Carbon Emission Factors Subworkgroup

Low Carbon Fuel Standard (LCFS) Indirect Land Use Change Expert Workgroup

A Report to the California Air Resources Board

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Executive Summary

This report summarizes our findings of the literature review and recommendation for the calculation of emission factors in the analysis of indirect land use change (ILUC). The list of topics our sub workgroup considers includes:

- Carbon stock values: including biomass carbon (C) with specific focus on forest biomass and peatlands, and soil C.
- Carbon emission rate upon land conversion: loss rates on conversion, harvested wood products, fire emissions, and non-kyoto greenhouse gas (GHG) emissions.
- Emission factors of other indirect effects: including livestock emissions, rice cultivation, crop switching, and differences in on-farm energy and agrichemical use
- Uncertainty analysis

The above list only includes what the subgroup is able to examine to date and does not imply the exclusion of other important emission factors yet to be examined. As expected, there are several cross-disciplinary issues across workgroups that need to be addressed in a consistent manner and require interactions with each other. Even though many of these interdisciplinary issues are relevant to the emission factors discussion, some of these issues are briefly summarized here and discussed more extensively in the other workgroups, such as the discussion on land cover types, time accounting, uncertainties, and emissions from co-products.

The Emission Factor subgroup conducted literature review and experts consultation, and reached the following recommendations:

Must do

- Develop a spatially explicit database for biomass and carbon stocks

Short term

- Consider the long-term carbon stored in the harvested wood products (HWP)
- Provide clear justification for the consideration of livestock and rice emissions
- Consider taking into account the high carbon stock stored in peatlands in the tropical regions in Malaysia and Indonesia
- Provide better estimates for emission factors for stock changes
- Use range of estimates and sensitivity analysis for uncertainty analysis

Longer Term

- Consider the complexity of GHG emissions from crop switching
- Examine impacts non-Kyoto climate forcing gases and particles
- Use Monte Carlo simulation for uncertainty analysis

1. Introduction

A key step of estimating the impacts of direct and indirect land use conversions as a result of increased biofuel demand is to estimate the amount, and the duration, of greenhouse gas (GHG) emissions from land use and land use conversions in the "base case" (i.e., no biofuel policy case) and various other scenarios. These can include the emissions from above-ground and below-ground biomass carbon stock changes, soil carbon stock changes, foregone sequestration due to the loss of a forest carbon sink, as well as significant emissions of non-GHG from biomass burning, livestock and manure management, and N_2O emissions from fertilizer use.

California Air Resources Board's (CARB) indirect land use (ILUC) analysis for biofuels using Global Trade Analysis Project (GTAP) model (ISOR 2009) and a subsequent GTAP analysis by Tyner et al. (2010)(hereafter CARB analysis and Tyner analysis, respectively) both characterize two kind of emissions in their analyses: (1) carbon loss when forests or grasslands are cleared and converted into cropland, resulting in the loss of biomass and soil carbon stock; (2) foregone CO2 sequestration by forest. The data for biomass carbon and soil carbon stock values come from the Woods Hole data set, which has a spatial resolution of ten world regions and thirty one types of ecosystems. For any region, however, the number of ecosystem type ranges from three to seven.

The conversion of land in each world region is based on an assumed percentage breakdown of ecosystems that are available for conversion. These percentage breakdowns are constant regardless of biofuel use scenarios. For example,

- Europe: temperate evergreen forest (25%), temperate deciduous forest (25%), boreal forest (25%), and temperate grassland (25%)
- United States: broadleaf Forest (2%), mixed Forest (34%), coniferous Pacific (2%), and grassland (62%)
- Latin America: tropical evergreen forest (3%), tropical seasonal forest (22%), tropical open forest (47%), temperate evergreen forest (3%), temperate seasonal forest (1%), grassland (24%), and desert (1%).

The resulting soil carbon stock concentration per hectare of land converted in each world region is illustrated in Figure 1.1 below. A similar graph can also be drawn for biomass carbon stock.

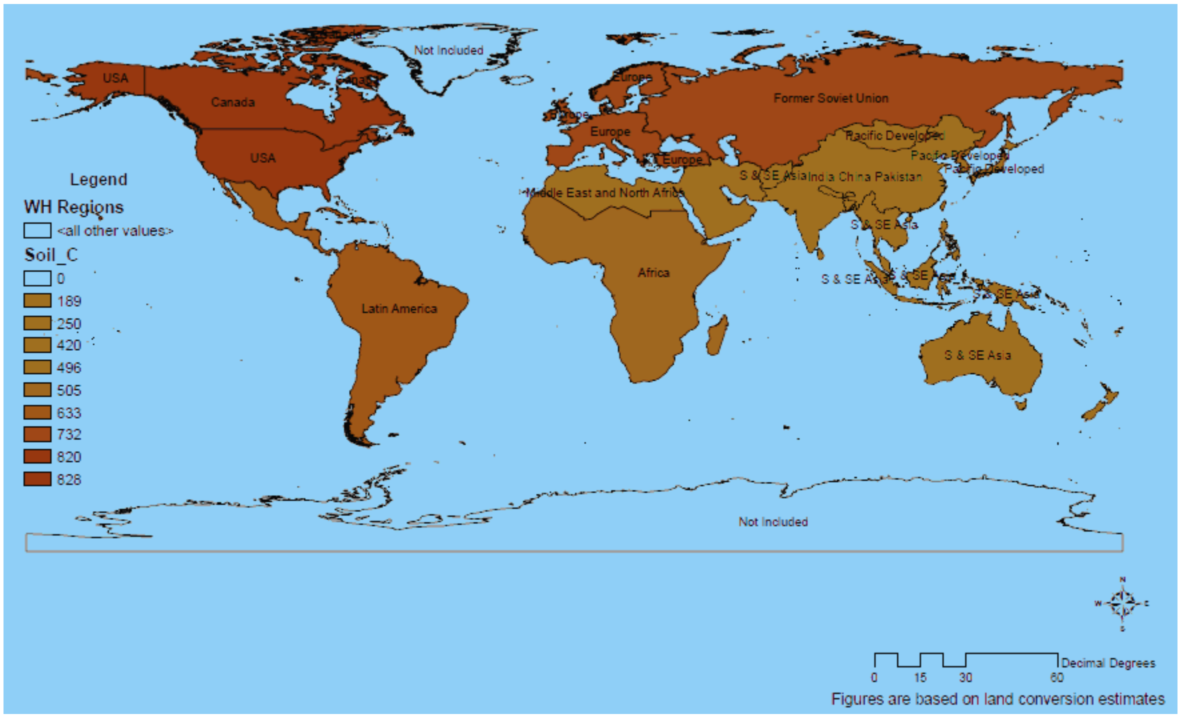

Figure 1.1. Woods Hole soil carbon stock (metric ton CO_2 per hectare) of available land for conversion in each of the ten world regions.

The CARB analyses further assume that land conversion will result in 25% of the carbon stored in its soil and 100% of carbon in biomass will be released into the atmosphere at the time of land conversion (75% of forest biomass and 100% of grassland vegetation in Tyner analysis).

The GTAP model has a much finer spatial resolution that includes nineteen world regions and Agro Ecological Zones (AEZs). Each AEZ shares common climate, precipitation and moisture conditions (Figure 1.2).

