Estimating emissions related to indirect peatland loss in Southeast Asia due to biofuel production

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ILUC stands for indirect land use change or induced land use change, which is normally accounted for its impact on biofuels' greenhouse gas (GHG) emissions (Chen *et al.*, 2018). Due to its complexity, the ILUC emissions are estimated using models involving area changes of specific land types and emission factors (EFs) for conversion of one land type to another. Without diving into too many details, one can identify two major "ILUC factors" determining the ILUC emissions – i) the *ΔILUC* which reflects the area of land that transits from one type of land use to another and ii) the *EFs* that determine specific (i.e., CO_2, N_2O, and CH_4) or total GHG emissions per unit area changed associated with specific ILUC. It is critical to include both factors in ILUC emissions estimation. Here we show recent updates that are specific to *ΔILUC* and *EFs* for one of the ILUCs contributed to biofuels' ILUC emissions, the forest-on-peat to palm transition in Southeast (SE) Asia (mainly Indonesia and Malaysia). Further, we incorporate such updates into the CCLUB (Carbon Calculator for Land Use change from Biofuels production) module that used in the GREET® model to estimate ILUC impacts, and briefly discuss ILUC emissions associated with soy biodiesel production in the U.S.

Recent updates on ILUC factors

The straightforward way to estimate total GHG emissions associated with forest-on-peat to palm transition is by multiplying *ΔILUC* (area of forest-on-peat to palm transition) by *EF* (of forest-on-peat to palm transition). Economic models can predict newly expanded palm area (or marginal palm expansion) in SE Asia due to U.S. soy biodiesel production but they usually do not have the level of fidelity of various types of land available for new palm plantations. Thus, *ΔILUC* for forest-on-peat to palm conversion has to be calculated by assessing the proportion of new palm expansion that is established on forest-on-peat. This *palm-on-peat factor*, the ratio of predicted future new palm-on-peat to new palm on all lands, has largely relied on historical palm plantation pattern. It varies among different studies and has evolved with up-to-date data. A recent critique "Don't throw out California's ILUC factors yet" refreshes discussion about this factor (Searle, 2018).

In Searle (2018), the author maintains that new studies suggest a factor of 33% for the ratio, which confirms "California's assumption of 28%-30%." Searle (2018) brought up the need to carefully review new studies and provided some valuable references. Searle suggested that

Chen *et al.* (2018) assumed a factor of 5% for the *palm-on-peat factor*. However, Chen *et al.* (2018) did not use the *palm-on-peat factor* or the factor of 5% in the CCLUB version (Dunn *et al.*, 2016), but rather adopted EPA's approach by assuming a portion of the land is on peat and this portion varies from 0 to 44% depending on where the land is located (by administration unit in SE Asia), while the rest of land (56-100%) is on mineral soils (Harris *et al.*, 2009). Therefore, for most of the land transitions, both peat and mineral soils have contributed to GHG emissions. Searle (2018) might have misunderstood by the inaccurate description in Chen *et al.* (2018), and our personal discussion via email did not help. In Chen *et al.* (2018), the following was mentioned to be equivalently comparable with California Air Resources Board (CARB) study, "CCLUB adopts the U.S. EPA methodology, which assesses an average of 5% total land loss (0–44%, varying by administration unit) occurs on peatland…" If one simply looked at the portion of peat (%) in each administration unit and averaged the percentage values (arithmetic mean) over Indonesia and Malaysia, the finding would be that "… only 5% of land conversion occurs on peatland… Searle (2018)". However, this simple average approach neglects the soil carbon changes included in both EPA approach (Harris *et al.*, 2009) and CCLUB (Dunn *et al.*, 2016).

