Guideline for Greenhouse Gas Emissions Calculation of Bioenergy Feedstock Production and Land Use Change (LUC):

A case study of Khon Kaen Province, Thailand

Authors

Dr.Thapat Silalertruksa

Dr. Jintana Kawasaki

March 2015

KMUTT SIIT-TU KMITNB CMU PSU JGSEE The Joint Graduate School of Energy and Environment

IGES Institute for Global Environmental Strategies

Ministry of the Environment

Guideline for Greenhouse Gas Emissions Calculation of Bioenergy Feedstock Production and Land Use Change (LUC):

A case study of Khon Kaen Province, Thailand

Authors

Dr. Thapat Silalertruksa[1]

Dr. Jintana Kawasaki[2]

[1]Life Cycle Sustainability Assessment Laboratory, The Joint Graduate School of Energy and Environment (JGSEE), King Mongkut's University of Technology Thonburi, 126 Pracha-uthit Rd., Bangmod, Tungkru, Bangkok 10140 THAILAND

[2]Institute for Global Environmental Strategies, Natural Resources and Ecosystem Service Area, 2108-11 Kamiyamaguchi, Hayama, Kanagawa 240-0115 JAPAN

Financial Support: Ministry of Environment, Japan

INTRODUCTION

Life cycle greenhouse gas (GHG) emissions of bioenergy is known as an important environmental sustainability indicators. It is used to refer to the standards in bioenergy production under the EU Renewable Energy Directive (EU-RED), the Global Bioenergy Partnership (GBEP), and the US Renewable Fuel Standard (RFS) program (BEFSCI, 2010; Carre et al., 2010). In addition, the potential for bioenergy use to reduce GHG emissions in comparison with fossil fuel use can be evaluated using the life cycle approach.

In practice, the results of life cycle GHG emissions can be different depending on the assumptions made for the calculations. Studies have revealed that the stage of bioenergy feedstock cultivation in the life cycle of bioenergy production contributes significantly to environmental impacts. The complexity assessment of bioenergy feedstock cultivation includes the agricultural land use and management associated with various GHG emissions and removals e.g. CO_2 emissions and removals resulting from C stock changes in biomass and soil organic matter, non-CO_2 emission from fire and the managed land, and N_2O emissions from fertilizer applications (FAO, 2014).

The benefit of biofuels for GHG emissions mitigation can be criticized, if "*Land use change (LUC)*" is not taken into account in the life cycle GHG emissions calculation of the feedstock production. Moreover, towards the sustainable food and fuel production along with forest conservation, the appropriate arable land use and management as well as the good agricultural practices to improve crop productivity are necessary for the specific location, and contribute to provide recommendations for policy makers and farmers.

An increasing demands of food and bioenergy lead causes of deforestation and competing uses of agricultural land for food-energy crops production in Thailand. Past and on-going agricultural areas under rice cultivation have been converted to biofuel feedstock and forest land encroachment for biofuel feedstock production. Due to the different biofuel feedstock production practices in the different location, the GHG emissions assessment framework here is intended to provide general guideline for calculating GHG emissions of bioenergy crops production using the methodology of life cycle approach.

LIFE CYCLE GHG EMISSIONS CALCULATION OF BIOENERGY CROPS PRODUCTION

The guideline is intended to provide the methodology for conducting the assessment of the life cycle GHG emissions at the bioenergy feedstock production stage including direct land-use change. The specific case study of biofuel feedstock production like sugarcane in Khon Kaen Province in the northeast of Thailand has been used for elaboration the methodology. This guideline is designed by putting as the common methodological framework that users should consider in their study on the life cycle GHG assessment of bioenergy crops production. In practice, different bioenergy crop production systems may have the difference in scope and assumptions which must be designed specifically case-by-case by the users. The guideline includes the following topics:

(1) Definition of functional unit and reference flows
(2) GHG covered and global warming potential (GWP) values
(3) General life cycle GHG emissions calculation of bioenergy/biofuel
(4) Life cycle GHG emissions calculation of bioenergy crop production: a case study of Khon Kaen Province, Thailand

1. DEFINITION OF FUNCTIONAL UNIT AND REFERENCE FLOWS

In lifecycle assessment (LCA), the functional unit is the reference for evaluating products or services on a common basis (Nemecek et al., 2014). The reference flow is the amount of product or activity required in order to fulfil the functional unit. Nevertheless, in various studies on LCA which the scope of the assessment is limited at the production stage e.g. agricultural production, the basis for the assessment as well as the inventory data collected will be typically rely on the reference flow. For example, to assess the life cycle of bioenergy feedstock production, the reference flow for assessment is generally based on a mass reference e.g. one kilogram or one ton of feedstock sugarcane. For bioenergy production stage, the reference flow for assessment is generally be calorific value reference of bioenergy as well as biofuels e.g. MJ of bio-ethanol. However, if the life cycle assessment is considered covering on the use stage of bioenergy, the functional unit can based on the efficiency of bioenergy/biofuels when they are used to replace fossil fuel e.g. based on the kilometer driven distance by car for the case of biofuels. **Table 1** shows the main life cycle stage of bioenergy and examples of reference flows/functional units that can be applied.

Table 1 Life cycle stage of bioenergy and examples of reference flows

	Life cycle stage		
	Feedstock production	Bioenergy production	Bioenergy use
Examples of the reference flows/ functional units at the end of each life cycle stage	1 kg output of crop product, at farm exit gate 	1 MJ of bioenergy product BIOFUEL	1 MJ of bioenergy used or 1 km of driven distance of the car using biofuel 

2. GHGs Covered and Global Warming Potential (GWP) Values

Since there are a number of GHGs available, and the Global Warming Potential (GWP) values of them will be revised regularly by the Intergovernmental Panel on Climate Change (IPCC). Therefore, it is necessary to provide the scope of GHGs covered and the impact assessment method used for the transparency of the assessment. The GHGs consist of Carbon dioxide (CO_2), Dinitrogen oxide (N_2O) and Methane (CH_4). The impacts of the non-CO_2 GHGs are expressed in terms of the equivalent amount of CO_2 (CO_2eq). The equivalency factors of the different gases are dependent on the time over. The equivalency is calculated since different gases have different residence times in the atmosphere. Based on the 4th IPCC Assessment Report (2007), the "100 years" Global Warming Potential values of GHGs are referred (IPCC, 2007). For example, in the study, the three greenhouse gases are considered for the life cycle GHG emissions assessment of bioenergy crop production i.e. CO_2, CH_4 and N_2O. **Table 2** shows the checklist for clarifying the scope of GHGs considered in the study.