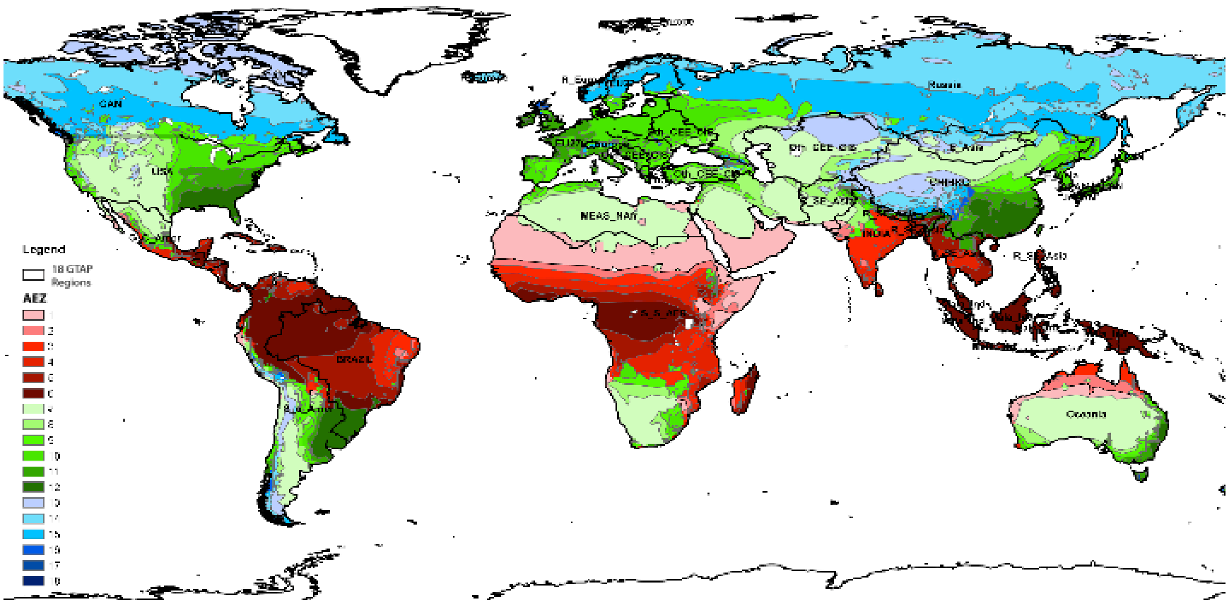

Figure 1.2. GTAP's nineteen world regions and Agro Ecological Zones (AEZs).

The purpose of this report is to critically review the assumptions used in the CARB and Tyner analyses and to make recommendations for improvements in CARB's future analyses
We recognize that some of the recommendations may require more time and resources, therefore they are broken into "must", "short-term", and "long-term" recommendations.

2. Biomass Carbon Stock

GTAP estimates biomass and soil carbon stocks using the Woods Hole Research Center (WHRC) database, which is based on an extensive literature review by R.A. Houghton (See Gibbs et al. 2007 for synthesis of data sources). The WHRC data is not spatially explicit but rather provides a look-up table for broad regions that is applied to all of the AEZs in a regions.

Table 2.1. Regional comparison of Winrock and WHRC databases with GTAP regions.

GTAP	Winrock*	WHRC	Winrock*
United States	49	United States	49
Canada	13	Canada	13
Sub Saharan Africa	85	Africa	85
EU 27	26		
E Europe and Rest of Former Soviet Union	10	Europe	
Rest of European Countries	10		43
Russia	88	Former Soviet Union	93
Brazil	29		
Central and Caribbean Americas	39	Latin America	
S & Other Americas	56		124
Mid East & N Africa	45	N Africa	45
E Asia	4		
Oceania	10	Pac Developed	
Japan	1		15
China & Hong Kong	31	China/India/Pakistan	
India	35		67
Rest of SE Asia	172		
Rest of S Asia	6	S & SE Asia	
Malaysia & Indonesia	45		222

2.1 Winrock Forest Biomass Carbon Database

The EPA relies on a database created by Winrock International (Harris et al 2008). Winrock synthesized a range of forest biomass carbon datasets each created using different methodologies. The global vegetation carbon map created by Ruesch and Gibbs (2008) is used to fill in gaps where more detailed datasets are unavailable. All datasets are published except for a satellite-based approach led by Sassan Saatchi and Winrock that is still being finalized.

Most of the datasets are spatially-explicit, which is a major advantage over the WHRC look-up table because it provides estimates tailored as much as possible to the regions of interest. The spatially-explicit data also have advantages over the estimates compiled by Sohngen (Section 2.2) because in most cases they are based on more data points and better account for the variation of carbon stocks across the landscape. For the EPA analysis, Winrock used a geographic information system (GIS) to clip the carbon maps to each country / administrative unit and calculate the weighted average. We recommend using the Winrock database (with minor refinements to account for recently published carbon maps) to estimate forest carbon stocks for each GTAP AEZ and region.

Note that it is important to capture the carbon stocks of the forests most likely to be cleared rather than an average for the entire region as is currently used by GTAP (based on WHRC). Please see the report by the Land Cover Types Subgroup for recommendations on methods to exclude forests that are inaccessible and develop conversion probabilities.

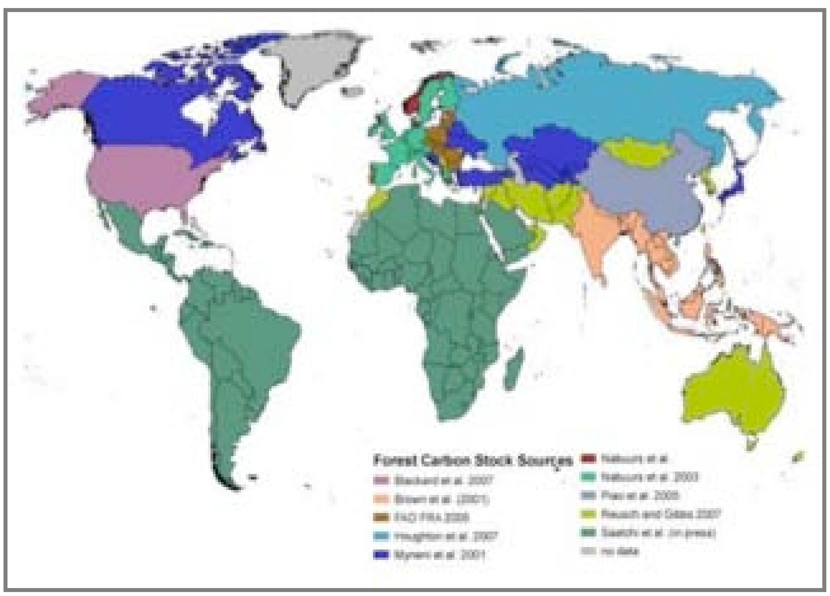

Figure 2.1. Range of data sources used by Winrock (Harris et al. 2008) to estimate forest carbon stocks.

2.1.2 Winrock Cropland Biomass Carbon Database

Winrock uses a single IPCC default value for all annual croplands and all plantations. While cropland carbon stocks do not vary as much as forest carbon stocks, they do vary according to yields and crop type. We recommend using crop yield maps by Monfreda et al (2008) to provide regionally-specific biomass estimates for different crop types. Crop biomass values could be scaled according to yield as in Gibbs et al. (2008) or by assuming that calculations of net primary productivity (NPP) based on yield data are equivalent to the standing carbon stock as in West et al. (2010).

2.1.3 Winrock Grassland, Savana and Shrubland Biomass Estimates

Winrock used the IPCC default values for grassland, savannas and shrubland for all countries except Brazil where they followed de Castro and Kauffman (1998). Similar to croplands, biomass values vary across landscapes for these cover types but the variation is less than with forests. We recommend reviewing the literature for more recent efforts to estimate and map these carbon stocks in different regions, to help provide more detailed values for key regions and AEZs.

2.2 Alternative Approach to Forest Biomass

Data compiled by Prof. Brent Sohngen at OSU can be used to derive an alternative set of emissions factors to the currently used Woods Hole dataset. [1] OSU, as part of the Global Timber Market and Forestry Data Project produced country-specific datasets listing accessible and inaccessible forest areas with the respective accessible and inaccessible above ground tons carbon. OSU datasets are available for 150 countries across all GTAP regions. Furthermore, the datasets cover 18 AEZ regions. All land area and carbon data sets are available online.[2] The individual forest inventory source data varies by country. FAO data was used for most countries. For the US inventory data was taken from the USDA FIA, and for the remaining countries including China, inventory data was sourced from official country-specific publications.

According to Brent Sohngen, accessible and inaccessible lands are delineated differently depending on the geographic region. For the US, accessibility is a function of timber demand and price as outlined in Sohngen and Sedjo (1999).[3] For Europe, all forests are deemed accessible and for the tropics accessibility is based on proximity of forestland to roadways.

Table 2.2 below illustrates the available data with the US as an example and compares the derived emissions factor to the Woods Hole data. For the US, the data would suggest forest emissions factors for accessible land of 48 tC/ha, 96 tC/ha for inaccessible land, and a combined factor of 62 tC/ha, compared to the Woods Hole factor of 113 tC/ha. As part of this analysis we extracted data for several other key countries and compared the derived emissions factors to the Woods Hole factors. The results are listed in Table .3. Compared to the Woods Hole factors, the

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[1] Global Timber Market and Forestry Data Project, Version 5, 2007, Sohngen and Tennity, OSU. Data has been compiled and made available with the financial assistance of the US EPA, Climate Analysis Branch.
[2] http://aede.osu.edu/people/sohngen.1/forests/GTM/data2.htm
[3] Sohngen, Brent and Roger Sedjo, "Potential Carbon Flux from Timber Harvests and Management in the Context of Global Timber Market"; Report funded by the US Department of Energy and Resources for the Future, 1999, available at http://www-agecon.ag.ohio-state.edu/people/sohngen.1/forests/c_stor.pdf

combined (accessible land and inaccessible land) factors are the same for Brazil and Japan but, similar to the factor for the US, lower for Canada, India, and Russia.

