgCO_2e/L)

= 1.3540 kgCO_2e/ton MPO

Thus;

GHG emissions from diesel fuel used in the production process

= 0.2147 + 0.0079 + 1.3540 kgCO_2e/ton MPO

= 1.5766 kgCO_2e/ton MPO

Therefore:

GHG emissions without allocation from dry extraction process production

= 386.9155 + 0.2170 + 52.4759 + 1.5766 kgCO_2e/ton MPO

= 441.185 kgCO_2e/ton MPO

GHG emission calculation allocation of mill 3

- Allocation by energy

% Energy distribution $_{MPO}$ = [39,084 (MJ/ton) x 3,652 (ton)] / [$\sum$ (39,084 (MJ/ton) x 3,652 (ton) + $\sum$ (19,142 (MJ/ ton) x 3,270 (ton)) + $\sum$ (26,127 (MJ/ton) x 1,280 (ton))]

= 0.5978

Emission $_{MPO, allocated}$ = [(441.185 (kg CO_2e) x 3,652 (ton)) x 0.5978] / 3,652 (ton)

= 263.7404 kg CO_2e/ton MPO

% Energy distribution $_{palm\ cake}$ = [19,142 (MJ/ton) x 3,270 (ton)] / [$\sum$ (39,084 (MJ/ton) x 3,652 (ton) + $\sum$ (19,142 (MJ/ ton) x 3,270 (ton)) +$\sum$ (26,127 (MJ/ton) x 1,280 (ton))]

= 0.2622

Emission $_{palm\ cake, allocated}$ = [(441.185 (kg CO_2e) x 3,652 (ton)) x 0.2622] / 3,270 (ton)

= 129.1922 kg CO_2e/ton palm cake

% Energy distribution $_{fine\ palm\ residue}$ = [26,127 (MJ/ton) x 1,280 (ton)] / [$\sum$ (39,084 (MJ/ton) x 3,652 (ton) + $\sum$ (19,142 (MJ/ ton) x 3,270 (ton)) +$\sum$ (26,127 (MJ/ton) x 1,280 (ton))]

= 0.1401

Emission $_{fine\ palm\ residue, allocated}$ = [(441.185 (kg CO_2e) x 3,652 (ton)) x 0.1401] / 1,280 (ton)

= 176.3517 kg CO_2e/ton fine palm residues

Therefore;

GHG emission with allocation by energy for dry extraction process of mill 3

MPO	=	263.74	kg CO_2e/ton MPO
Palm cake	=	129.19	kg CO_2e/ton palm cake
Fine palm residues	=	176.35	kg CO_2e/ton fine palm residues

- Allocation by mass

% Energy distribution $_{MPO}$ = [3,652 (ton)] / [$\sum$ (3,652 (ton) + 3,270 (ton) + 1,280 (ton))]

= 0.4453

Emission $_{MPO, allocated}$ = [(441.185 (kg CO_2e) x 3652 (ton)) x 0.4453] / 3,652 (ton)

= 196.4408 kg CO_2e/ton MPO

% Energy distribution $_{palm\ cake}$ = [3,270 (ton)] / [$\sum$ (3,652 (ton) +3,270 (ton) + 1,280 (ton))]

= 0.3987

Emission $_{\text{palm cake, allocated}}$ = [(441.185 (kg CO_2e) x 3,652 (ton)) x 0.3987] / 3,270 (ton)

= 196.4408 kg CO_2e/ton palm cake

% Energy distribution $_{\text{fine palm residue}}$ = [1,280 (ton)] / [$\sum$ (3,652 (ton) + 3,270 (ton) + 1,280 (ton))]

= 0.1561

Emission $_{\text{fine palm residue, allocated}}$ = [(441.185 (kg CO_2e) x 3,652 (ton)) x 0.1561] / 1,280 (ton)

= 196.4408 kg CO_2e/ton fine palm residues

Therefore;

GHG emission with allocation by mass for dry extraction process of mill 3

MPO	=	196.44	kg CO_2e/ton MPO
Palm cake	=	196.44	kg CO_2e/ton palm cake
Fine palm residues	=	196.44	kg CO_2e/ton fine palm residues

B.2. GHG emission calculation for composting process

(1) GHG emissions from EFB in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from EFB production] + [GHG emissions from EFB transportation]

- GHG emissions from EFB production

Equation

GHG emissions ($kgCO_2e$) = Quantity of EFB (kg) x Emission Factor ($kgCO_2$/ton EFB)

Determine

Quantity of EFB in the production process = 2.00 tons EFB/ton compost

Emission factor of EFB production = 0.00 $kgCO_2$/ton EFB

GHG emissions from EFB production

= (2.00 tons EFB/ton compost) x (0.00 $kgCO_2e$/ton EFB)

= 0.00 $kgCO_2e$/ ton compost

- GHG emissions from EFB transportation into plant

Equation

GHG emissions ($kgCO_2$) = Quantity of EFB (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of EFB (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of EFB (tons) / Quantity of EFB in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of EFB into plant = 2.00 ton EFB/ton compost

Detail transportation following as:

- 40 % EFB, transportation by truck 10 wheel, 16 ton, distance 20 km
- 40 % EFB, transportation by truck 10 wheel, 16 ton, distance 50 km
- 20 % EFB, transportation by truck 10 wheel, 16 ton, distance 70 km