Table 2 Checklist for GHGs covered and Global Warming Potential (GWP) values

GHG substances covered		GWP Values (kg CO_2eq/kg GHG substance)	Reference
☒	Carbon dioxide (CO_2)	1	IPCC (2007)
☒	Methane (CH_4)	25	
☒	Dinitrogen oxide (N_2O)	298	

3. General Life cycle GHG emissions calculation of bioenergy/biofuel

Figure 1 shows the simplified biofuel system which consists of (1) land use change, (2) feedstock production, (3) feedstock processing, (4) biofuel production and (5) use of biofuel in the vehicle. In addition, the transportation of raw material as well as the intermediate products associated with the production processes of each life-cycle stage is generally accounted into the life cycle GHG assessment of biofuel/bioenergy.

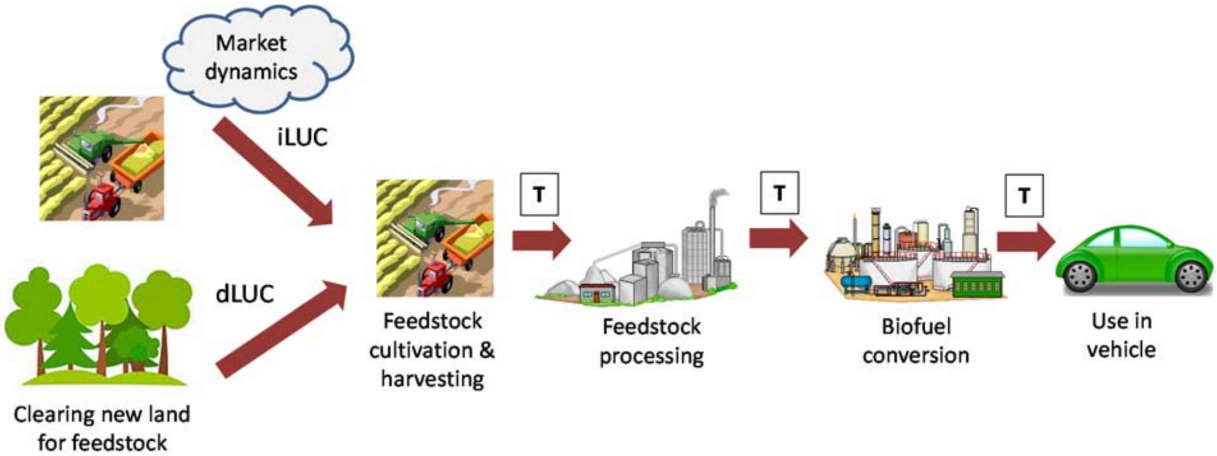

Figure 1 Life cycle stages associated with biofuels

Equation (1) is the standard formula that widely used for GHG emissions calculation of bioenergy/biofuel. The equation is given in the EU Directives 2009/28/EC (the directive on the promotion and the use of energy from renewable energy resource) and also used by the International Sustainability & Carbon Certification (ISCC) to calculate the overall GHG emissions of bioenergy supply chain (ISCC, 2011).

Equation (1): General formula for LC-GHG emissions calculation of bioenergy

$$E = E_{ec} + E_{lu} + E_{p} + E_{td} + E_{u} - E_{sca} - E_{ccs} - E_{ccr} - E_{ee}$$

Where:

- E = Total emissions from the use of the fuel (kg CO_2eq/unit of bioenergy product)
- E_{ec} = Emissions from the extraction or cultivation of raw materials
- E_{lu} = Annualized emissions from carbon stock changes caused by land-use change

- E_p = Emissions from processing
- E_{td} = Emissions from transportation and distribution
- E_u = Emission from the fuel in use
- E_{sca} = Emission saving from soil carbon accumulation via improved agricultural practices
- E_{ccs} = Emission saving from carbon capture and geological storage
- E_{ccr} = Emission saving from carbon capture and replacement
- E_{ee} = Emission saving from excess electricity from cogeneration

4. Life cycle GHG emissions calculation of bioenergy crop production: A case study of Khon Kaen Province, Thailand

As mentioned earlier, the methodological guideline provided in this study will be focused on the scope of GHG calculation of biofuel feedstock production especially the GHG emissions of crop products. Equation (2) is therefore modified from the Equation (1) to use as the standard formula for calculating the life cycle GHG emissions of bioenergy crop plantation in the study sites in Thailand. The GHG emissions sources associated with bioenergy crop production system are as follows:

1. Land Use Change and Management (E_{LU})
2. Manufacturing of fertilizers, agrochemicals, materials used in farming (E_{ec})
3. Emissions of N_2O and CO_2 resulted from fertilizers application (E_{field})
4. Fossil fuel used in the field operation (E_{field})
5. Transportation of material (E_{td})
6. GHG emissions credits from the improved agricultural practices (E_{crd})

Equation (2): Total LC-GHG emissions of energy crop plantation

$$E_{Total} = E_{LU} + E_{ec} + E_{field} + E_{td} - E_{crd}$$

Where:

- E_{Total} = Total GHG emissions of energy crop production (kg CO_2eq/ha-year)
- E_{LU} = Annualized GHG emissions from C-Stock changes caused by land-use change and management during land clearance before cultivation (kg CO_2eq/ha-year).
- E_{ec} = GHG emissions from production of input materials including fertilizers, agrochemicals, etc. (kg CO_2eq/ha-year)
- E_{field} = GHG emissions occurred during plantation activities e.g. direct and indirect N_2O emissions from the applied fertilizers, and GHG emissions from combustion of fuels in agricultural machinery (kg CO_2eq/ha-year)
- E_{td} = GHG emissions caused by transportation of raw materials used (kg CO_2eq/ha-year)
- E_{crd} = GHG emissions credits from the improved agricultural practices (kg CO_2eq/ha-year)

The life cycle GHG emissions of energy crop plantation as shown in Equation (2) is generally calculated based on the mass reference unit of about "*a ton of crop product, at farm exit gate*", for example, a ton of sugarcane at farm exit gate. To determine the GHG emission as per ton of crop product, the total GHG emissions obtained Equation (2) will be divided by the agricultural productivity per hectare per year as shown in Equation (3).

Equation (3): Total GHG emissions of a ton crop product (at farm exit gate)

$$E_{Crop} = E_{Total}/Q_{Crop}$$

Where:

- E_{Crop} = Total GHG emissions of energy crop (kg CO_2eq/ton crop product)
- E_{Total} = Total GHG emissions from the life cycle of crop production (kg CO_2eq/ha-year)
- Q_{Crop} = Amount of crop produced in one year (ton crop product/ha-year)

4.1 Emissions from Land Use Change (E_{LU})

Land use change (LUC) can be classified into two types i.e. "*Direct Land-Use Change (DLUC)*" and "*Indirect Land-Use Change (ILUC)*". DLUC occurs when a plot of land either natural lands like forests, native grasslands or agricultural lands e.g. croplands are displaced for growing bioenergy crops (IEA Bioenergy, 2010; Alberici and Hamelinck, 2010). Meanwhile, ILUC is the consequential effect from the displacement of land currently used for agriculture e.g. food production to bioenergy crop production. In other words, ILUC refers to the ripple effects if the new bioenergy crops are grown by taking place on the existing agricultural land (WBGU, 2010; Ros et al., 2010). The major concern on DLUC for bioenergy crop on carbon stock change and GHG emissions is the conversion of natural forest lands for bioenergy production. However, the most concern on ILUC for bioenergy crop is not only the consequences of ILUC on net GHG emissions of bioenergy but also the consequences of ILUC on arable land competition and food security. However, since the ILUC issues and models for ILUC assessment for bioenergy are currently under development and debating due to the high variables with the market factors and it occurs outside normal geographic and temporal boundaries of analysis. Thus, the ILUC issue is excluded from the scope of this study.