In summary, the OSU emissions factors provide a higher resolution than the Woods Hole factors since data is available for all GTAP regions and by AEZ. However, the inventory data sets are dated and the accessible/inaccessible land delineation for the tropics is likely too simplified for CARB’s purposes. The OSU factors may indicate that the Woods Hole datasets are either comparable to or overestimate carbon emissions from above ground forest biomass. However, more updated datasets should be analyzed to confirm this finding.

Table 2.2. OSU Data for the United States

United States AEZ	Accessible ha	In-accessible ha	Total (ha)	Accessible Million tC	In-accessible Million tC	Total Million tC	Accessible t/C per ha	In-accessible t/C per ha	Total tC/ha	Woods Hole - GTAP 2010 tC/ha
1	0	0	0	0	0	0	0.0	0.0	0.0	
2	0	0	0	0	0	0	0.0	0.0	0.0	
3	0	0	0	0	0	0	0.0	0.0	0.0	
4	0	0	0	0	0	0	0.0	0.0	0.0	
5	0	0	0	0	0	0	0.0	0.0	0.0	
6	0	0	0	0	0	0	0.0	0.0	0.0	
7	1,262,860	1,541,948	2,804,808	49	113	162	39.1	73.3	57.9	
8	5,051,441	6,167,791	11,219,232	198	452	650	39.1	73.3	57.9	
9	3,367,627	4,111,861	7,479,488	132	301	433	39.1	73.3	57.9	
10	36,344,528	12,030,874	48,375,401	1,862	994	2,856	51.2	82.6	59.0	
11	21,507,454	7,711,778	29,219,231	1,223	697	1,920	56.9	90.4	65.7	
12	68,734,685	21,424,930	90,159,614	3,138	2,662	5,800	45.7	124.3	64.3	
13	1,894,290	2,312,922	4,207,212	74	170	244	39.1	73.3	57.9	
14	1,894,290	2,312,922	4,207,212	74	170	244	39.1	73.3	57.9	
15	420,953	513,983	934,936	16	38	54	39.1	73.3	57.9	
16	1,473,337	1,798,939	3,272,276	58	132	189	39.1	73.3	57.9	
17	0	0	0	0	0	0	0.0	0.0	0.0	
18	0	0	0	0	0	0	0.0	0.0	0.0	
							48	96	62	113

Table 2.3. Emissions Factor Comparison

	Accessible Land (tC/ha)	Inaccessible Land (tC/ha)	Accessible and Inaccessible Land (tC/ha)	Woods Hole (tC/ha)
US	48	96	62	113
Brazil	102	103	102	102
Canada	30	30	30	74
India	29	70	60	139
Russia	17	46	39	65
Japan	46	108	74	75

2.3 Recommendations

Must do

Use GIS to quantify forest carbon stocks for each GTAP region and AEZ combination based on the Winrock database and other recently published biomass maps

Short term

-
- Use GIS analysis to quantify cropland carbon stocks for each GTAP region and AEZ based on crop yield maps from Monfreda et al. (2008)
- Conduct literature review of savanna, shrubland, and grassland biomass estimates to create an improved look-up table for the GTAP regions and AEZs

Long term

- Refine estimates to account for different carbon stocks based on likelihood of conversion.

3. Soil Carbon Stock

CARB and GTAP analysis used Woods Hole Research Center (WHRC) database to characterize soil carbon stock values. As shown in Figure 1.1, the spatial resolution of such data is rather coarse compared with the spatial resolution of the projected land use change from the GTAP model (Figure 1.2).

Winrock used data from the World Harmonized Soil Database (WHSD). This database is a combination of 4 databases to create an international soil map (Soil Map of the World, SOTER Regional Studies, European Soil Database, Soil Map of China 1:1 Million Scale). Figure 3.1 below shows the coverage of each of the datasets.

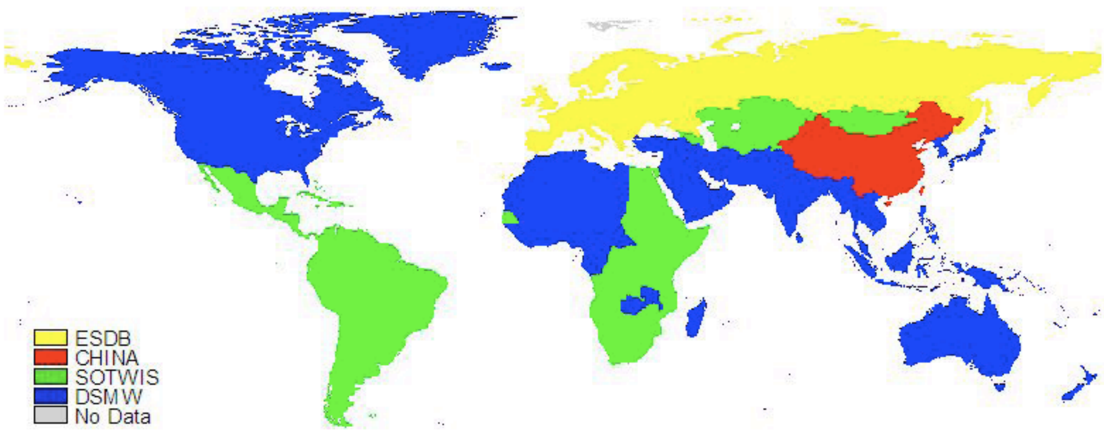

Figure 3.1. Harmonized World Soil Database

The HWSD provides information for 15773 soil mapping units at 30 arc second resolution. Database shows the composition of each soil mapping unit and standardized soil parameters for top (0-30cm) and subsoil (30-100cm). The total carbon per ha was not provided, but provided information to calculate the total C ha-1 using and equation from Guo and Gifford (2002).

$$Ct = BD \times Cc\% \times D$$

Where,

Ct = total soil carbon concentration (t /ha)
BD = soil bulk density (g cm^{-3})
Cc% = soil concentration (%)
D = soil sampling depth (cm)

Some areas lacked information on bulk density, for these areas the following equation was used:

$$BD = \frac{100}{\frac{\%OM}{0.244} + \frac{100 - \%OM}{1.64}}$$

Where,

%OM = organic matter (or loss by ignition) as a percentage of soil dry mass.

The map below (Figure 3.2) shows the carbon estimates based on the HWSD 0-100 cm data. The HWSD collected information about the topsoil (0-30cm) and subsoil (30-100cm).

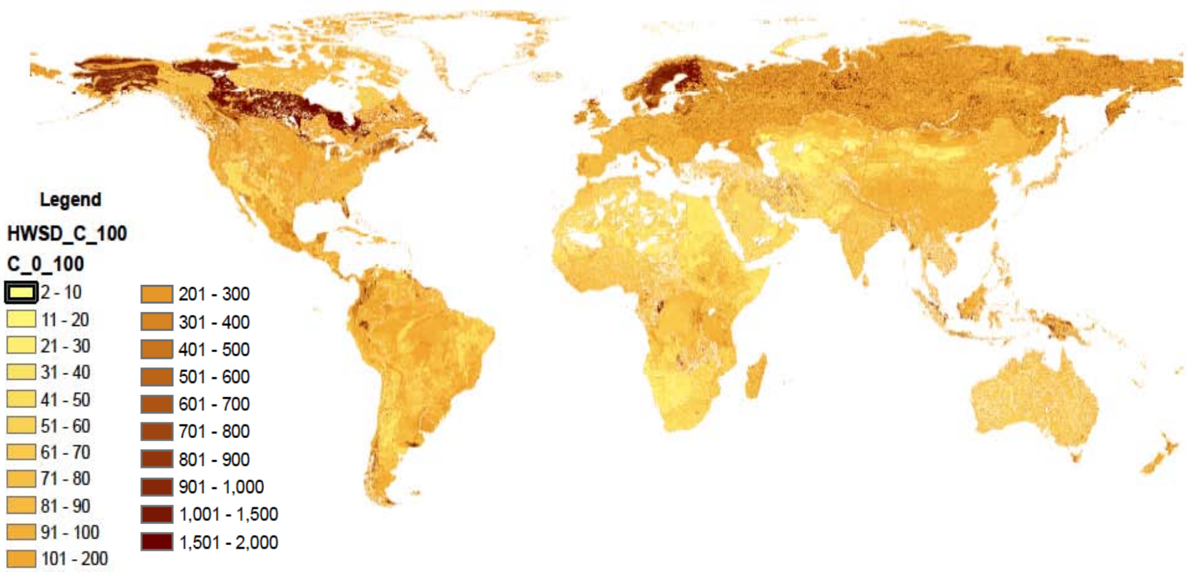

Figure 3.2. Soil carbon (t C/ha) calculated for 0-100 cm depth based on data from HWSD.