GHG emissions from transportation into plant

= [(40%*2.00 tons*20 km*0.0529 $kgCO_2e$/ton-km) + ((40%*2.00 tons / 16 tons)*20 km*0.5851 $kgCO_2e$/km)] + [(40%*2.00tons*50 km*0.0529 $kgCO_2e$/ton-km) + ((40%*2.00 tons / 16 tons)*50 km*0.5851 $kgCO_2e$/km)] + [(20%*2.00 tons *70 km*0.0529 $kgCO_2e$/ton-km) + ((20%*2.00 tons / 16 tons)*70 km*0.5851$kgCO_2e$/km)]

= [0.8464 + 0.5851] + [2.1160 + 1.4627] + [1.4812 + 1.0239]

= 7.5153 $kgCO_2e$/ ton compost

Thus;

GHG emissions from EFB in the production process

= 0.00 + 7.5153 $kgCO_2e$/ ton compost

= 7.5153 $kgCO_2e$/ ton compost

(2) GHG emissions of decanter cake in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from decanter cake production] + [GHG emissions from decanter cake transportation]

- GHG emissions from decanter cake production

Equation

GHG emissions ($kgCO_2e$) = Quantity of decanter cake (kg) x Emission Factor ($kgCO_2e$/ton decanter cake)

Determine

Quantity of decanter cake in the production process = 1.67 tons decanter cake/ton compost

Emission factor of decanter cake production = 0.00 $kgCO_2e$/ton decanter cake

GHG emissions from decanter cake production

= (1.67 tons decanter cake/ton compost) x (0.00 $kgCO_2e$/ton decanter cake)

= 0.00 $kgCO_2e$/ ton compost

- GHG emissions from decanter cake transportation into plant

Equation

GHG emissions ($kgCO_2$) = Quantity of decanter cake (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of decanter cake (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of decanter cake (tons) / Quantity of decanter cake in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of decanter cake into plant = 1.67 ton decanter cake/ton compost

Detail transportation following as:

- 20% decanter cake, transportation by truck 6 wheel, 11 ton, distance 20 km
- 40% decanter cake, transportation by truck 10 wheel, 16 ton, distance 30 km
- 40 % decanter cake, transportation by truck 10 wheel, 16 ton, distance 50 km

GHG emissions from transportation of decanter cake into plant

= [(20%x1.67 tonsx20 kmx0.0609 $kgCO_2e$/ton-km) + ((20%x1.67 tons / 11 tons)x20 kmx0.4882 $kgCO_2e$/km)]

+ [(40%x1.67 tonsx30 kmx0.0529 $kgCO_2e$/ton-km) + ((40%x1.67 tons / 16 tons)x30 kmx0.5851 $kgCO_2e$/km)]

+ [(40%x1.67 tonsx50 kmx0.0529 $kgCO_2e$/ton-km) + ((40%x1.67 tons / 16 tons)x50 kmx0.5851 $kgCO_2e$/km)]

= [0.4068 + 0.2964] + [1.0601 + 0.7328] + [1.7669 + 1.2214]

= 5.4844 $kgCO_2e$/ ton compost

Thus;

GHG emission from decanter cake in the production process

= 0.00 + 5.4844 $kgCO_2e$/ ton compost

= 5.4844 $kgCO_2e$/ ton compost

(3) GHG emissions from firewood in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from firewood production] + [GHG emissions from firewood transportation] + [GHG emission from firewood combustion]

- GHG emissions from firewood production

Equation

GHG emissions ($kgCO_2$) = Quantity of firewood (ton) x Emission Factor ($kgCO_2e$/ton)

Determine

Quantity of firewood used = 0.54 tons firewood /ton compost

Emission Factor of firewood production = 0.000 $kgCO_2e$/ ton firewood

GHG emission from firewood production

= (0.54tons firewood /ton compost) x (0.000 kg CO_2e/ton firewood)

= 0.0000 $kgCO_2e$/ton compost

- GHG emissions from firewood transportation

Equation

GHG emissions ($kgCO_2$) = Quantity of firewood (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of firewood (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of firewood (tons) / Quantity of firewood in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of firewood = 0.54 tons firewood /ton compost

Detail transportation following as:

- 50% biomass fuel, transportation by truck 4 wheel 7 ton, distance 10 km
- 50% biomass fuel, transportation by truck 10 wheel 16 ton, distance 30 km

GHG emissions from firewood transportation

= [(50%x0.54 tonsx10 kmx0.1399 $kgCO_2e$/ton-km) + ((50%x0.54 tons/7 tons)x10 kmx0.3105 $kgCO_2e$/km)] + [(50%x0.54 tonsx30 kmx0.0529 $kgCO_2e$/ton-km) + ((50%x0.54tons / 16 tons)x30 kmx0.5851 $kgCO_2e$/km)]

= [0.3777 + 0.1198] + [0.4285 + 0.2962] $kgCO_2e$/ ton compost

= 1.2222 $kgCO_2e$/ ton compost

- GHG emissions from firewood combustion

Equation

GHG emission ($kgCO_2$) = Quantity of firewood (ton) x Emission Factor ($kgCO_2e$/ton)

Determine

Quantity of firewood used	=	0.54	tons firewood /ton compost
Emission factor of firewood combustion	=	0.000	$kgCO_2e$/ton firewood

GHG emissions from firewood combustion

= (0.54tons firewood/ton compost) x (0.000 kg CO_2e/ton)

= 0.0000 $kgCO_2e$/ton compost

Thus;

GHG emissions from firewood in the production process

= 0.000 + 1.2222 + 0.000 $kgCO_2e$/ton compost

= 1.2222 $kgCO_2e$/ton compost

(4) GHG emissions from chemical in the production process

(4.1) Urea

- GHG emissions from urea in the production process

Equation

GHG emissions ($kgCO_2$) = [GHG emissions from urea production + GHG emissions from urea transportation]