Step 1: Identify reference land use and period

The reference land use prior to be changed to the land for bioenergy/biofuels crops cultivation and the time period (T) over which direct land use change emissions are allocated, that must be identified in the calculation. For example, the EU-RED has defined that the reference land use shall be the land use in January 2008 or 20 years before the bioenergy crop products was obtained, whichever is the later. In general, the time period of land being use after conversion will be referred to the IPCC's default value i.e. "**20 years**" (Carre et al., 2010; European Commission, 2009). However, for the case of perennial, the full life cycle of perennial plant can be used. For instance, the Roundtable on Sustainable Palm Oil (RSPO) has considered the time period over the full life cycle of oil palm at **"25 years"** (Chase et al., 2012).

Step 2: Identify types of land use change

The 2006 IPCC Guidelines defines the types of land use into six categories i.e. Forest land, Cropland, Grassland, Wetlands, Settlements and other lands. However, the potential land-use changes for bioenergy crop plantation in Thailand can be summarized as Table 3. Croplands are classified into two types i.e. perennial and annual cropland. For example, sugarcane and cassava plantations are classified as annual cropland; meanwhile, plantations of fruit, oil palm, oranges, tangerines, mandarins, etc. are defined as perennial cropland.

Table 3 Potential land-use changes for bioenergy crop plantation in Thailand

Type of reference land (Before conversion)	**Land use/activity**	**Types of actual land use for bioenergy crop plantation (After conversion)**	
		Perennial Cropland (PCL)	**Annual Cropland (ACL)**
	Forest land (FL)	FL converted PCL (FL – PCL)	FL converted ACL (FL – ACL)
	Grassland (GL)	GL converted to PCL (GL – PCL)	GL converted to ACL (GL – ACL)
	Perennial Cropland (PCL)	PCL remaining PCL (PCL – PCL)	PCL converted to ACL (PCL – ACL)
	Annual Cropland (ACL)	ACL converted to PCL (ACL – PCL)	ACL remaining ACL (ACL – ACL)

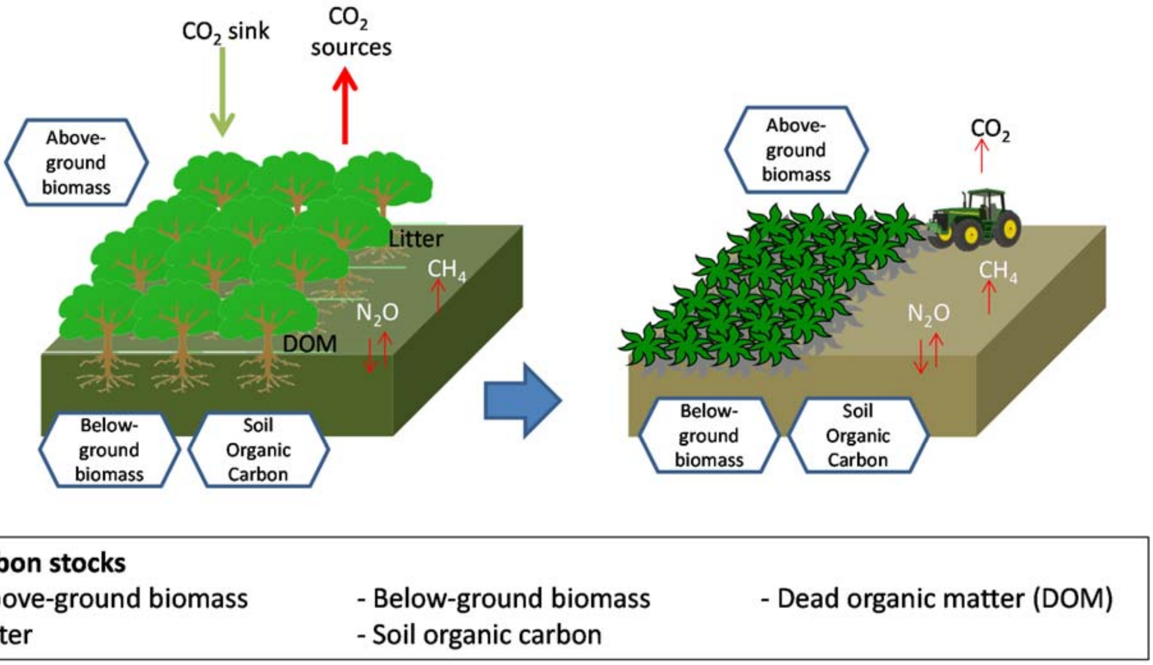

Figure 2 Direct land-use change and carbon sources and sinks

Step 3: Identify methodology for GHG emissions assessment of land use change

There are two approaches for assessing GHG emissions of land use for agricultural and forestry activities i.e. "stock-difference" and "gain-loss" approaches (IPCC, 2006). The stock-difference method determines the net change in carbon stocks resulting from the land-use change and then estimates the total CO_2 impacts over its lifetime by assuming that any change in carbon stocks will represent in atmospheric carbon, in the form of CO_2. Meanwhile, the gain-loss approach will determine the net CO_2 impact of bioenergy project by accounting for CO_2 emissions and carbon sequestration on an annual basis throughout the project lifetime. Equation (4) shows the standard formula of the IPCC's stock-based approach. This method is also referred in the EU directive to estimate annualized emissions from carbon stock changes of a plot of land use for bioenergy.