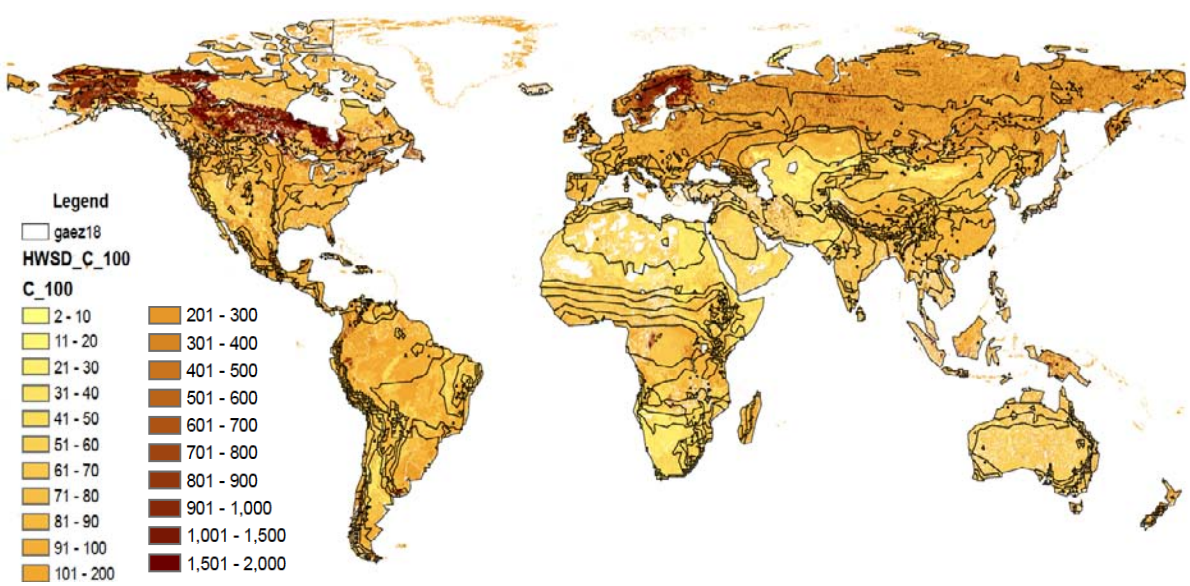

Figure 3.3. Soil carbon (t C ha-1) 0-100 cm depth by AEZ

3.1 Land Conversion

The effect of land management and land cover type has considerable effect on soil carbon and nitrogen. In a meta analysis done by Guo and Gifford, the impacts of land management on soil carbon and nitrogen was reviewed from 74 different publications. The study concluded that certain land conversion (such as native forest to crop or pasture to crop) will release a great deal of carbon, but other land conversions (such as crop to secondary forest) can have a positive impact on soil carbon stock (Guo Gifford 2002). In a separate study, the land conversion from forest to cultivated land shows the average loss to be 22% - with the most soil carbon loss in the first 20 years (Murty et al 2002). Below lists the impacts of land conversion on soil carbon (Guo Gifford 2002):

pasture → plantation: -10%
native forest → plantation: -13%
native forest → crop: -42%
pasture → crop: -59%
native forest →pasture: +8%
crop → pasture: +19%
crop → plantation: +18%
crop → secondary forest: +53%
native forest or pasture → broad leaf plantation: ~0
native forest or pasture → pine plantation: -12-15%

The above list exemplifies the importance in considering the difference in carbon losses or gains of different conversion types (though the above example does not differentiate between climatic regions), as opposed to a uniform loss rate of 25% assumed in the CARB analysis. A comprehensive review of land conversion emission factors is discussed in Section 5.

3.1 Recommendations

- Use best available spatially-explicit, published datasets to provide estimates by GTAP regions and AEZ combinations
- Use GIS to estimate soil C for region / AEZ using global datasets; STATSGO for U.S.
- Use satellite-based land cover maps to pull out carbon estimates for grassland, forest, cropland etc.
- Use GIS to overlay land cover and land management type

4. Peatlands Emissions

The CARB and Tyner analyses do not explicitly represent peatlands as one of the land use type, nor do they consider the conversion of peatlands for agricultural and other purposes. In the Winrock analysis for the EPA's RFS2 (ref), peatland areas cover 2-44% and 2-22% in some of the corresponding administrative regions in Indonesia and Malaysia, respectively. The emission rates are assumed to be 20 t C/ha/yr using 80 cm drainage depth. The emission factors are calculated for 30 and 80 years and the cumulative emissions are 600 and 1600 t C/ha, respectively.

In an earlier study published in Science, Fargione et al. (Fargione et al. 2008) estimated the CO2 released from drained peat soils in tropical rainforest Southeast Asia over 50 years is 941 t C/ha (750, 145, 797, and 47 in soil, aboveground, belowground, and root respectively), equivalent to 18.8 t C/ha/yr. Fargione et al. (Fargione et al. 2008) acknowledge that this underestimates the CO2 that would be released if drainage were to be sustained for longer than 50 years.

Both studies regard the assumptions of peatland emissions are highly uncertain.

4.1 Peatland Areas and Carbon Stocks

There are several estimates of the total area of peatland as well as the overall carbon stock and emissions. The values from various journals and articles show a range of 3~10% of global coverage of peat land (Jaenicke et al 2008, Hadi et al 2001). Studies show that although peat land does not have significant land area, it has a considerable carbon and nitrogen pool (15~33% of the global carbon (Page et al 2008, Furukawa et al 2000). Although temperate and boreal regions have the greatest extent of peat land, Southeast Asia has the greatest extent within tropical peatlands − over 50% of the tropical peatlands is in Southeast Asia with estimates ranging from 56~80% of tropical peatlands in Southeast Asia ((Page et al 2008, Hooijer et al, Furukawa et al). Table 4.1 below shows a breakdown of peatland carbon pools and carbon stock density per unit area of land.

Table 4.1. Estimates of global and tropical peatland carbon pools. Source: IPCC WG1, Vitt et al (2000) and Page et al (2010).

	Minimum	Best estimate	Maximum	Carbon density (t C /ha)
Tropical forest (Gt)		216		122
Global peat carbon pool (Gt)	598.4	610	617.9	
Boreal/temperate peat carbon pool (Gt)	516.7	521.4	526.1	900-1390
Tropical peat carbon pool (Gt)	81.7	88.6	91.9	1400-2110
Souteast Asian peat carbon pool (Gt)	66.3	68.5	69.9	2200-3500

According to Page et al 2008, the total area of tropical peatland lies within: 387,201~657,430 km^2 (best estimate of 441,025km^2) divided into the following regions. Southeast Asia=56%, Africa=13%, South America=24%, Central and Caribbean=5%, Asia (other)=1%, Pacific region <1%.

4.2 Conversion and Emissions

Peatland conversion has increased significantly in the past few decades, in Southeast Asia alone 47% of peatland (12.9 Mha) was deforested by 2006 –estimated 1.3% deforestation rate per year in Indonesia (Hooijer et al 2006). Within that 47%, majority (67%) was deforested for small scale agriculture, the remaining was a split between large scale agriculture or cleared and burnt lane (Hooijer et al 2006). From 1997-2000 logging increased by 44% in Indonesia (Page et al 2001). The estimate of CO_2 emissions from decomposition of drained peatlands is between 355 Mt/yr ~ 855 Mt/yr (Hooijer et al 2006). Hooijer's emissions estimate comes from peatland extent, thickness, projected and current land use, water management practices and decomposition rates. Indonesia is emissions approximately cover 82% (7954 Mt) of the emissions for 2006, at this rate, by 2015 CO_2 emissions could peak at 745 Mt/yr (if continued without mitigation).