- GHG emissions from urea production

Equation

GHG emissions ($kgCO_2$) = Quantity of urea (kg) x Emission factor ($kgCO_2e/kg_{Chemical}$)

Determine

Quantity of urea in the production process	=	10	kg urea/ton compost
Emission Factor of urea production	=	5.5300	kg CO_2e/kg Urea

GHG emissions from urea production

= (10 kg urea/ton compost) x (5.5300 kg CO_2e/kg Urea)

= 55.3000 $kgCO_2e$/ ton compost

- GHG emission from urea transportation into plant

Equation

GHG emissions ($kgCO_2$) = Quantity of urea (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of urea (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of urea (tons) / Quantity of urea in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of urea into plant = 0.010 tons urea/ton compost

Detail transportation following as:

- 100% urea, transportation by truck 10 wheel 16 ton, distance 157 km
- 100% urea, transportation by truck 10 wheel 16 ton, distance 890 km

GHG emissions from urea transportation

= [(100%x0.010 tons)x(157 km)x(0.0529 $kgCO_2e$/ton-km)]+ [(100%x0.010 tons/16)x(157 km)x(0.5851 $kgCO_2e$/ km)]

+ [(100%x0.010 tons)x(890 km)x(0.0529 $kgCO_2e$/ton-km)]+ [(100%x0.010 tons /16)x(890 km)x(0.5851 $kgCO_2e$/ km)]

= [0.0830 + 0.0574] + [0.4708 + 0.3255] $kgCO_2e$/ ton compost

= 0.9367 $kgCO_2e$/ ton compost

GHG emissions from urea in the production process

= (55.3000 $kgCO_2e$/ ton compost) + (0.9367 $kgCO_2e$/ ton compost)

= 56.2367 $kgCO_2e$/ ton compost

(4.2) Molasses

- GHG emissions from molasses in the production process

Equation

GHG emissions ($kgCO_2$) = [GHG emissions from molasses production + GHG emissions from molasses transportation]

Determine

Quantity of molasses in the production process	=	20	kg molasses/ton compost
Emission Factor of molasses process	=	1.08	$kgCO_2e$/kg Molasses

GHG emissions from molasses production

= (20 kg molasses/ton compost) x (1.08 $kgCO_2e$/kg molasses)

= 21.6000 $kgCO_2e$/ ton compost

- GHG emissions from molasses transportation into plant

Equation

GHG emissions ($kgCO_2$) = Quantity of molasses (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of molasses (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of molasses (tons) / Quantity of molasses in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of molasses into plant = 0.02 ton molasses/ton compost

Detail transportation following as:

- 100% molasses, transportation by truck 18 wheel, 32 ton, distance 828 km

GHG emissions from molasses transportation

= [(100%x0.02 tons)x(828 km)x(0.0441 $kgCO_2e$/ton-km)]+[(100%x0.02 tons/32)x (828 km)x(0.8612 $kgCO_2e$/km)]

= 0.7303 + 0.4457 $kgCO_2e$/ton compost

=1.1760 $kgCO_2e$/ton compost

Total GHG emissions from molasses in the production process

= (21.6 $kgCO_2e$/ ton compost) + (1.1760 $kgCO_2e$/ ton compost)

= 22.7760 $kgCO_2e$/ton compost

(4.3) Dolomite

- GHG emissions from dolomite in the production process

Equation

GHG emissions ($kgCO_2$) = [GHG emissions from dolomite production + GHG emissions from dolomite transportation]

- GHG emissions from dolomite production

Determine

Quantity of dolomite in the production process = 266.67 kg Dolomite/tons compost

Emission Factor of dolomite production = 0.0265 kg CO_2e/kg Dolomite

GHG emissions from dolomite production

= (266.67kg Dolomite/tons compost) x (0.0265 kg CO_2e/kg Dolomite)

= 7.0667 kgCO_2e/ton compost

- GHG emissions from dolomite transportation

Equation

GHG emissions (kgCO_2) = Quantity of dolomite (tons) x Average one-way distance (km) x Emission Factor from transportation (kgCO_2e/ton-km)

GHG Emissions (kgCO_2) = [Quantity of dolomite (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load (kgCO_2e/ton-km)] + [(Quantity of dolomite (tons) / Quantity of dolomite in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload (kgCO_2e/ton-km)]

Determine

Quantity of dolomite into plant = 0.2667 kg Dolomite/tons compost

Detail transportation following as:

- 100% dolomite, transportation by truck 10 wheel 16 ton, distance 211 km

GHG emissions from dolomite transportation

= [(100% x 0.2667 ton dolomite/ton compost) x (211 km) x (0.0529 kgCO_2e/ton-km)]

+ [(100% x 0.2667 ton dolomite/ton compost) /16) x (211 km) x (0.5851 kgCO_2e/ km)]

= 2.9769 + 2.0578 kgCO_2e/ton compost

= 5.0347 kgCO_2e/ton compost

GHG emissions from dolomite in the production process

= 7.0667 kgCO_2e/ ton compost + 5.0347 kgCO_2e/ ton compost

= 12.1014 kgCO_2e/ton compost

(4.4) EM

- GHG emissions from EM in the production process

Equation

GHG emissions ($kgCO_2$) = [GHG emissions from EM production + GHG emissions from EM transportation]

- GHG emissions from EM production

Determine

Quantity of EM in the production process = 4.00 kg EM tons/ton compost

Emission Factor of EM production = 0.00 kg CO_2e/kg EM

GHG emissions from EM production

= (4.00 kg EM tons/ton compost) x (0.00 $kgCO_2e$/kg EM)