Equation (4): GHG emissions caused by LUC

$$E_{LU} = \left(\frac{CS_R - CS_A}{T}\right) \times 3.664 + \frac{E_{fire,Non-CO2}}{T}$$

Where:

- E_{LU} = Annualized emissions from carbon stock changes caused by LUC (kg CO_2-eq/ha-year)
- CS_R and CS_A = Carbon stock per unit area associated with the reference land (land prior to convert to bioenergy crop plantation) and the actual land (land use for bioenergy crop plantation) (kg C/ha).
- T = Time period of land being use after conversion (the IPCC's default value is 20 years)
- Constant "3.664" is the conversion factor for mass carbon to mass carbon dioxide (CO_2)
- $E_{fire,Non\text{-}CO2}$= Annualized GHG (Non-CO_2) emissions occurred from the biomass that is actually burnt during the clearance of native forest or native grasslands (kg CO_2eq/ha)

Step 4: Perform carbon stock calculations

(4.1) Land Carbon Stock (CS)

Land carbon stock consists of (1) carbon stored in the biomass (C_B), (2) carbon stored in the dead organic carbon (C_{DOM}), and (3) carbon stored in the soil or namely soil organic carbon (C_{SOC}) as shown in **Figure 2**. The carbon stocks per unit area associated with the reference land use (CS_R) and the actual land use for bioenergy crop plantation (CS_A) as indicated in the **Equation (4)** can be calculated based on IPCC rules and assumptions which details are described below.

$$CS = (C_{VEG} + C_{SOC}) \times A \qquad \text{(Equation 4.1)}$$

Where:

- A = Land area of the stratum being estimated (Ha) [1 Hectare (Ha) = 6.25 Rai]
- CS = Carbon stock of land concerned (t C/ha)
- C_{VEG} = Carbon stock in the above and below ground vegetation (C_{VEG}) (t C/ha)
- C_{SOC} = Carbon stock in the soil (C_{SOC}) (t C/ha)

(4.2) Above and Below Ground Vegetation Carbon Stock (C_{VEG})

$$C_{VEG} = C_B + C_{DOM} \qquad \text{(Equation 4.2)}$$

Where:

- C_{VEG} = Above and below ground vegetation carbon stock (t C/ha)
- C_B = Above and below ground carbon stock in living biomass (t C/ha)
- C_{DOM} = Above and below ground carbon stock in dead organic matter (t C/ha), the value for C_{DOM} can be considered as "0" unless the land use type concerned is the continuously forested area (European Commission, 2009)

(4.2.1) Living Biomass

$$C_B = C_{AGB} + C_{BGB} \qquad \text{(Equation 4.2.1)}$$

Where:

- C_B = Carbon stock in the above and below ground living biomass (t C/ha)
- C_{AGB} = Carbon stock in the above ground living biomass (t C/ha); whereas $C_{AGB} = B_{AGB} \times CF_B$
- C_{BGB} = Carbon stock in the below ground living biomass (t C/ha); whereas $C_{BGB} = B_{BGB} \times CF_B$ or else $C_{BGB} = C_{AGB} \times R$
- B_{AGB} = Mass of above ground living biomass (t biomass dry matter/ha); the value for B_{AGB} shall be the weight of the above ground living biomass at half-life of the production cycle for the case of annual and perennial crops, and forest plantations (European Commission, 2009)
- B_{BGB} = Mass of below ground living biomass (t biomass dry matter/ha)
- CF_B = Carbon fraction of dry matter in the living biomass (t C/t dry matter); the value of 0.47 can be used as the default value (European Commission, 2009)
- R = Ratio of carbon stock in the below ground living biomass to carbon stock in the above ground living biomass; the values for R has been provided in IPCC guidelines (IPCC, 2006)

(4.2.2) Dead Organic Matter

$$C_{DOM} = C_{DW} + C_{LI} \qquad \text{(Equation 4.2.2)}$$

Where:

- C_{DOM} = Above and below ground carbon stock in dead organic matter (t C/ha),
- C_{DW} = Carbon stock in dead wood pool (t C/ha); $C_{DW} = DOM_{DW} \times CF_{DW}$
- DOM_{DW} = Mass of dead wood pool (t dry matter/ha)
- CF_{DW} = Carbon fraction of dry matter in dead wood pool (t C/t dry matter), the default value of 0.5 may be used for CF_{DW} (European Commission, 2009**)**
- C_{LI} = Carbon stock in litter (t C/ha); $C_{LI} = DOM_{LI} \times CF_{LI}$
- DOM_{LI} = Mass of litter (t dry matter/ha)
- CF_{LI} = Carbon fraction of dry matter in litter (t C/t dry matter), the value of 0.4 may be used as default value for CF_{DW} **(**European Commission, 2009**)**

Based on the IPCC Tier 1 assumption, carbon stocks in litter and dead wood (C_{DOM}) in alll non-forest land-use categories are "zero"

Table 4 C_{VEG} values for forestland with more 30% canopy cover, excluding plantation (t C/ha)

Continent	Tropical rain forest	Tropical, moist	Tropical, dry	Tropical mountain	Subtropical, humid	Subtropical, dry	Subtropical, steppe	Temperate, oceanic	Temperate, continental	Temperate, mountain	Boreal, coniferous	Boreal, mountain
Africa	204	156	77	77		88	46					
Asia (continental)	185	110	83	88	109	109	41		87	93	53	53
Asia (insular)	230	174	101	101	173	173	47		87	93	53	53
Europe								84	87	93	53	53
North America	198	133	131	94	132	130	53	406	93	93	53	53
New Zealand								227				
South America	198	133	131	94	132	130	53	120	93	93	53	53
World average	**203**	**141.2**	**104.6**	**90.8**	**136.5**	**126**	**48**	**209.25**	**89.4**	**93**	**53**	**53**

Remark: Values are derived based on the EU COMMISSION DECISION of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC, Official Journal of the European Union, L 151/19

Source: Blonk consultants: Direct LUC Assessment Tool Version 2014.1 (2014); Carre et al. (2010)

Table 5 C_{VEG} values for grassland (t C/ha)

Continent	Boreal grassland	Cold temperate dry grassland	Cold temperate wet grassland	Warm temperate dry grassland	Warm temperate wet grassland	Tropical dry grassland	Tropical moist & wet grassland
Africa	4.0	3.1	6.4	2.9	6.3	4.1	7.6
Asia (continental)	4.0	3.1	6.4	2.9	6.3	4.1	**7.6**
Asia (insular)	4.0	3.1	6.4	2.9	6.3	4.1	7.6
Europe	4.0	3.1	6.4	2.9	6.3	4.1	7.6
North America	4.0	3.1	6.4	2.9	6.3	4.1	7.6
New Zealand	4.0	3.1	6.4	2.9	6.3	4.1	7.6
South America	4.0	3.1	6.4	2.9	6.3	4.1	7.6
Average	**4.0**	**3.1**	**6.4**	**2.9**	**6.3**	**4.1**	**7.6**

Remark: Derived from IPCC 2006 Guidelines based on *47% carbon content of dry matter biomass*

Source: Blonk consultants: Direct LUC Assessment Tool Version 2014.1 (2014); Carre et al. (2010)

Table 6 C_{VEG} values for croplands (t C/ha) based on EU-RED

Continent	Perennial cropland (Temperate)	Perennial cropland (Tropical, dry)	Perennial cropland (Tropical, moist)	Perennial cropland (Tropical, wet)	Annual cropland
Africa	43.2	6.2	14.4	34.3	0.0
Asia (continental)	43.2	6.2	14.4	34.3	0.0
Asia (insular)	43.2	6.2	14.4	34.3	0.0
Europe	43.2	6.2	14.4	34.3	0.0
North America	43.2	6.2	14.4	34.3	0.0
New Zealand	43.2	6.2	14.4	34.3	0.0
South America	43.2	6.2	14.4	34.3	0.0
Average	**43.2**	**6.2**	**14.4**	**34.3**	**0.0**

Remark: Derived from IPCC 2006 Guidelines based on *50% carbon content of dry matter biomass*

For annual cropland, IPCC approach assumes that the entire biomass and dead organic matter are removed during land clearance before new planting. Therefore, carbon stocks in biomass after conversion are assumed to be zero.