It is found that unit CO_2 emission is a linear function of groundwater depth and % area drained in converted land. Peatland emissions can be estimated based on the following equation (Hooijer et al 2006):

$$CO_2 \text{ emission} = \text{LU Area} \cdot \text{D Area} \cdot \text{D Depth} \cdot CO_2 \text{ 1m [t/y]} \qquad \text{(Equation x)}$$

Where,

LU Area = peatland area with specific land use [ha]
D Area = drained area within peatland area with specific land use [fraction]
D Depth = average groundwater depth in drained peatland area with specific land use [m]
CO_2 1m = CO2 emission at an average groundwater depth of 1m = 91 [t CO2 /ha/yr]

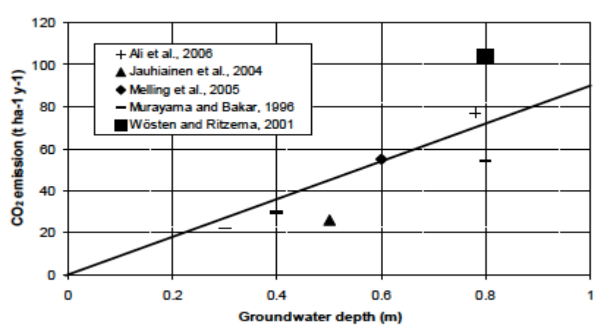

Figure 4.1. Linear relation between groundwater depth in peatland and CO2 emission caused by peat decomposition. The line has been fitted through published measurements in agricultural areas in peatland, including oil palm plantations. Source: Hoojier et al (2006)

Peatland drained to 0.95m typical needed for large croplands, including plantation, on average emits 86 t CO2 /ha/yr. Cropland/palm plantation keeps average water tables always below 0.7 m, but they are often as deep as 1.2m on average. For small-scale agriculture such as mixed cropland and shrubland, peatland is typically drained to 0.6m depth for 88% of area and emits 48 t CO_2 /ha/yr. For shrubland in recently cleared and brunt area, the drainage depth is typically 0.33m over half of area and emits 15 t CO_2 /ha/yr.

Table x. Typical tropical peatland emissions (metric ton CO_2/ha/yr). Source: Hooijer et al (2010)

Large croplands, including plantations	86 (73-100)
Mixed cropland / shrubland: small-scale agriculture	48 (27-73)
Shrubland; recently cleared & burnt areas	15 (6-27)

4.3 Recommendation

Due to the high likelyhood of peatland conversion for agricultural purposes in some regions (Hooijer et al 2010), and the high carbon stock and emission rates associated with peatland conversion, we recommend the consideration of peatland emission factors by land conversion type in future CARB's GTAP analysis. However, such implementation requires a better understanding of *when* and *how* much of peatland will be converted under various scenarios. It is understood that such capability may not be possible under the current GTAP model structure in the short term, and the topic is discussed in greater detail in a separate report by the Land Conversion Type sub-workgroup. Therefore it is appropriate to consider this recommendation as a short-term goal for improvement.

5. Factors for Emission Factor Calculation

Emission factors per conversion scenario are evaluated for iLUC studies conducted by Winrock for EPA Renewable Fuel Standard (RFS2) and CARB for the Low Carbon Fuel Standard (LCFS). Additional approaches to calculating EF by other methods were also reviewed[4].

5.1 Comparisons of Assumptions of Factors for Emission Factor Calculation

IPCC Tier 1 through 2 and stock change emission factor methods are used in both Winrock RFS2 analysis CARB LCFS iLUC calculations. EFs are calculated per pool and are variable. Generally, default stock change factors were applied in both assessments. Although IPCC recommends carbon stock changes in the five pools must be reported: aboveground biomass, belowground biomass, dead wood, litter, and soil organic carbon; it is simply not possible for some land types and the default is then set to '0'. Also, a decrease in one pool may be offset by increases in another pool, e.g., biomass pools decline after a disturbance such as fire but litter and dead wood pools can increase. Therefore, the change in a single pool can be greater than the net change in the sum of the pools. Table x identifies each pool or factor, the general IPCC GHG conversion response, and calculation steps used by Winrock and CARB.

Table 5.1. IPPC Recognizes the Following a) Carbon Pools and b) Factors for Emission Factor Calculation (IPCC LULUCF, 2006) [5] EPA and CARB incorporated each pool and factor into Emission Factor calculations for different land types converted. IPCC default calculation steps were followed for some pools and factors as listed.[6] Note! Assumptions of treatment of sequestration, forgone emissions, and reversion are described in more detail in the CEC Report as not fully described in this table.

a) C Pools	GHG Conversion Response for EF	EPA vs. CARB Treatment for Emission Factor	IPCC Default Calculation
Aboveground Biomass (AG)	Emitted by conversion, forgone by harvested wood or sequestered through new growth	EPA and CARB use IPCC default calculation. Pool estimated by EPA combination of carbon maps/ground measurement; CARB used WHRC historical averages	Stock change approach AG (tC per ha); dry weight converted to CO_2
Belowground Biomass (BG) including roots	Emitted by conversion, forgone by reduced tillage or sequestered by using different crop practices	EPA and CARB did not account for roots.	Carbon in all biomass of live roots. Fine roots of less than 2 mm diameter are excluded, because these often cannot be distinguished empirically from soil organic matter

[4] Note the approaches in O'Hare et al., (2009), Golub et al., (2010), Hertel (2010), etc.on time treatment and uncertainty is covered by other EWG sub-groups

[5] Note IPCC (2006) Best Practice guide for C stock estimates and emissions is somewhat different to the AFLOU method used in the CDM and REDD accounting for national inventory reporting.

[6] Note: Updates to IPCC methods include the JRC carbon EF where some IPCC defaults were used and categories are clearly separated by management practice (JRC, 2010). It is suggested to review the JRC stock change methods and new FAO methods for REDD for comparison.

a) C Pools	GHG Conversion Response for EF	EPA vs. CARB Treatment for Emission Factor	IPCC Default Calculation
			or litter. Can include below ground part of stump.
C in Litter	Emitted by natural decay; sped up by conversion by fire and in some cases re-incorporated back to the soil by sequestration	Not accounted for by EPA or CARB	Litter (tC/ha) Carbon in all non-living biomass with a diameter less than the minimum diameter for dead wood (e.g. 10 cm), lying dead in various states of decomposition above the mineral or organic soil.
Dead Wood	Emitted by natural decay; converted to biochar for sequestration back into SOC or burned to increase initial emissions	Not accounted for by EPA or CARB	DW (usually omitted except for forest systems can be substantial- tC/ha). Carbon in all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country[7].
Soil Carbon (SOC)	Assumed linked to conversion response of aboveground biomass	BG =SOC measurements in top 30cm of soil followed by EPA and use of HWSD; CARB used top 100cm (non –IPCC) and regained SOC factor 75%and WHRC estimates. Both used IPCC default for 20 years to reach equilibrium.	SOC (as 25% of AG estimate in tC/ha or using regional data as tC/ha). IPCC default 30 cm depth; 20 years to reach equilibrium. Organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country and applied consistently through the time series. Fine roots < 2mm can be included. Inorganic carbon is not included.
b) C Factors		**Description**	**Acronym and Calculation Step**
Wood/timber	Emitted differently depending on the product so counted as a negative emission for a set period of time	Harvested Wood Products (HWP) for export counted as stored product as a percentage for iLUC emission factors. CARB used 90% factor; EPA used factors in uncertainty analysis although variable.	HWP (3 + methods in IPCC- no one favored). New GREET based on Sohngen data (FAOSTAT)
Fire	Considered a conversion response as an immediate emission	EPA and CARB used IPCC default factors for N_20 and CH_4 combustion	LU (factor) calculated by CO2 and other GHG including N_20 and CH_4 Natural or human caused but numbers in IPCC are for both combustion methane and N_20

[7] Often ignored, or assumed in equilibrium, this carbon pool can contain 10-20% of that in the AGB pool in mature forest (Delaney et al., 1998). However, in immature forests and plantations both standing and fallen dead wood are likely to be insignificant in the first 30-60 years of establishment (Watson, UNDP, 2009).

a) C Pools	GHG Conversion Response for EF	EPA vs. CARB Treatment for Emission Factor	IPCC Default Calculation
Disturbance	Considered as a conversion response as an immediate emission	EPA and CARB did not include ‘other’ disturbance	LU (factor) disturbances vary and usually not included in calculation. By insect, disease, other abiotic factors, e.g. drought, storm, insect disturbance, etc.
Forest Management; LU management	Considered in a variety of response variables for immediate emission or sequestration value for reduced or ‘better’ management practice as opposed to conventional methods	EPA and CARB included LU factors although differently. EPA assumed full tillage and medium inputs.	LUF (management) factored separately as ordinal value. Several factors relevant to on-farm practice

5.2 IPCC Approach

IPCC provides a decision tree method to estimate emission factors from land conversion in the Agriculture Forest and Other Land Use (AFOLU) and additional guidelines in the IPCC LULUCF Good Practice to incorporate default data and methods. The IPCC Tier 1 emission factor method assumes that the net change in the carbon stock for litter (forest floor), dead wood and soil organic carbon (SOC) pools is zero, but using national accounting (Tier 2 and above) the belowground biomass, litter, dead wood and SOC should all be counted unless the country chooses not to count a pool that can be shown not to be a source. Therefore Tier 1 can only be applied if the litter, dead wood and SOC pools can be shown not to be a source using the methods outlined by IPCC. Tier 1 can also only be applied if forest management is not considered a key category, which can only be the case if “forests remaining forests”.