= 0.00 $kgCO_2e$/ton compost

- GHG emissions from EM transportation

Equation

GHG emissions ($kgCO_2$) = Quantity of dolomite (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of dolomite (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of dolomite (tons) / Quantity of dolomite in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of EM into plant = 0.004 ton EM tons/ton compost

Detail transportation following as:

- 100% EM, transportation by truck 10 wheel 16 ton, distance 814 km

GHG emissions from EM transportation

= [(100% x 0.004 ton EM tons/ton compost)x(814 km)x(0.0529 $kgCO_2e$/ton-km)]

+ [(100% x 0.004 ton EM tons/ton compost)/16) x (814 km)x(0.5851 $kgCO_2e$/ km)]

= 0.1722 + 0.1191 $kgCO_2e$/ton compost

= 0.2913 $kgCO_2e$/ton compost

GHG emissions from EM in the production process

= 0.00 $kgCO_2e$/ ton compost + 0.2913 $kgCO_2e$/ton compost

= 0.2913 $kgCO_2e$/ton compost

Thus;

GHG emissions from chemical used in the production process

= 56.2367 + 22.7760+ 12.1014 + 0.2913 $kgCO_2e$/ton compost

= 91.4054 $kgCO_2e$/ton compost

(5) GHG emissions from grid electricity used

Equation

GHG emissions ($kgCO_2$) = Quantity of electricity used (kWh) x Emission Factor ($kgCO_2e$/kWh)

Determine

Quantity of grid electricity used	=	112.10	kWh/ton compost
Emission factor of grid electricity	=	0.5610	$kgCO_2e$/kWh

Thus;

GHG emissions from grid electricity in the production process

= (112.10 kWh/ton compost) x (0.5610 $kgCO_2e$/kWh)

= 62.8881 $kgCO_2e$/ton compost

(6) GHG emissions from diesel fuel in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from diesel fuel production] + [GHG emissions from diesel fuel transportation] + [GHG emission from diesel fuel combustion]

GHG emission ($kgCO_2$) = Quantity of diesel fuel (L) x Emission Factor ($kgCO_2e$/L)

Determine

Quantity of diesel fuel used	=	8.00	L/ton compost
Emission factor of diesel fuel production	=	0.4293	kg CO_2e/L
Emission factor of diesel fuel combustion	=	2.7080	$kgCO_2e$/L
Density of diesel fuel	=	0.85	g/cm^3
Quantity of diesel fuel	=	0.0068	ton diesel/ton compost

Detail transportation following as

- 100% diesel, transportation by boat bulk distance 823 km
- 100% diesel, transportation by truck 6 wheel, 8.5 ton distance 211 km

GHG emissions from diesel fuel production = (8.00 L/ton compost) x (0.4293 kg CO_2e/L)

= 3.4344 $kgCO_2e$/ton compost

GHG emissions from diesel fuel transportation

= [(0.0068 tons diesel x 823 km x 0.002 $kgCO_2e$/ton-km) +

((0.0068/1,700,000 tons) x 823 km x 0.002 $kgCO_2e$/ton-km)]+

[(0.0068 tons diesel x 211 km x0.0672 $kgCO_2e$/ton-km) +

((0.0068 tons diesel/8.5 tons) x 211 km x 0.4238 $kgCO_2e$/ton-km)]

= [0.0112 + 0.0000 + 0.0964 + 0.0715] $kgCO_2e$/ ton compost

= 0.1791 $kgCO_2e$/ ton compost

GHG emissions from diesel fuel combustion = (8.00 L/ton compost) x (2.7080 $kgCO_2e$/L)

= 21.6640 $kgCO_2e$/ton compost

Thus;

GHG emissions from diesel fuel used in the production process

= [3.4344+ 0.1791 + 21.6640] $kgCO_2e$/ ton compost

= 25.2775 $kgCO_2e$/ton compost

(7) GHG emissions from composting section

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from CH_4] + [GHG emissions from N_2O]

Determine

Quantity of composting	=	1,800	ton compost
Quantity of EFB	=	3,600	ton EFB
Quantity of decanter cake	=	3,000	ton decanter cake
Emissions Factor of composting	=	0.043	kg CO_2/ton compost
Global Warming Potential (GWP) of Methane (CH_4)	=	25	kg CO_2/kg CH_4
Global Warming Potential (GWP) of Nitrous Oxide (N_2O)	=	310	kg CO_2/kg N_2O
Φ	=	0.9	
F	=	0.5	
DOC_f	=	0.5	
MCF	=	1	
DOC_j(EFB)	=	0.43	

Equation

$PE_{c,N2O,y}$ = Quantity of composting (ton) x Emission Factor x GWP_{N2O}

Thus

GHG emissions from N_2O = 0.043 kg N_2O/ ton compost x 310

= 13.3300 kg CO_2e/ ton compost

Equation

GHG emissions from CH_4

$PE_{CH4,Anaerobic,y} = \Psi(16/12)F \times DOC_f \times MCF \times GWP_{CH4} \times \sum\sum A_{project,j,x} \times DOC_j \cdot e^{-kj(y-x)}(1-e^{-kj})$

$PE_{CH4,Comp,y} = PE_{CH4,Anaerobic,y} \times S_{a,y}$

Thus;

$PE_{CH4,Anaerobic,y}$ = [0.9 x (16/12) x 0.5 x 0.5 x 1 x 25 x 3,600 ton x 0.43 x ($e^{-0.035(1-0)}$) x (1- $e^{-0.035}$)] +

[0.9 x (16/12) x 0.5 x 0.5 x25 x 3,000 ton x 0.15 x ($e^{-0.4(1-0)}$) x (1- $e^{-0.4}$)]