Source: Blonk consultants: Direct LUC Assessment Tool Version 2014.1 (2014); Carre et al. (2010)

(4.3) Soil Organic Carbon (C_{SOC})

Management of cropland can affect to the soil C stocks; however, the changes can vary in the different degree depending on the agricultural practices influence C input and output from the soil system (IPCC, 2006). The management practices that can affect soil C stocks in croplands are such as the tillage management, fertilizer management, residue management, irrigation management, and type of crop and intensity of cropping management. Although, both organic and inorganic forms of C can be found in the soils; however, the organic carbon is the main part that will be influenced by the land use and management activities. This guideline thus focuses on soil organic carbon. Equation 4.3 shows the general formula for assessing the changing soil organic carbon given by IPCC (2006). The calculation procedures are as follows:

$$SOC = SOC_{Ref} \times F_{LU} \times F_{MG} \times F_{I} \qquad \textbf{(Equation 4.3)}$$

where

- SOC = Soil Organic Carbon (ton C/ha) of the studied area
- SOC_{Ref} = Reference SOC in the 0-30 cm. topsoil layer (ton C/ha); the value for SOC_{Ref} can be obtained from IPCC default value which will be varied depending on the climate region and soil type of the area concerned. The specific value of SOC from measurement or literature can be also used in the calculation.
- F_{LU} = Stock change factor for the land-use system for a particular land-use (dimensionless)
- F_{MG} = Stock change factor for the land management regime (dimensionless)
- F_{I} = Stock change factor for input of organic matter (dimensionless)

The influence of land use and management on soil C stock is drastically different between mineral and organic soil type. However, for Thailand, the organic soils which it is generally exist in wetlands and peatlands are rare; this guideline is thus focused on the SOC of mineral soil. Especially, the conversion of forest land and native grassland to cropland.

Selection of the reference SOC (SOC_{Ref})

For SOC changes calculation, the value for SOC_{Ref} can be selected from Table 7 by using the conditions of climate region and soil type of the studied area. The appropriate climate region can be identified by the climate regions map as shown in Figure 3; meanwhile, the soil type of the studied areas can be simply identified by the criteria shown in Table 8.

Table 7 Default reference soil organic carbon stocks (SOC_{REF}) for mineral soils under native vegetation (t C/ha in 0-30 cm depth)

Climate region	HAC soils	LAC soils	Sandy soils	Spodic soils	Volcanic soils	Wetland soils
Boreal, all	68	28.5	10	117	20	146
Cold temperate, dry	50	33	34	116	20	87
Cold temperate, moist	95	85	71	115	130	87
Cold temperate, wet	95	85	71	115	130	87
Warm temperate, dry	38	24	19	116	70	88
Warm temperate, moist	88	63	34	116	80	88
Warm temperate, wet	88	63	34	116	80	88
Tropical, dry	38	35	31	116	50	86
Tropical, moist	65	47	39	116	70	86
Tropical, wet	44	60	66	116	130	86
Tropical montane	88	63	34	116	80	86

Remark: From IPCC 2006. All values in tones C/ha in 0-30 cm depth.

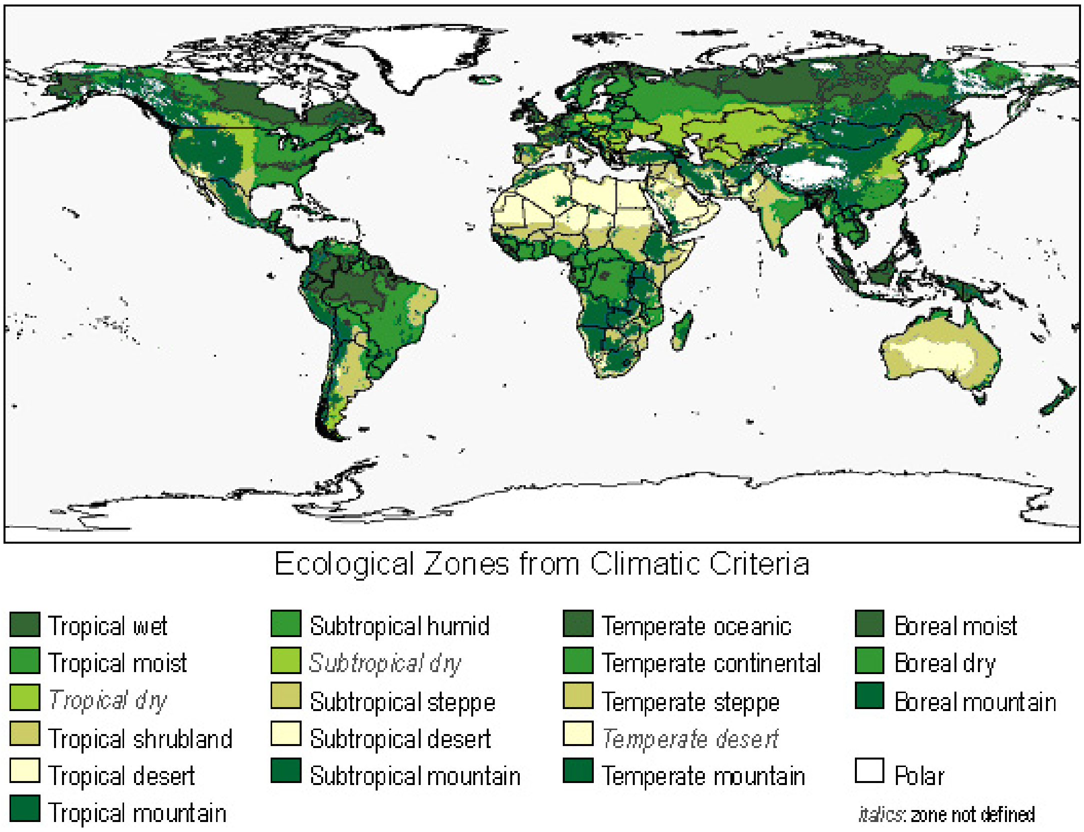

Figure 3 Ecological zones from climatic criteria (IPCC, 2006)