Tier 1 defaults include carbon stock change in biomass loss set to zero if the average age of the tree population is less than or equal to 20 years; otherwise assume that carbon stock change in biomass growth is equal to loss. Also estimates of above-ground biomass stocks change for grasslands are only meant to be used to calculate emission factors from burning.

Another example of why Tier 1 should not be used for forest inventory is dead wood. Mortality, for example, of stems that are excluded during forest grown can represent 30-50% of total productivity in a stand during its lifetime in extensively managed stands without periodic or partial cuts (IPCC 2007).

Two IPCC options for a Tier 2 estimation of changes in carbon stock in living biomass are available: 1) crown cover area method, e.g. stock change approach (SCA); and b) tree growth rate method, e.g., atmospheric flow approach (AFA); equations are:

Stock change approach (SCA):
Global emission (SCA) $= -\Sigma\Delta S_i = -\Delta S_1 - \Delta S_2$
Atmospheric flow approach (AFA):

Global emission (AFA) $= \Sigma AFi = AF1 + AF2 = (-\Delta S1 - F12) + (-\Delta S2 + F12) = -\Delta S1 - \Delta S2 =$ ***Global emission (SCA)***[8]

Each approach differs in credits and debits for CO2 flows or changes by accounting for carbon stock in wood products because this is accounted for differently among countries that produce or consume wood (Lim et al., 1999). Tier 3 or 'all' regional data suggests using a combination of dynamic models along with inventory measurements of biomass stock changes, do not employ simple stock change or emission factors per se. Estimates of emissions/removals using model-based approaches derive from the interaction of multiple equations that estimate the net change of biomass stocks within the models. In many instances, the carbon stocks in forests may change without a change in forest area. Examples include losses of biomass associated with selective wood harvest, forest fragmentation, ground fires, shifting cultivation, browsing, and grazing (Barlow et al., 2003, Houghton, 2005).

5.3 Stock Change Factors and improved practice

Carbon stock change is affected by several dynamic processes including harvested wood products, fire, disturbance and forest management. Land practice is critical to including and particular assumptions, e.g. full tillage practice, can adversely influence emission factors. IPCC notes high uncertainty associated with these values, Tier 1 do not specify to include uncertainty from each factor.

IPCC uses a decision tree approach for any given activity in any year. Utilized for national reporting under the Marrakesh Accords, this method recognizes land can have multiple activity and that allocation to shirts in land use can be problematic, although annual tracking is suggested or 'by interpolation' method. Table x identifies the land based accounting approach where improved practice would influence the net change of carbon stocks depending on the practice (IPCC, 2006).

Table 5.2. Relative potential in 2010 for net change in carbon stocks through some improved management and changed land-use activities[9]

Global Estimates for Activities	Total Area (M ha)	Assumed % total of Area under activity in 2010	Net annual rate of change in t C per ha/yr	Estimated net change in C in 2010 (Mt C/ yr)

[8] **AF1, AF2** = C fluxes into the atmosphere; **F12** = lateral C flux between pool 1 and 2 **ΔS1, ΔS2** = stock changes in C pools 1 and 2

[9] IPCC Land Based Accounting http://www.ipcc.ch/ipccreports/sres/land_use/index.php?idp=8..

Global Estimates for Activities	Total Area (M ha)	Assumed % total of Area under activity in 2010	Net annual rate of change in t C per ha/yr	Estimated net change in C in 2010 (Mt C/ yr)
a) Improved Management within a Land Use				
Forest Management	4050	10	0.4	0.4
Cropland Management	1300	30	0.3	125
Grazing Land Management	3400	10	0.7	240
Agroforestry	400	20	0.3	26
Rice Paddies	150	50	0.1	7
Urban Land Management	100	5	0.3	2
b) Land-Use Change				
Agroforestry	630	20	3.1	390
Conversion of Cropland to Grassland	1500	3	0.8	38
Wetland Restoration	230	5	0.4	4
Restoring Severely Degraded Land	280	5	0.3	3

IPCC notes uncertainty was not included in the table for several reasons: i) The list of candidate activities is not exclusive or complete; ii) it is unlikely that all countries would apply all candidate activities; and iii) the analysis does not presume to reflect the final interpretations of Article 3.4. of the Kyoto protocol. However, these estimates provide an example of how short term effects from improved management within a land category would likely have a far greater impact from agroforestry and grazing management.

Assumptions for Emission Factor Calculations by CARB and EPA are compared in the Life Cycle Associates CEC Report (forthcoming).

5.4 Additional References/Studies to Review:

- Long term forest re-growth rates. See: Lewis et al. (2009) and Phillips et al.(2008) (updated in RFS2)
- Regional crop and pasture modeling (such as updated by RFS2) for Brazil
- International fertilizer emissions; update
- Modeling emission factors into a static model. A forward looking model is required to capture short term and long term carbon stocks and emissions.
- International Rice Research Institute (IRRI).
- International Crop Residue Burning Emissions

- International fertilizer production, livestock changes, enteric fermentation and manure management

There are many other factors, beyond agronomic factors, that limit land mobility within an AEZ. These include costs of conversion, managerial inertia, unmeasured benefits from crop rotation, etc. (Golub et al., 2010). At present, emission factors cannot capture how these activities will impact emissions from land projected past the baseline.

5.5 Recommendation

- Introduce replacement cropping systems for carbon storage
- Review assumptions of management practice effects on overall EF, particularly tillage (See section 7)
- Incorporate new data on perennial storage in roots, soil and aboveground biomass
- Compile new data on disturbance effects and stages of sequestration at regional level
- Review accounting of baseline- production period and time treatment (other EWG sub-group)

6. Long-term Carbon Storage in Harvested Wood Products (HWPs)

When biomass is removed from forest, some are left onsite and only a portion of forest biomass is removed from the forest. Those that are left onsite, typically nonstemwood tissues including the bark, branches and leaves, provide critical ecological service such as conservation and protection of soil health. The biomass removed from the forest (so-called merchantable biomass or harvested wood products, HWPs) usually end up in one of the four carbon pools: products-in-use, landfill, emitted with energy capture, emitted without energy capture. Product-in-use typically include industrial, commercial and residential wood products such as construction materials (lumber, plywood, oriented strandboard, nonstructural panels) and miscellaneous products and paper. These wood products have different lifespans that range from 2–100 years, with longer lifespan for lumber and shortest for paper. The C deposition between these four carbon pools (products-in-use, landfill, emitted with energy capture, emitted without energy capture) will change over time as less products will remain in product-in-use and end up in the landfill and continue to be stored in the landfill or decomposed and released to the atmosphere as CH_4.

The treatment of carbon stored in HWPs varies. For example, IPCC tier 1 values recommend treating HWPs as *instantaneous emissions* once biomass is removed from biomass system. On the other hand, several other guidelines consider the storage factor and the fate of the carbon in HWPs include IPCC (references), California Climate Action Registry (CCAR), DOE 1605 Forestry Emission Guidelines, Chicago Climate Exchange, etc.

The CARB and Tyner analysis assumes that when biomass is removed, 90% of carbon in biomass (75% of forest biomass and 100% of grassland vegetation in Tyner analysis) will be released into the atmosphere at the time of land conversion.

6.1 Carbon Stored in Wood Products

The calculation of carbon storage in HWPs requires the following key information:

- The (dynamic) market share of the HWPs over time
- The lifetime (fate of carbon stored) of HWPs over time

Figure 6.1 shows the disposition of forest biomass once it is disturbed (t = 0) for Canada (reference, 2003). As shown, only about 30% of the total forest biomass is in the merchantable wood, and of those only about 10% become lumber, the wood product category has the longest lifetime among all the wood products (Figure 6.1).