= 385.59 + 746.2125 kg CO_2e/ ton compost

= 1,131.8025 kg CO_2e/ ton compost

$PE_{CH4,Comp,y}$ = [1,131.8025 kgCO_2e/ton compost] x [60/365]

= 186.0497 kg CO_2e/ ton compost

Thus;

GHG emissions from composting section

= 13.3300 + 186.0497 kg CO_2e/ ton compost

= 199.3797 kg CO_2e/ ton compost

Therefore:

Total GHG emissions from composting process

= 7.5153 + 5.4844 + 1.2222 + 91.4054 + 62.8881 + 25.2775 + 199.3797

= 393.1726 kg CO_2e/ ton compost

B.3. GHG emission calculation for electricity generation process

(1) GHG emissions from EFB in the production process

Equation

GHG emissions (kgCO_2e) = [GHG emissions from EFB production] + [GHG emissions from EFB transportation] + [GHG emission from shell combustion]

- GHG emissions from EFB production

Equation

GHG emissions (kgCO_2e) = Quantity of EFB (kg) x Emission Factor (kgCO_2/ton EFB)

Determine

Quantity of EFB in the production process = 1.7116 tons EFB/MWh

Emission factor of EFB production = 0.00 kgCO_2/ton EFB

GHG emissions from EFB production

= (1.7116 tons EFB/MWh) x (0.00 $kgCO_2e$/ton EFB)

= 0.0000 $kgCO_2e$/MWh

- GHG emissions from EFB transportation into plant

Equation

GHG emissions ($kgCO_2$) = Quantity of EFB (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of EFB (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of EFB (tons) / Quantity of EFB in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of EFB into plant = 1.7116 ton EFB/MWh

Detail transportation following as:

- 25 % EFB, transportation by truck 18 wheel, 32 ton, distance 40 km
- 20 % EFB, transportation by truck 18 wheel, 32 ton, distance 70 km
- 25 % EFB, transportation by truck 10 wheel, 16 ton, distance 65 km
- 30 % EFB, transportation by truck 6 wheel, 11 ton, distance 10 km

GHG emissions from transportation into plant

= [(25%x1.71 tonsx40 kmx0.0441 $kgCO_2e$/ton-km) + ((25%x1.71 tons /32 tons) x40 kmx0.8612 $kgCO_2e$/km)] + [(20%x1.71 tonsx70 kmx0.0441 $kgCO_2e$/ton-km) + ((20%x1.71 tons /32 tons)x70 kmx0.8612 $kgCO_2e$/km)] + [(25%x1.71 tons x65 kmx0.0529 $kgCO_2e$/ton-km) + ((25%x1.71 tons /16 tons)x65 km x0.5851 $kgCO_2e$/km)] + [(30%x1.71 tonsx10 kmx0.0609 $kgCO_2e$/ton-km) + ((30%x1.71 tons /11 tons)x10 kmx0.4882 $kgCO_2e$/km)]

= [0.7541 + 0.4602] + [1.0557 + 0.6443] + [1.4699 + 1.0161] + [0.3124 + 0.2277] $kgCO_2e$/ MWh

= 5.9404 $kgCO_2e$/ MWh

- GHG emissions from EFB combustion

Equation

GHG emission ($kgCO_2$) = Quantity of EFB (ton) x Emission Factor($kgCO_2e$/ton)

Determine

Quantity of EFB used = 1.7116 tons EFB/MWh

Emission factor of EFB combustion = 0.00 $kgCO_2e$/ton EFB

GHG emissions from EFB combustion

= (1.7116 ton EFB/MWh) x (0.00 kg CO_2e/ton)

= 0.0000 $kgCO_2e/MWh$

Thus;

GHG emissions from EFB in the production process

= 0.0000 + 5.9404 + 0.0000 $kgCO_2e/MWh$

= 5.9404 $kgCO_2e/MWh$

(2) GHG emissions of fibers in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from fibers production] + [GHG emissions from fibers transportation] + [GHG emission from fibers combustion]

- GHG emissions from fibers production

Equation

GHG emissions ($kgCO_2e$) = Quantity of fibers (ton) x Emission Factor ($kgCO_2$/ton fibers)

Determine

Quantity of fibers in the production process = 0.6220 tons fiber/MWh

Emission factor of fibers production = 0.00 $kgCO_2$/ton fiber

GHG emissions from fibers production

= (0.6220 tons fibers/MWh) x (0.00 $kgCO_2$/ton fibers)

= 0.0000 $kgCO_2e/MWh$

- GHG emissions from fibers transportation into plant

Equation

GHG emissions ($kgCO_2$) = Quantity of fibers (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of fibers (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of fibers (tons) / Quantity of fibers in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of fibers into plant = 0.6220 ton fruit fiber/MWh

Detail transportation following as:

- 70% fiber, transportation by truck 10 wheel, 16 ton, distance 90 km
- 15% fiber, transportation by truck 10 wheel, 16 ton, distance 10 km
- 15 % fiber, transportation by truck 6 wheel, 11 ton, distance 1 km

GHG emissions from transportation of fibers into plant

= [(70%x0.622 tonsx90 kmx0.0529 $kgCO_2e$/ton-km) + ((70%x0.622 tons/16 tons)x90 kmx0.5851 $kgCO_2e$/km)]

+ [(15%x0.622 tonsx10 kmx0.0529 $kgCO_2e$/ton-km) + ((15%x0.622 tons/16 tons)x10 kmx0.5851 $kgCO_2e$/km)]

+ [(15%x0.622 tonsx1 kmx0.0609 $kgCO_2e$/ton-km) + ((15%x0.622 tons /11 tons)x1 kmx0.4882$kgCO_2e$/km)]