Table 8 Soil type classifications

Soil type	Description	Reletive to World Reference Base for Soil Resources (WRB) claissification
HAC soils	Soil with high activity clay (HAC) minerals are lightly to moderately weathered soils, which are dominated by 2:1 silicate clay minerals	Leptosols, Vertisols, Kastanozems, Chernozems, Phaeozems, Luvisols, Alisols, Albeluvisols, Solonetz, Calcisols, Gypsisols, Umbrisols, Cambisols, Regosols
LAC soils	Soil with high activity clay (LAC) minerals are highly weathered soils, which are dominated by 1:1 clay minerals and amorphous iron and aluminium oxides	Acrisols, Lixisols, Nitisols, Ferralsols, Durisols
Sandy soils	All soils having sand > 70% and clay < 8%	Arenosols
Spodic soils	Soils exhibiting strong podzolization	Podzols
Volcanic soils	Soils derived from volcanic as with allophanic mineralogy	Andosols
Wetland soils	Soils with restricted drainage leading to periodic flooding and anaerobic conditions	Gleysols

Source: European Comission (2009)

Table 9 Relative stock change factors (F_{LU}, F_{MG}, and F_I) (over 20 years) for different management activities on croplands

Factor	Management option	Boreal, dry	Boreal, moist	Boreal, wet	Cold temperate, dry	Cold temperate, moist	Cold temperate, wet	Warm temperate, dry	Warm temperate, moist	Warm temperate, wet	Tropical, dry	Tropical, moist	Tropical, wet	Tropical montane
Land use (F_{LU})	Annual cropland	0.80	0.69	0.69	0.80	0.69	0.69	0.80	0.69	0.69	0.58	0.48	0.48	0.64
	Paddy rice	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10	1.10
	Perennial cropland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Set aside (<20 years)	0.93	0.82	0.82	0.93	0.82	0.82	0.93	0.82	0.82	0.93	0.82	0.82	1.00
Tillage (F_{MG})	Full	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Reduced	1.02	1.08	1.08	1.02	1.08	1.08	1.02	1.08	1.08	1.09	1.15	1.15	1.09
	No-till	1.10	1.15	1.15	1.10	1.15	1.15	1.10	1.15	1.15	1.17	1.22	1.22	1.16
Input (F_I)	Low	0.95	0.92	0.92	0.95	0.92	0.92	0.95	0.92	0.92	0.95	0.92	0.92	0.94
	Medium	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	High without manure	1.04	1.11	1.11	1.04	1.11	1.11	1.04	1.11	1.11	1.04	1.11	1.11	1.08
	High with manure	1.37	1.44	1.44	1.37	1.44	1.44	1.37	1.44	1.44	1.37	1.44	1.44	1.41

Source: Blonk consultants: Direct LUC Assessment Tool Version 2014.1 (2014); Carre et al. (2010)

Table 10 Relative stock change factors (F_{LU}, F_{MG}, and F_I) (over 20 years) for forest lands and grassland conversion to croplands

Factor	Management option	Boreal, dry	Boreal, moist	Boreal, wet	Cold temperate, dry	Cold temperate, moist	Cold temperate, wet	Warm temperate, dry	Warm temperate, moist	Warm temperate, wet	Tropical, dry	Tropical, moist	Tropical, wet	Tropical montane
Land use (F_{LU})	Native forest	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Managed forest	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Grassland	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Tillage (F_{MG})	Native forest	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Managed forest	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Grassland (non-degraded)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Grassland (moderately degraded)	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.97	0.97	0.97	0.96
	Grassland (severely degraded)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	Grassland (improved)	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.17	1.17	1.17	1.16
Input (F_I)	Native forest	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	Managed forest	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Grassland (improved)-Medium input	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Grassland (improved)-High input	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11
	Grassland (others)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

*n/a = not applicable, in these cases FMG and FI shall not apply. The calculation of SOC can be: $SOC = SOC_{Ref} \times F_{LU}$

Source: Author modified from IPCC (2006)

(4.4) GHG (Non-CO_2) Emissions from Land Clearance ($E_{fire,Non\text{-}CO2}$)

If the burning of biomass occurs as part of clearance of reference land such as native forest lands or grasslands prior to establishment of new bioenergy crop plantation, all GHG emissions from this biomass burning must be accounted as the part of GHG emission source. This is because the carbon neutrality assumption is not valid for the case of native forest land or native grasslands clearing due to the lack of synchrony with the rates of CO_2 uptake. CO_2 emissions of forest biomass burning therefore will be accounted. Equation 4.4 shows the general method for estimate the GHG (Non-CO_2) emissions for the case of biomass burning.

$$E_{fire,Non\text{-}CO2} = (M_B \times C_f \times G_{ef,CH4} \times 25) + (M_B \times C_f \times G_{ef,N2O} \times 298) \quad \text{(Equation 4.4)}$$

Where:

- $E_{fire,Non\text{-}CO2}$= Annualized GHG (Non-CO_2) emissions occurred from the biomass that is actually burnt during the clearance of native forest *or* native grasslands (kg CO_2eq/ha)
- M_B = mass of fuel available for combustion (ton/ha), litter and dead wood pools are assumed to be zero when IPCC Tier 1 methods are used
- C_f = Combustion factor for fires (dimensionless)
- G_{ef} = Emission factor (kg/t dry matter burnt)

Table 11 Fuel biomass (DOM + live biomass) consumption values (M_B x C_f)

Vegetation type	Subcategory	M_BxC_f (ton dm/ha)
Primary tropical forests	All	119.6
Secondary tropical forests	All	42.2
Tertiary tropical forests	All	54.1
Boreal forests	All	41.0
Eucalyptus forests	All	69.4
Savanna Grasslands	All (early dry season burns)	2.1
Savanna Grasslands/Pastures	All (mid/late dry season burns)	10.0
Agricultural residues (Post harvest field burning)	Rice residues	5.5
	Sugarcane	6.5

Remark: Values in this Table can be used to represent M_B x C_f in case that the data for M_B and C_f are not available
Source: IPCC (2006)

Table 12 Combustion factor values (C_f)

Vegetation type	Subcategory	C_f values
Primary tropical forests	All	0.36
Secondary tropical forests	All	0.55
Tertiary tropical forests	All	0.59
Boreal forests	All	0.34
Eucalyptus forests	All	0.63
Savanna Grasslands	All (early dry season burns)	0.74
Savanna Grasslands/Pastures	All (mid/late dry season burns)	0.77
Agricultural residues (Post harvest field burning)	Rice residues	0.80
	Sugarcane	0.80

Source: IPCC (2006)

Table 13 Emission factors (G_{ef}) (kg/t dry matter burnt)

Vegetation type	CO_2	CH_4	N_2O
Tropical forests	1580	6.8	0.20
Savanna Grasslands	1613	2.3	0.21
Agricultural residues	1515	2.7	0.07

Source: IPCC (2006)

4.2 Emissions from Material Extractions (E_{ec})

Bioenergy crop production is carried out by various materials, chemical and energy inputs including diesel, fertilizers, pesticides, and electricity that it would increase the GHG emissions. The emissions from the extraction of raw materials used in farming (kg CO_2-eq/ha-year) can be estimated by the following equation.