By employing palm-on-peat areas (Miettinen *et al.*, 2016) and total palm harvested areas (USDA - Foreign Agricultural Service, 2018) in Indonesia and Malaysia, Searle (2018) derived new *palm-on-peat factors* of 25 and 36% for Indonesia and Malaysia during the 2010-2015 period, respectively (Table 1). These were then suggested to show the most recent trends of palm plantations. However, the *palm-on-peat factors* estimated by Searle (2018) might be problematic because these are highly dependent on the estimates of palm areas for recent years. For example, the harvested areas of FAO statistics (2018) are quite different from those of USDA Foreign Agricultural Service. Also, the Miettinen *et al.* (2016) study used relatively old peatland maps to assess peat areas in SE Asia (dated back to 2005 and earlier), although it provided valuable information on peat distribution and allocation in Indonesia and Malaysia. A latest study used similar approach but more recent and official peat soil data (by Indonesian Ministry of Agriculture in 2011) found that only about 20% of palm plantations actually expanded on peat lands in Indonesia through different time periods (Austin *et al.*, 2017) (Table 1). If this trend of new palm expansion continues, the *palm-on-peat factor* to be used for future palm plantations would be about 20% for Indonesia. In our recent updates in CCLUB 2018 (see below for more details), we adopt new *palm-on-peat factors* estimated for the period of 2010 to 2015 - the Austin *et al*. (2017) value (19%) for Indonesia and Searle (2018)'s value (35%) for Malaysia. By taking an area-weighted average based on the harvested palm areas of the two countries, we come up with 22% to reflect up-to-date *palm-on-peat factor* in SE Asia. Further efforts and updates on this factor in future will be reflected in future CCLUB versions.

Table 1. Estimated *palm-on-peat factor* in different studies.

References	%	Region	Time period	Notes
Austin *et al.* (2017)	20%	Indonesia	1995-2015	Remote sensing images for palm area estimates, and soil maps for peat area estimates
	21%	Indonesia	1995-2000	
	18%	Indonesia	2000-2005	
	20%	Indonesia	2005-2010	
	19%	Indonesia	2010-2015	
Searle (2018)	25%	Indonesia	2010-2015	Based on Miettinen *et al.* (2016) and historical palm areas for Indonesia and Malaysia (USDA Foreign Agricultural Service, 2018). Miettinen *et al.* (2016) is based on peatland maps and soil maps for peat area estimates, and remote sensing images for palm-on-peat area estimates.
	36%	Peninsular Malaysia, Sumatra and Borneo	2010-2015	
Carlson *et al.* (2013)	13%	Kalimantan, Indonesia	-2012	Based on remote sensing images
Miettinen *et al.* (2012)	26%	Peninsular Malaysia, Sumatra and Borneo	-2010	Based on remote sensing images for palm, peatland maps and soil maps for peat
EPA (2012)	22%	Indonesia	-2009	Based on model estimates
	13%	Malaysia	-2009	
	15%	Indonesia	-2022	
	10%	Malaysia	-2022	
	13%	Indonesia	2022	
	9%	Malaysia	2022	
	12%	Indonesia, Malaysia	2022	
Koh *et al.* (2011)	11%	Peninsular Malaysia, Sumatra and Borneo	-2011	Based on remote sensing images
Sheil *et al.* (2009)	17%	*Kalimantan (Indonesia)*		Based on land use permits. Data from: *Casson, A. Tacconi, L. and Deddy, K. 2007 Strategies to reduce carbon emissions from the oil palm sector in Indonesia. Prepared for the Indonesian Forest Climate Alliance, Jakarta.*
	13-50%	*Riau, Sumatra (Indonesia)*		
Hooijer *et al.* (2006)	27%	Indonesia	-2000	Based on soil map, remote sensing data, and land use data
	25%	Indonesia	2005	A projection due to global oil palm demand

Searle (2018) did not address another important factor determining the ILUC emissions, and that is *EF*. In CARB's ILUC emissions estimation, an *EF* of 95 t CO_2e ha^{-1} yr^{-1} (an uncertainty range of 54 to 115) was used for peat loss resulted from forest-on-peat converted to palm which is based on Page *et al.* (2011). Chen *et al.* (2018) used 73 t CO_2e ha^{-1} yr^{-1} in their version of CCLUB to be consistent with EPA methodology. In 2014, IPCC (Intergovernmental Panel on Climate Change) released a wetland supplement report to extend the content of the 2006 IPCC Guidelines (IPCC, 2014). In this report, IPCC referred to more studies and sites and provided an EF of 55 t CO_2e ha^{-1} yr^{-1} (or 15 t C ha^{-1} yr^{-1}) for plantations (average of emission factors for acacia and oil palm) and 40.3 t CO_2e ha^{-1} yr^{-1} (or 11 t C ha^{-1} yr^{-1}) for palm in the tropical regions. It should be noted that the higher *EF* used by CARB or EPA than IPCC is due to the consideration of an early emissions pulse after drainage. Studies have reported that in the first few years after drainage of pristine peat soils for palm plantations (transition phase), carbon emissions through a combination of peat oxidation and soil compression result in higher *EF* than the IPCC *EF*, which is derived from the later more stable phase of plantation management (Miettinen *et al.*, 2017). Although we recognized the importance of such early emissions pulse, CCLUB 2018 does not include it due to a lack of *EFs* derived from explicitly consideration in heterogeneity of the type of peat soil (e.g., mineral content, carbon content, depth, extent of degradation) and water management practices that promote peat GHG emissions. Instead, we adopt the IPCC *EF* of 55 t CO_2e ha^{-1} yr^{-1} in CCLUB 2018 as revised *EF*. This decision can be considered as be conservative (Miettinen *et al.*, 2017).