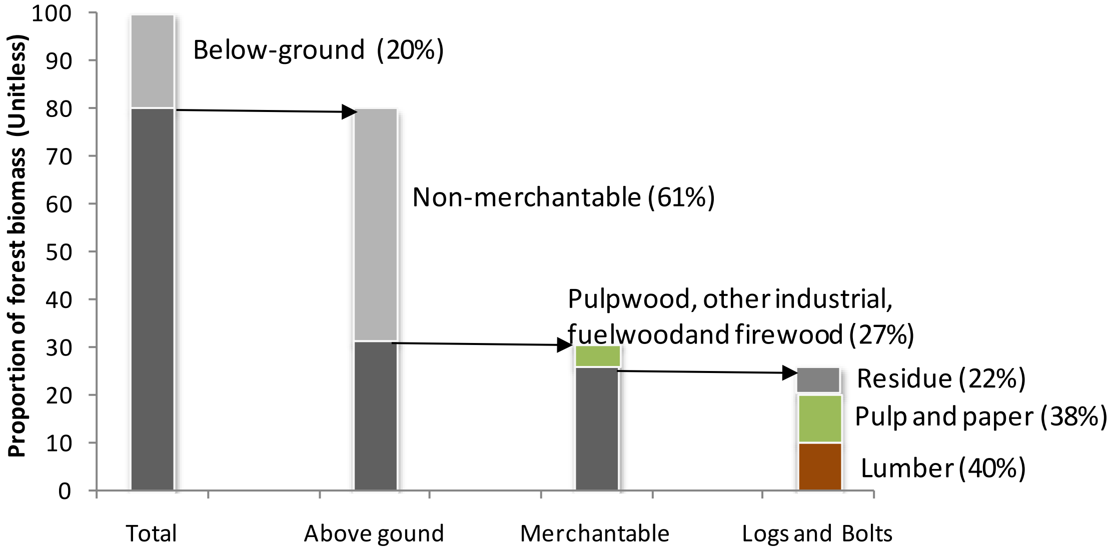

Figure 6.1. Disposition of forest biomass after disturbance. Source (Wood et al. 2003)

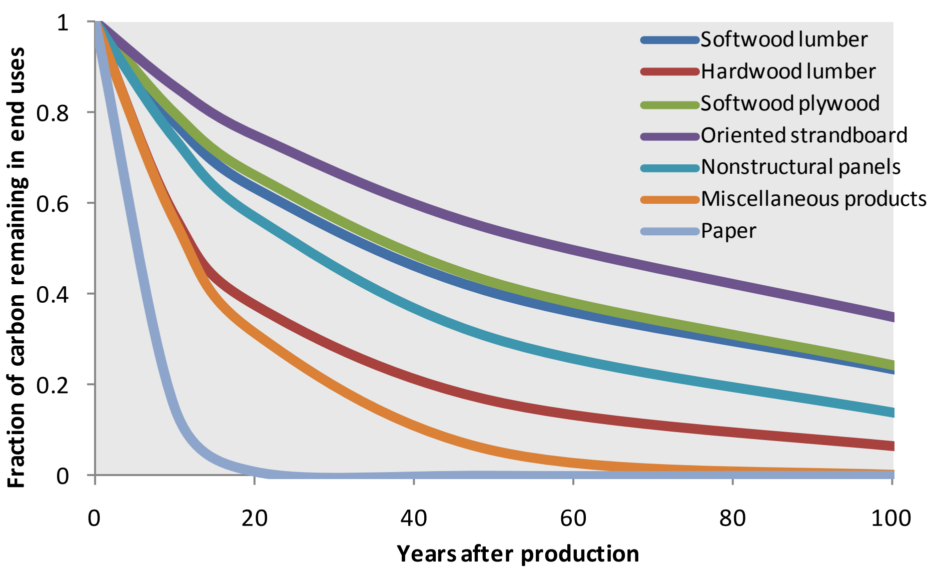

Figure 6.2. Fraction of carbon in primary wood products remaining in end uses up to 100 years after production. Source: U.S. DOE (2006).

Combing the Figures 6.1 and 6.2, the above calculation shows that the total carbon stored in wood products is 5.6%, 3% and 1.6% after 20, 50, and 100 years (Table 6.1). The results shown here are significantly different from the discussion in Section 6.2. This calculation relies on the calculation of carbon remains in end-use products, while the calculation in Section 6.2 relies on tracking carbon stored by the types of wood products.

Table 6.1. Fraction of carbon stored in end-usess after 20, 50, and 100 years by end-uses category.

Year after production	Softwood and hardwood lumber (%)	Pulp and paper (%)	Misc (%)	Total carbon stored in wood products (%)
20	5.27	0.13	0.20	5.6
50	2.95	-	0.04	3.0
100	1.56	-	0.00	1.6

The issue of HWP is also examined in the Winrock report for the RFS2 analysis (Harris et al. 2009). The proportion of extracted timber that goes to long-lived wood products and the proportion of extracted timber as inherited emissions for the world region is presented in Table x.

For example, assuming that 25% of this carbon ends up in long-lived (>5 yrs) wood products (i.e., the value calculated in Table 2 above for Indonesia), the emission factor estimated for forest conversion after taking into account carbon storage in wood products would be approximately 1-2% of the emission factor value. Thus the Winrock analysis concludes that "carbon stored in wood products long-term is probably immaterial for most regions of the world, especially if considering a timeframe of 30 years."

Table 6.2. proportion of extracted timber that goes to long-lived wood products and the proportion of extracted timber as inherited emissions. All units are in Tg C. From Winjum et al. (1998). SWD=sawnwood, WBP=woodbase panels, OIR=other industrial roundwood and P&P=paper and paperboard. Source: (Haris, et al 2009).

Category / Country	Industrial Roundwood Production*	Commodity use ≥ 5 yr#					Inherited emissions	% HWP	% Inherited Emissions
		SWD	WBP	OIR	P&P	Total			
Developing									
Brazil	23	4	1	1	1	7	4	30	17
India	9	4	0.1	1	1	6	3	67	33
Indonesia	12	2	0.1	1	0.42	3	1	25	8
Ivory Coast	1	0.05	0.03	0.2	0.01	0.3	0.2	30	20
Developed									
Canada	39	3	1	1	2	7	1	18	3
Finland	9	0.6	0.2	0.1	0.4	1.2	0.3	13	3
New Zealand	2.7	0.3	0.1	0.1	0.2	0.6	0.3	22	11
U.S.A.	102	23	8	3	23	57	17	56	17
Worldwide									
Developing	128	26	6	22	14	68	42	53	33
Developed	308	70	27	29	58	184	71	60	23
Total	436	96	33	51	72	252	113	58	26

s

6.2 Analysis of Carbon Release from Conversion of US Forest Ecosystems

Mueller (2010) combined data from USDA's Resource Planning Act RPA tables with a report on harvested carbon estimates from USDA (USDA 2006 Report).[10,11] This analysis did not include wood combusted with energy capture as well as the displacement of wood products in use. This

[10] Forest Inventory and Analysis National Program, 2007 RPA Resource Tables, available at http://www.fia.fs.fed.us/program-features/rpa

[11] Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States. Prepared by James Smith, Linda Heat, Kenneth Skog, and Richard Birdsey, General Technical Report NE-343, April 2006. Available at http://www.treesearch.fs.fed.us/pubs/22954

would have required a life cycle analysis with a displacement approach similar to the analysis performed by Oneil and Lippke (2009) or Scharai-Rad (2002).[12,13] A complete LCA would have required substantial time and resources. Mueller concludes that the attached results are likely underestimating the total harvested carbon. The derived factor supports the HWP factor used in the 2010 GTAP analysis. It also confirms the importance of taking HWP into consideration. The present analysis presented below employed the following steps:

1. In the first step the fractions of softwood and hardwood removals that leave harvest sites from forest ecosystems by region were determined using Table 40 from the RPA tables.[14] The derived values are listed in Table 6.3. Wood leaving harvest sites is termed harvested wood.

   Table 6.3. Fractions of total wood removals that are softwood (or hardwood) that leave the harvest site and the fractions of softwood (hardwood) that leaves the site that is sawlogs or pulpwood.