Equation (5): Emissions from the extraction of material used

$$E_{ec} = EM_{fertilser} + EM_{fuel} + EM_{electricity} + EM_{inputs}$$

Where:

- E_{ec} = Emissions from the production of materials used in farming (kg CO_2eq/ha-year)
- $EM_{fertiliser}$ = Emissions of the production of fertilizers used (kg CO_2eq/ha-year); whereas $\boldsymbol{EM_{fertilser} = M_{fertilizer} \times EF_{fertilizer\ production}}$
- EM_{fuel} = Emissions from the production of fuels used in farm machinery (kg CO_2eq/ha-year); whereas $\boldsymbol{EM_{fuel} = M_{fuel} \times EF_{fuel}}$
- $EM_{electricity}$ = Emissions from electricity used (kg CO_2eq/ha-year); whereas $\boldsymbol{EM_{electricity} = M_{electricity} \times EF_{electricity}}$
- EM_{inputs} = Emissions from other inputs used (kg CO_2eq /ha-year); whereas $\boldsymbol{EM_{input} = M_{input} \times EF_{input}}$
- $M_{fertiliser}$ = Fertilizers used in the farming (kg fertilizer/ha-year)
- M_{fuel} = Fuels used in farm machinery (litre of fuel/ha-year)
- $M_{electricity}$ = Electricity used in farm operation (kWh/ha-year)
- M_{inputs} = Other inputs (specify) used in farming (kg or litre of inputs/ha-year)
- $EF_{fertilizer}$ = Emission factors from fertilizer production (kg CO_2eq/kg fertilizer)
- EF_{fuel} = Emission factors from fuels production (kg CO_2eq/litre fuel)
- $EF_{electricity}$ = Emission factor from country electricity mix (kg CO_2eq /kWh)
- EF_{input} = Emission factors from the production of other inputs used(kg CO_2eq /kg or litre of inputs)

Table 14 GHG emission factors used for life-cycle GHG emissions assessment

GHG Emission Factor (EF)		Unit	Values	Data sources
Fertilizers	N fertilizer	kg CO_2 eq/kg N	2.6	TGO (2014)
	P_2O_5 fertilizer	kg CO_2 eq/kg P	1.57	TGO (2014)
	K_2O fertilizer	kg CO_2 eq/kg K	0.50	TGO (2014)
	Urea	kg CO_2eq/kg	5.53	TGO (2014)
Agrochemicals	Paraquat	kg CO_2eq/kg	3.23	TGO (2014)
	Glyphosate	kg CO_2eq/kg	16.0	TGO (2014)
	Atrazine	kg CO_2eq/kg	5.01	TGO (2014)
	Fungicide	kg CO_2eq/litre	8.51	TGO (2014)
	Insecticide	kg CO_2eq/litre	17.22	TGO (2014)

4.3 Direct GHG Emissions from Plantation Activities (E_{field})

(1) GHG emissions from fertilizers application

Apart from the GHG emissions from the production of fertilizers used in feedstock plantation, the application of fertilizers especially N-fertilizer into the soil will also cause the non-CO_2 GHG emissions e.g. Nitrous oxide (N_2O) which has to be accounted in the life cycle GHG emission assessment. N_2O is produced during nitrification and denitrification processes. Based on IPCC (2006) Tier 1 factor.

Equation (6): Emissions from the fertilizer application

$$E_{field,N} = [(0.01 \times M_{N,tot}) + (0.001 \times M_{N,Chem} + 0.002 \times M_{N,Org}) + (0.0075 \times FR_L \times M_{N,tot})] \times \frac{44}{28} \times 298$$

Where:

- $E_{field,N}$ = Emission due to N-fertilizer applied into the soil (kg CO_2-eq /ha-year)
- $M_{N,tot}$ = Total Nitrogen from input fertilizers (kg N/ha-year); whereas $M_{N,tot} = M_{N,Chem} + M_{N,Org}$
- $M_{N,Chem}$ = Total Nitrogen from input chemical fertilizers (kg N/ha-year)
- $M_{N,Org}$ = Total Nitrogen from input organic fertilizers (kg N/ha-year)
- The constant 0.01 is the emission factor for direct N_2O emission from N fertilizer inputs (kg N_2O-N/kg N)
- The constant 0.001 is the emission factors for indirect N_2O emission from chemical fertilizer N that volatilizes as NH_3 and NO_x (Kg N_2O-N/kg N) (IPCC, 2006)
- The constant 0.002 is the emission factors for indirect N_2O emission from organic fertilizer N that volatilizes as NH_3 and NO_x (Kg N_2O-N/kg N) (IPCC, 2006)
- FR_L = Fraction of all N added to the soil of the plantation that is lost through leach and runoff (kg N/kg N); the default value is 0.3 kg N/kg N (IPCC, 2006)
- Constant 0.0075 is the emission factor for indirect N_2O emissions from N leaching and runoff (kg N_2O-N/kg N)

Table 15 Nutrients elements of the organic and chemical fertilizers

Fertilizers		Nutrient Element (%)		
		N	P_2O_5	K_2O
Organic	Manure, chicken	1.9	0.7	2
	Manure, swine	4.4	2.1	2.6
	Manure, cow	2.4	0.7	2.1
Chemical	Ammonium Sulfate	21	0	0
	Urea	46	0	0
	Ammonium Nitrate	35	0	0
	Ammonium Chloride	28	0	0
	Diammonium Phosphate	21	54	0

Fertilizers		Nutrient Element (%)	
	N	P_2O_5	K_2O
Super Phosphate	0	21	0
Double Super Phosphate	0	40	0
Rock phosphate	0	36	0
Potassium Chloride	0	0	60

(2) GHG emissions from fuels used

The GHG emission from the fuel combustion of agricultural machines and equipment is calculated from the amount of fuel multiplies by emission factor of combustion of each fuel.

Equation (7): Emissions from the fuel combustion

$$E_{field,fuel} = M_{fuel} \times EF_{fuel}$$

Where:

- $E_{field,fuel}$ = Emission from the field due to fuel combustion of the agricultural machines and equipment (kg CO_2-eq /ha-year)
- M_{fuel} = Fuel used in agricultural machinery (litre of fuel/ha-year)
- EF_{fuel} = Emission factor from the use of fuel (kg CO_2-eq/litre of fuel)

Table 16 Emission factors (EF) for fuel used

Emission factors	Unit	Values	Data sources
Diesel (production)	kg CO_2eq/litre	0.28	TGO (2014)
Diesel (combustion)	kg CO_2eq/litre	2.745	TGO (2014)
Gasoline (production)	kg CO_2eq/litre	0.52	TGO (2014)
Gasoline (combustion)	kg CO_2eq/litre	2.238	TGO (2014)
Liquefied Petroleum Gases (LPG)	kg CO_2eq/kg	0.41	TGO (2014)
Electricity (grid mix)-Thailand	kg CO_2eq/kWh	0.61	TGO (2014)

(3) GHG (Non-CO_2) Emissions from land clearance activity ($E_{fire,Non-CO2}$)

If the burning of biomass occurs as part of clearance of field activity e.g. agricultural residue burnt in croplands, only non-CO_2 emissions i.e. CH_4 and N_2O will be considered. This is due to the assumption that CO_2 emissions would be counterbalanced by CO_2 removals from the subsequent re-growth of the vegetation within one year (IPCC, 2006).