= [2.0729 + 1.4330] + [0.0493 + 0.0341] + [0.0057 + 0.0041] $kgCO_2e$/MWh

= 3.5991 $kgCO_2e$/MWh

- GHG emissions from fibers combustion

Equation

GHG emission ($kgCO_2$) = Quantity of fiberที่ (ton) x Emission Factor($kgCO_2e$/ton)

Determine

Quantity of fibers used = 0.6220 tons fiber /MWh

Emission factor of fibers combustion = 0.00 $kgCO_2e$/ton fiber

GHG emissions from fibers combustion

= (0.6220 ton fruit fiber/MWh) x (0.00 kg CO_2e/ton)

= 0.0000 $kgCO_2e$/MWh

Thus;

GHG emission from fibers in the production process

= 0.00 + 3.5991 + 0.00 $kgCO_2e$/MWh

= 3.5991 $kgCO_2e$/MWh

(3) GHG emissions from shells in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from shells production] + [GHG emissions from shells transportation] + [GHG emission from shells combustion]

- GHG emissions from shells production

Equation

GHG emissions ($kgCO_2$) = Quantity of shellที่ (ton) x Emission Factor ($kgCO_2e$/ton)

Determine

Quantity of shells used = 0.5809 tons shell/MWh

Emission Factor of shells production = 373.00 $kgCO_2e$/ ton shell

GHG emission from shells production

= (0.5809 tons shell/MWh) x (373.00 kg CO_2e/ton shell)

= 216.6757 $kgCO_2e$/MWh

- GHG emissions from shells transportation

Equation

GHG emissions ($kgCO_2$) = Quantity of shellท (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of shells (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of shells (tons) / Quantity of shells in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of shells = 0.5809 tons shell /MWh

Detail transportation following as:

- 60% shell, transportation by truck 10 wheel 16 ton, distance 40 km
- 40% shell, transportation by truck 6 wheel 11 ton, distance 10 km

GHG emissions from shells transportation

= [(60%x0.5809 tonsx40 kmx0.0529 $kgCO_2e$/ton-km) + ((60%x0.5809 tons/16 tons)x40 kmx0.5851 $kgCO_2e$/km)] + [(40%x0.5809 tonsx10 kmx0.0609 $kgCO_2e$/ton-km) + ((40%x0.5809 tons /11 tons)x10 kmx0.4882 $kgCO_2e$/km)]

= [0.7375 + 0.5098] + [0.1415 + 0.1031] $kgCO_2e$/MWh

= 1.4919 $kgCO_2e$/MWh

- GHG emissions from shells combustion

Equation

GHG emission ($kgCO_2$) = Quantity of shells (ton) x Emission Factor($kgCO_2e$/ton)

Determine

Quantity of shells used = 0.5809 tons shell/MWh

Emission factor of shells combustion = 0.00 $kgCO_2e$/ton shell

GHG emissions from shells combustion

= (0.5809 ton shell/MWh) x (0.00 kg CO_2e/ton)

= 0.0000 kgCO_2e/MWh

Thus;

GHG emissions from shells in the production process

= 216.6757 + 1.4919 + 0.0000 kgCO_2e/MWh

= 218.1676 kgCO_2e/MWh

(4) GHG emissions from chemical in the production process

(4.1) NaOH

- GHG emissions from NaOH in the production process

Equation

GHG emissions (kgCO_2) = [GHG emissions from NaOH production + GHG emissions from NaOH transportation]

- GHG emissions from NaOH production

Equation

GHG emissions (kgCO_2) = Quantity of NaOH (kg) x Emission factor (kgCO_2e/kg$_{Chemical}$)

Determine

Quantity of NaOH in the production process = 0.5149 kg NaOH/MWh

Emission Factor of NaOH production = 1.0377 kg CO_2e/kg NaOH

GHG emissions from NaOH production

= (0.5149 kg NaOH/MWh) x (1.0377 kg CO_2e/kg NaOH)

= 0.5343 kgCO_2e/MWh

- GHG emission from NaOH transportation into plant

Equation

GHG emissions (kgCO_2) = Quantity of NaOH (tons) x Average one-way distance (km) x Emission Factor from transportation (kgCO_2e/ton-km)

GHG Emissions (kgCO_2) = [Quantity of NaOH (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load (kgCO_2e/ton-km)] + [(Quantity of NaOH (tons) / Quantity of urea in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload (kgCO_2e/ton-km)]

Determine

Quantity of NaOH into plant = 0.0005 tons NaOH/MWh

Detail transportation following as:

- 100% NaOH, transportation by truck 10 wheel 16 ton, distance 823 km

GHG emissions from NaOH transportation

= [(100%x0.0005 tons)x(823 km)x(0.0529 $kgCO_2e$/ton-km)]+ [((100%x0.0005tons)/16)x(823 km)x(0.5851 $kgCO_2e$/ km)]

= 0.0218 + 0.0150 $kgCO_2e$/ MWh

= 0.0368 $kgCO_2e$/ MWh

GHG emissions from NaOH in the production process

= (0.5343 $kgCO_2e$/MWh) + (0.0368 $kgCO_2e$/MWh)

= 0.5711 $kgCO_2e$/MWh

(4.2) Anionic Polymer

- GHG emissions from anionic polymer in the production process

Equation

GHG emissions ($kgCO_2$) = [GHG emissions from anionic polymer production + GHG emissions from anionic polymer transportation]

Determine

Quantity of anionic polymer in the production process = 0.1204 kg anionic polymer/MWh