Current evidence on peatland loss in SE Asia is still limited, and there is no consensus on specific *EF* value for peat to palm transition (EPA, 2014; FAO, 2014). Future efforts are highly appreciated for improving our understanding of peat transition and evaluating *EF*s associated with LUC related to peat loss (e.g., other possible emissions sources, initial drainage, and allocation of emissions to palm production) (EPA, 2014; FAO, 2014).

Major updates in CCLUB

We agree that new and most up-to-date data should be incorporated into new estimates, and caution should be exercised when interpreting these new data and models. To better reflect recent developments in the field of ILUC emissions, CCLUB is under continuous improvement including an ongoing effort to update the *ΔILUC* and *EFs* related to palm plantations in the SE Asia. Here we document a few major updates of *ΔILUC* and *EFs* in CCLUB to improve understanding of the role of palm conversion in overall ILUC impacts. A complete technical report documenting the model and recent updates will be released separately (Qin *et al.*, 2018).

In CCLUB 2018, in order to explicitly consider peat and non-peat land transitions, palm plantations in SE Asia (*Ind_Mal* region in GTAP model) were specifically modeled to estimate emissions associated with ILUC for peatland (mainly peat forest) conversions to palm. Several key parameters/factors are listed in Table 2. Besides the *palm-on-peat factor* (22%) and *EF* for peat loss (55 t CO_2e ha^{-1} yr^{-1}), CCLUB 2018 incorporated emissions/sequestration related to other processes including N_2O emissions, forgone peat accumulation and biomass changes (Table 2). With CCLUB 2018, emissions associated with LUC will be somewhat different from previous CCLUB versions for some pathways with significant ILUC linked to peat loss in SE Asia (e.g., soy biodiesel pathway).

Table 2. Key parameters used in AEZ-EF of California Air Resources Board and CCLUB of Argonne National Laboratory to estimate emissions associated with palm grown on peatland[*].

	AEZ-EF[†]	CCLUB 2016[‡]	CCLUB 2018[¶]	CCLUB 2018 references and notes
Related to palm-on-peat area				
-Palm-on-peat factor (% of new palm on peat forest in SE Asia)	33%	Not specified[§]	22%	Based on Austin *et al.* (2017), Miettinen *et al.* (2016), and Searle (2018). See further notes in the main text.
Emissions related to peat loss (t CO_2e ha^{-1} yr^{-1})				
-CO_2 emissions	95.0	73.0	55.0	On the basis of plantations in tropical region (IPCC, 2014; Miettinen *et al*., 2017). See further notes in the main text.
-N_2O emissions due to LUC	10.7		1.5	Based on IPCC (2014).
-Forgone peat accumulation in the forest			2.8	Based on Murdiyarso *et al.* (2010).
-Burnt peat from land-clearing fire			0	According to Carlson *et al.* (2013), fire is not the primary means of clearing vegetation for oil palm plantations since the 2000s.
Emissions related to biomass loss and new biomass growth (t CO_2e ha^{-1} yr^{-1})				
-Biomass in harvested wood product	-(0.6-0.7)		-0.7	Consistent with AEZ-EF.
-Carbon sequestration in palm biomass		-0.6	-0.6	Consistent with CCLUB 2016.
Global warming potential				
-CH_4	34	34	28	Based on Fifth Assessment Report of IPCC (2013)
-N_2O	298	298	265	Based on Fifth Assessment Report of IPCC (2013)

[*]AEZ-EF is the primary ILUC emission factor model used by CARB, and CCLUB is the ILUC module in GREET model including both LUCs and LUC emission factors. Many other parameters in CCLUB 2018 are in line with CCLUB 2016, and they are not listed here.