4.4 GHG Emissions Caused by the Transportation of Raw Materials (E_{td})

The GHG emissions from the transportation of each raw material (round trips) is calculated from loading capacity of each raw material when it is transported from a source to the field multiplies by the emission factor for mode of transportation of each raw material, depending on what vehicle is used and the distance of the source to bioenergy crop plantation. The GHG emissions when the empty vehicle travels from feedstock plantations back to a raw material source after unloading the raw material is calculated from emission factor multiplies by the distance between plantations and the raw material source.

Equation (8): Emissions from the transportation of raw material

$$E_{td} = \sum[(EF_{td-a,i} \times W_{td-a,i} \times D_{td-a,i}) + (EF_{td-r,i}/L_{td-r,i} \times D_{td-r,i})]$$

Where:

- E_{td} = GHG emissions caused by transportation of raw materials used (kg CO_2eq/ha-year)
- $EF_{td-a,i}$ = Emission factor of the vehicle used for transport material i, at full loaded assumption (kg CO_2eq/ton-km)
- $W_{td-a,i}$ = Weight of the transported material i – Away trip (ton)
- $D_{td-a,i}$ = Transport distance for material i – Away trip (km)
- $EF_{td-r,i}$ = Emission factor of the vehicle used for transport material i, at empty loaded assumption (kg CO_2eq/km)
- $L_{td-r,i}$ = Loading capacity of the vehicle used (ton)
- $D_{td-r,i}$ = Transportation distance of raw material i – Return trip (km)

Table 17 Emission factors (EF) for transport

Emission factors	Unit	Values	Data sources
Pick up, 4 wheels, 7 ton load, full loaded	kg CO_2eq/t-km	0.1402	TGO (2014)
Pick up, 4 wheels, 7 ton load, empty loaded	kg CO_2eq/km	0.3111	TGO (2014)
Truck, 10 wheels, 16 ton load, full loaded	kg CO_2eq/t-km	0.045	TGO (2014)
Truck, 10 wheels, 16 ton load, empty loaded	kg CO_2eq/km	0.571	TGO (2014)
Trailer, 18 wheels, 32 ton load, full loaded	kg CO_2eq/t-km	0.045	TGO (2014)
Trailer, 18 wheels, 32 ton load, empty loaded	kg CO_2eq/km	0.816	TGO (2014)

4.5 GHG Emissions Credits from Improvement of Agricultural Practices (E_{crd})

The credits of by-product utilization and adaptation of the good agricultural practices for energy crop plantation which will result in the reduction of GHG emissions e.g. amount of compost and green manure can be calculated by the following equation.

Equation (9): Emission credits

$$\mathrm{E}_{cre} = \left(\mathrm{M}_{\text{substitued material/chemical/fuel}} \times \mathrm{EF}_{\text{substituted material/chemical/fuel}}\right)$$

Where:

- E_{crd} = GHG emissions credits from the improved agricultural practices (kg CO_2eq/ha-year)
- $M_{\text{substituted fuel/material}}$ = Amount of fossil fuel or petroleum derived material inputs that would be substituted by the compost or green manure during biofuel crops plantation (kg or MJ/year)
- $EF_{\text{substituted fuel/material}}$ = Emission factor of the fuel or material that would be replaced by the by-product generated from biofuel production system (kg CO_2-eq /kg or MJ of the substituted fuel or material)

REFERENCES

Alberici, S. and C. Hamelinck. (2010). Annotated example of a GHG calculation using the EU Renewable Energy Directive methodology. Ecofys.

Alberici, S., C. Hamelinck and V. Schueler. (2010). Annotated example of a land carbon stock calculation using standard values. Ecofys.

BEFSCI. (2010). Bioenergy and food security criteria and indicators project. FAO, 2010. (http://www.fao.org/bioenergy/foodsecurity/befsci/62379/en/)

Blonk Consultants. (2014). The direct land use change assessment tool. Gouda. Retrieved from http://blonkconsultants.nl/en/tools/land-use-change-tool.html

Carre, F., R. Hiederer, V. Blujdea and R. Koeble. (2010). Background guide for the calculation of land carbon stocks in the biofuels sustainability scheme: Drawing on the 2006 IPCC guidelines for national greenhouse gas inventories. EUR 24573 EN. Luxembourg: Office for Official Publications of the European Communities: 109.

Chase, L.D.C., et al. (2012). The palm GHG calculator: The RSPO greenhouse gas calculator for oil palm products, Beta-version. The Roundtable for Sustainable Palm Oil – RSPO. Kuala Lumpur, Malaysia.

Ecoinvent Database. (2007). Swiss centre for life cycle inventories. Dubendorf: In SimaPro 7.

European Commission. (2009). Draft commission decision of [31 December 2009] on guidelines for the calculation of land carbon stocks for the purpose of Annex V of Directive 2009/28/EC.

FAO (2014). Estimating greenhouse gas emissions in agriculture: A manual to address data requirements for developing countries. Food and Agriculture Organization of the United Nations, Rome.

GBEP (2011). The global bioenergy partnership sustainability indicators for bioenergy: First edition. GBEP, FAO, Rome.

IEA Bioenergy. (2010). Bioenergy, land use change and climate change mitigation. IEA Biopenergy ExCo: 2010:03.

IPCC (2006). IPCC guidelines for national greenhouse gas inventories: Agriculture, forestry and other land use, prepared by the National Greenhouse Gas Inventories Programme. Vol. 4, Eggleston H.S., Buendia L., Miwa K., Ngara T., Tanabe K., editors, Japan: Institute for Global Environment Strategies (IGES). http://www.ipcc-nggip.iges.or.jp/public/2006gl/ (accessed 20 December 2014)

IPCC (2007). Working group III report "mitigation of climate change". IPCC Fourth Assessment Report: Climate Change 2007. Cambridge.

ISCC (2011). ISCC 205 GHG emissions calculation methodology and GHG Audit. International Sustainability Carbon Certification (ISCC)

Nemecek, T., et al. (2014). Methodological guidelines for the life cycle inventory of agricultural products. Version 2.0, July 2014. World Food LCA Database (WFLDB). Quantis and Agroscope, Lausanne and Zurich, Switzerland.

Ros, J., et al. (2010). Identifying the indirect effects of bio-energy production. Netherlands Environmental Assessment Agency, Bilthoven.

TGO (2014). Emission factor for carbon footprint of product (CFP). Thailand Greenhouse Gas Management Organization. http://thaicarbonlabel.tgo.or.th/download/Emission_Factor_CFP.pdf (Accessed 20 December 2014)

WBGU. (2010). Future bioenergy and sustainable land use. German Advisory council on Global Change, Earthscan, London.