Emission Factor of anionic polymer process = 0.3500 $kgCO_2e$/kg anionic polymer

GHG emissions from anionic polymer production

= (0.1204 kg anionic polymer/MWh) x (0.3500 $kgCO_2e$/kg anionic polymer)

= 0.0421 $kgCO_2e$/MWh

- GHG emissions from anionic polymer transportation into plant

Equation

GHG emissions ($kgCO_2$) = Quantity of anionic polymer (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of anionic polymer (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of anionic polymer (tons) / Quantity of anionic polymer in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of anionic polymer into plant = 0.0001 ton anionic polymer/MWh

Detail transportation following as:

- 100% anionic polymer, transportation by truck 10 wheel, 16 ton, distance 823 km

GHG emissions from anionic polymer transportation

= [(100%x0.0001 tons)x(823 km)x(0.0529 $kgCO_2e$/ton-km)]+ [(100% x0.0001 tons/16)x(823 km)x(0.5851 $kgCO_2e$/km)]

= 0.0043 + 0.0030 $kgCO_2e$/MWh

= 0.0073 $kgCO_2e$/MWh

GHG emissions from anionic polymer in the production process

= (0.0421 $kgCO_2e$/MWh) + (0.0073 $kgCO_2e$/MWh)

= 0.0494 $kgCO_2e$/MWh

(4.3) Alum

- GHG emissions from alum in the production process

Equation

GHG emissions ($kgCO_2$) = [GHG emissions from alum production + GHG emissions from alum transportation]

- GHG emissions from alum production

Determine

Quantity of alum in the production process = 0.1070 kg alum/MWh

Emission Factor of alum production = 0.2770 kg CO_2e/kg alum

GHG emissions from alum production

= (0.1070 kg alum/MWh) x (0.2770 kg CO_2e/kg alum)

= 0.0296 $kgCO_2e$/MWh

- GHG emissions from alum transportation

Equation

GHG emissions ($kgCO_2$) = Quantity of alum (tons) x Average one-way distance (km) x Emission Factor from transportation ($kgCO_2e$/ton-km)

GHG Emissions ($kgCO_2$) = [Quantity of alum (tons) x Average one-way distance, arrival (km) x Emission factor for the truck of load ($kgCO_2e$/ton-km)] + [(Quantity of alum (tons) / Quantity of alum in one-way transportation) x Average one-way distance, departure (km) x Emission factor for the truck of Noload ($kgCO_2e$/ton-km)]

Determine

Quantity of alum into plant = 0.0001 ton alum/MWh

Detail transportation following as:

- 100% alum, transportation by truck 10 wheel 16 ton, distance 823 km

GHG emissions from alum transportation

= [(100%x0.0001 ton alum/MWh)x(823 km)x(0.0529 $kgCO_2e$/ton-km)]+

[(100%x0.0001 ton alum/MWh)/16)x(823 km)x(0.5851 $kgCO_2e$/ km)]

= 0.0043 + 0.0030 $kgCO_2e$/MWh

= 0.0073 $kgCO_2e$/MWh

GHG emissions from alum in the production process

= 0.0296 $kgCO_2e$/MWh + 0.0073 $kgCO_2e$/MWh

= 0.0369 $kgCO_2e$/MWh

Thus;

GHG emissions from chemical used in the production process

= 0.5711 + 0.0494 + 0.0369 $kgCO_2e$/MWh

= 0.6574 $kgCO_2e$/MWh

(5) GHG emissions from diesel fuel in the production process

Equation

GHG emissions ($kgCO_2e$) = [GHG emissions from diesel fuel production] + [GHG emissions from diesel fuel transportation] + [GHG emission from diesel fuel combustion]

GHG emission ($kgCO_2$) = Quantity of diesel fuel (L) x Emission Factor ($kgCO_2e$/L)

Determine

Quantity of diesel fuel used	=	0.6518	L/MWh
Emission factor of diesel fuel production	=	0.4293	kg CO_2e/L
Emission factor of diesel fuel combustion	=	2.7080	$kgCO_2e$/L
Density of diesel fuel	=	0.85	g/cm^3
Quantity of diesel fuel	=	0.0006	ton diesel/MWh

Detail transportation following as

- 100% diesel, transportation by boat bulk distance 823 km
- 100% diesel, transportation by truck 6 wheel, 8.5 ton distance 211 km

GHG emissions from fossil fuel production = (0.6518 L/MWh) x (0.4293 kg CO_2e/L)

= 0.2798 $kgCO_2e/MWh$

GHG emissions from diesel fuel transportation

= [(0.0006 tons diesel x 823 kmx 0.002 $kgCO_2e$/ton-km) +

((0.0006/1,700,000 tons) x 823 km x 0.002 $kgCO_2e$/ton-km)]+

[(0.0006 tons diesel x 211 km x0.0672 $kgCO_2e$/ton-km) +

((0.0006 tons diesel/8.5 tons) x 211 km x 0.4238 $kgCO_2e$/ton-km)]

= [0.0010 + 0.000+ 0.0085 + 0.0063] $kgCO_2e$/ ton compost

= 0.0158 $kgCO_2e$/ ton compost

GHG emissions from diesel fuel combustion = (0.6518 L/MWh) x (2.7080 $kgCO_2e$/L)

= 1.7651 $kgCO_2e/MWh$

Thus;

GHG emissions from diesel fuel used in the production process

= [0.2798+ 0.0158 + 1.7651] $kgCO_2e/MWh$

= 2.0607 $kgCO_2e/MWh$

(6) GHG emissions from waste water system without biogas in the production process