[†]Based on the model and Plevin *et al.* (2014).

‡Based on the model and Dunn *et al.* (2016). In CCLUB, one of the approaches for international LUC emissions estimation is based on EPA's ILUC database ('winrock') (Harris *et al.*, 2009); the other approach is based on Woods Hole database.

¶Based on the model and Qin *et al.* (2018).

§This factor was treated differently in CCLUB 2016; see further notes in the main text.

Another update in CCLUB 2018 is the averaging approach used for international LUC. Besides using arithmetic mean to aggregate EFs from administration unit (smaller region) to AEZ region (larger region) for GTAP predicted international LUC, we have added an option of using area-weighted mean for regions outside the U.S. (i.e., *EU27, BRAZIL, CAN, JAPAN, CHIHKG, INDIA, C_C_Amer, S_o_Amer, E_Asia, Mala_Indo, R_SE_Asia, R_S_Asia, Russia, Oth_CEE_CIS, R_Europe, MEAS_NAfr, S_S_AFR,* and *Oceania*). This new approach considers relative size of the administration units in each of the above GTAP modeling region. It can be important for regions with varying size of administration units and distinct EF characteristics. Also in CCLUB 2018, EPA datasets and other source data (including parameters in Table 2) have been explicitly included for transparency purpose.

Soy biodiesel ILUC emissions

The estimated ILUC emissions for soy biodiesel in the U.S. vary by LUC modeling cases (Fig. 1). The total ILUC emissions increased by 1.3-1.9 g CO_2e MJ^{-1} depending on LUC cases, in comparison with results in previous CCLUB 2016 (4.3-10.0 g CO_2e MJ^{-1}) (Chen *et al.*, 2018). This change is primarily due to new approaches adopted in CCLUB 2018 to specifically quantify emissions associated with peatland loss (Qin *et al.*, 2018). The new results are still much lower than emissions estimated by using AEZ-EF model (17-26 g CO_2e MJ^{-1}) (Chen *et al.*, 2018).

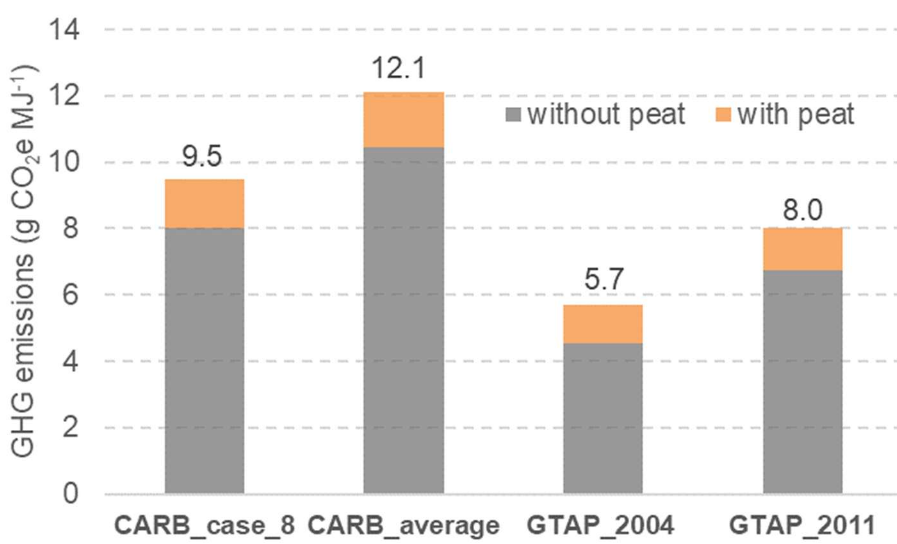

Fig. 1. ILUC GHG emissions from soy biodiesel production in the U.S. with and without specifically considering peatland loss in the SE Asia. The numeric values indicate total ILUC

GHG emissions. The four LUC cases (*CARB_case_8, CARB_average, GTAP_2004 and GTAP_2011*) indicate different LUC modeling results (Chen *et al.*, 2018). CCLUB 2018 was used for the estimation (Qin *et al.*, 2018). The emission in grey bars include CO_2, N_2O and CH_4 emissions associated with both domestic and international LUC resulted from soy biodiesel production in the U.S.

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