Equation

$$e_{wastewater}(kgCO_2e) = e_{Wastewater,\ treatment}\ (kgCO_2e) + e_{Sludge,\ treatment}\ (kgCO_2e) + e_{Wastewater,\ discharge}\ (kgCO_2e) + e_{Sludge,\ final}\ (kgCO_2e) + e_{Fugitive}\ (kgCO_2e) + e_{Biomass}\ (kgCO_2e) + e_{Flaring}\ (kgCO_2e)$$

Determine

Volume of wastewater treated in wastewater treatment system = 1.6887 m^3/MWh

COD wastewater from production process (inflow COD) = 63,920 mg/L

COD inlet to biogas system = 61,440 mg/L

COD outlet from biogas system = 1,612 mg/L

COD treated wastewater in final pond (outflow COD) = 437 mg/L

No discharging of treated water

No sludge treatment system and no sludge dredging

No biomass treatment

80 % efficiency of biogas capture system

Flare condition

- Volumetric flow rate of the residual gas = 0.00 m^3/MWh
- Volumetric fraction of methane in the residual gas = 0 %
- Flare efficiency = 80 % (Enclosed flares)

Calculation;

(6.1) $e_{Wastewater,\ treatment}\ (kgCO_2e) = \sum_i Q_{ww,i,y} \times COD_{removed,i,y} \times MCF_{ww,treatment,BL,I} \times B_{o,ww} \times UF_{BL} \times GWP_{CH4}$

By;

$e_{Wastewater,\ treatment,\ oxidation\ pond}$ = 1.6887 m^3 x (63,920 – 61,440) mg/L x 0.8 x 0.25 kg CH_4/kg COD x 0.89 x 25

= 18.6365 kg CO_2e/MWh

$e_{Wastewater,\ treatment,final\ pond}$ = 1.6887 m^3 x (1,612 – 437) mg/L x 0.8 x 0.25 kg CH_4/kg COD x 0.89 x 25

= 8.8297 kg CO_2e/MWh

GHG emissions from wastewater treatment = 18.6365 + 8.8297 kg CO_2e/MWh

= 27.4662 kg CO_2e/MWh

(6.2) $e_{Sludge,\ treatment}\ (kgCO_2e) = \sum_i S_{j,BL,y} \times MCF_{s,\ treatment,\ BL,\ j} \times DOC_s \times UF_{BL} \times DOC_F \times F \times (16/12) \times GWP_{CH4}$

= 0.00 kg CO_2e/MWh (No sludge treatment)

(6.3) $e_{Wastewater,\ discharge}\ (kgCO_2e) = Q_{ww,y} \times GWP_{CH4} \times B_{o,ww} \times UF_{BL} \times COD_{ww,\ discharge,\ BL,\ y} \times MCF_{ww,BL,discharge}$

= 0.00 kg CO_2e/MWh (No discharging of treated water)

(6.4) $e_{Sludge,\ final}\ (kgCO_2e) = S_{Final,\ BL,\ y} \times DOC_s \times UF_{BL} \times MCF_{s,\ BL,\ final} \times DOC_F \times F \times (16/12) \times GWP_{CH4}$

= 0.00 kg CO_2e/MWh (No sludge dredging)

(6.5) $e_{Fugitive}\ (kgCO_2e) = e_{fugitive,ww} + e_{fugitive,\ s}$

By

$e_{fugitive,ww}$ = $(1- CEF_{ww}) \times MEP_{ww,\ treatment} \times GWP_{CH4}$

= $(1- CE_{ww}) \times (Q_{ww} \times B_{o,ww} \times UF_{PJ} \times \sum_k COD_{removed,PJ,k} \times MCF_{ww,treatment,PJ}) \times GWP_{CH4}$

= (1 - 0.9) x (1.6887 x 0.25 kg CH_4/kg COD x 0.89 x (61,440 - 1,612)mg/L x 0.8 x 25

= 44.9590 kg CO_2e/MWh

$e_{fugitive,\ s}$ = $(1- CEF_s) \times MEP_{s,\ treatment} \times GWP_{CH4}$

= $(1- CEF_s) \times (\sum_l (S_{l,PJ} \times MCF_{s,treatment,PJ,l}) \times DOC_s \times UF_{PJ} \times DOC_F \times F \times (16/12)) \times GWP_{CH4}$

= 0.00 kg CO_2e/MWh

GHG emissions from fugitive = (44.9590 + 0.00) kg CO_2e/MWh

= 44.9590 kg CO_2e/MWh

(6.6) $e_{Biomass}$ ($kgCO_2e$) = 0.00 kg CO_2e/MWh

(6.7) $e_{Flaring}$ ($kgCO_2e$) = $TM_{RG,y}$ x (η -$1_{Flare,y}$) x $GWP_{CH}1000/_4$

= ($FV_{RG,h}$ x $fv_{CH4,RG,h}$ x $\rho_{CH4,n,h}$) x (η -$1_{Flare,y}$) x $GWP_{CH}1000/_4$

= 0.00 kg CO_2e/MWh (No flaring gas)

Thus;

GHG emissions from wastewater system with biogas from production process

= (27.4662 + 0.00 + 0.00 + 0.00 + 44.9590 + 0.00 + 0.00) kg CO_2e/MWh

= 72.4252 kg CO_2e/MWh

Therefore;

Total GHG emissions from electricity generation process

= 5.9404 + 3.5991 + 218.1676 + 0.6574 + 2.0607 + 72.4252

= 302.8504 $kgCO_2e$/MWh

VITAE

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Bunchai, A., H-Kittikun, A., Suttinun, O., and Musikavong, C. (2011). Evaluation of Greenhouse Gas Emission from Dry Extraction Process of Palm Oil Mill. Proceeding of the 10th National Environmental Conference. March 23-25, Songkhla, Thailand.