	Useful Wood Removed (from RPA Table 40)		End Use of Removals (Fron RPA Table 39)			
	softwood	Hardwood	softwood sawlogs	softwood pulpwood	hardwood sawlogs	hardwood pulpwood
North East	0.21	0.47	0.56	0.39	0.39	0.31
North Central	0.10	0.50	0.37	0.60	0.36	0.46
Southeast	0.51	0.19	0.49	0.51	0.37	0.43
Pacific Northwest	0.73	0.05	0.87	0.07	0.63	0.32
Pacific Southwest	0.80	0.01	0.68	0.00	0.05	0.30
United States	0.47	0.24	0.64	0.31	0.40	0.41

2. The second step determined what the harvested wood is used for. Using RPA Table 39, the fractions of harvested softwood and hardwood that go into sawlogs and pulpwood were determined. Veneer logs and sawlogs were classified as sawlogs, whereas composite products, posts, poles, pilings, and miscellaneous products were classified as pulpwood.[15] The derived values are also listed in Table 6.3.

3. Now that the fractions of sawlogs and pulpwood that are produced have been identified as well as the fractions of wood that leave forest ecosystems, the disposition patterns of carbon for the following categories were determined: products in use and material in landfills (combined). These fractions are provided for each year after production in Table

[12] Oneil, Elaine and Bruce Lippke. "Life Cycle Carbon Tracking for the Working Forests of British Columbia: Carbon Pool Interactions from Forests, to Building Products, and Displacement of Fossil Emissions"; University of Washington, 2009.
[13] "Environmental and energy balances of wood products and substitutes." Dr Mohammad Scharai-Rad University of Hamburg, Department of Wood Technology and Dr Johannes Welling Federal Research Centre for Forestry and Forest Products, Hamburg; 2002
[14]RPA Table 40 is titled "Roundwood products, logging residues, and other removals from growing stock and other sources by species group, region, and subregion, 2006."
[15] RPA Table 39 is titled "Volume of roundwood products harvested in the United States by source of material, species group, region, subregion, and product, 2006."

6 of the USDA 2006 Report. For this study the disposition fractions for the 30 year, 50 year, and 100 year time horizons were selected. The results are listed in Table 6.4.

Table 6.4. Disposition Patterns

	Disposition Patterns: 30 Years (from USDA 2006 Report Table 6)			
	softwood sawlogs	softwood pulpwood	hardwood sawlogs	hardwood pulpwood
North East	0.40	0.12	0.40	0.33
North Central	0.44	0.13	0.37	0.38
Southeast	0.43	0.18	0.38	0.24
Pacific Northwest	0.52	0.10	0.27	0.27
Pacific Southwest	0.45	0.45	0.45	0.45
United States	0.45	0.20	0.37	0.33

	Disposition Patterns: 50 Years			
	softwood sawlogs	softwood pulpwood	hardwood sawlogs	hardwood pulpwood
North East	0.36	0.10	0.36	0.30
North Central	0.39	0.11	0.33	0.35
Southeast	0.39	0.16	0.34	0.22
Pacific Northwest	0.47	0.09	0.24	0.24
Pacific Southwest	0.41	0.41	0.41	0.41
United States	0.40	0.17	0.33	0.30

	Disposition Patterns: 100 Years			
	softwood sawlogs	softwood pulpwood	hardwood sawlogs	hardwood pulpwood
North East	0.32	0.09	0.32	0.26
North Central	0.35	0.09	0.30	0.30
Southeast	0.34	0.14	0.30	0.19
Pacific Northwest	0.41	0.08	0.21	0.21
Pacific Southwest	0.36	0.36	0.36	0.36
United States	0.35	0.15	0.30	0.26

4. In a final step the fractions of wood removals (wood cut down) that are harvested wood were multiplied by the fractions used for sawlogs and pulpwood and the respective disposition fractions.

The results are listed in Table 6.5 below. For example, after 30 years, on average 2 percent of carbon from the softwood of stands removed from forests in the North Central region has been allocated to products in use or landfilled. In addition, 16 percent of carbon from the hardwood of stands removed from forests in the North Central region has been allocated to products in use and landfills. In total, 18 percent of the carbon from North Central stands can be considered sequestered after 30 years of production. Figure 6.3 shows the carbon sequestered by region for the three selected time horizons. Across the US, 23 percent of the carbon in forest stands has been sequestered to products in use and landfills after 30 years, implying that 77% of all carbon has been released. Only slightly less carbon has been sequestered after 50 years and 100 years.

Table 6.5. Fractions of Carbon Sequestered

	30 years			50 years			100 years		
	softwood	hardwood	Total	softwood	hardwood	Total	softwood	hardwood	Total
North East	0.06	0.12	0.18	0.05	0.11	0.16	0.04	0.10	0.14
North Central	0.02	0.16	0.18	0.02	0.14	0.16	0.02	0.12	0.14
Southeast	0.15	0.05	0.20	0.14	0.04	0.18	0.12	0.04	0.16
Pacific Northwest	0.34	0.01	0.35	0.30	0.01	0.31	0.26	0.01	0.27
Pacific Southwest	0.24	0.00	0.25	0.22	0.00	0.22	0.19	0.00	0.19
Jnited States	0.16	0.07	0.23	0.15	0.06	0.21	0.13	0.05	0.18

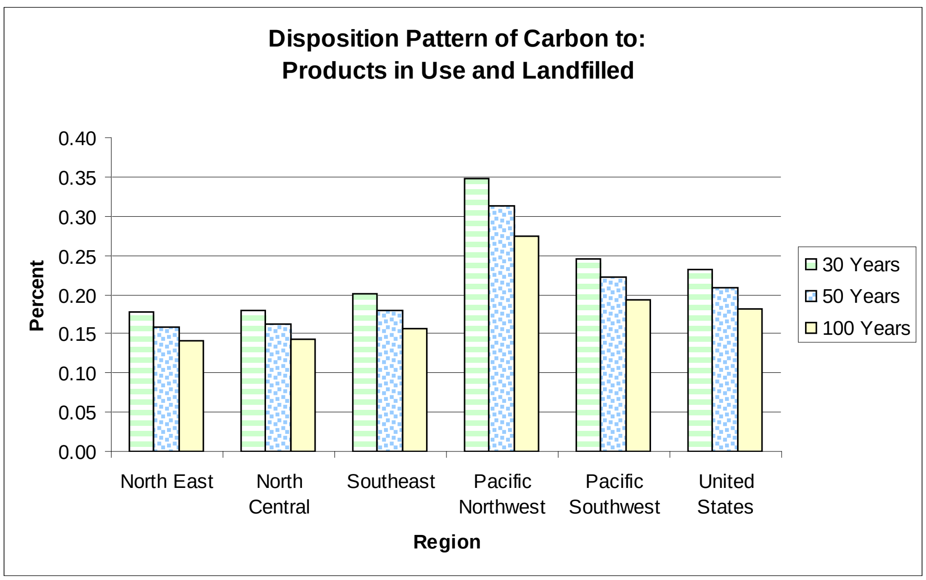

Figure 6.3. Carbon Sequestered by Region and Time

6.3 Other Factors Not Considered Above

The above discussion and examples do not take into account wood combusted with energy capture as well as the displacement of fossil-fuel intensive construction materials, both of which can displace GHG emissions from the use of fossil fuel. This would have required a life cycle analysis with a displacement approach similar to the analysis performed by Oneil and Lippke (2009) or Scharai-Rad (2002).[16,17]

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[16] Oneil, Elaine and Bruce Lippke. "Life Cycle Carbon Tracking for the Working Forests

6.4 Recommendations

- Based on our examination, there is sufficient data to consider C storage HWP in the US and other developed countries.
- However, data of global HWP disposition by country and long-term carbon storage factor by wood-type and end-product (preferably by region) is difficult to obtain.
- Short-term: include sensitivity analysis of C storage in HWP (30 yrs, 50 yrs, 100 yrs)
- Long-term: global calculation of HWP and include uncertainty in HWP disposition

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of British Columbia: Carbon Pool Interactions from Forests, to Building Products, and Displacement of Fossil Emissions"; University of Washington, 2009.

[17] "Environmental and energy balances of wood products and substitutes." Dr Mohammad Scharai-Rad University of Hamburg, Department of Wood Technology and Dr Johannes Welling Federal Research Centre for Forestry and Forest Products, Hamburg; 2002.

7. Other Non-Land Conversion Emissions

The Energy Independence and Security Act of 2007 (EISA) defined life cycle GHG emissions to include “direct emissions and significant indirect emissions such as significant emissions from land use changes” (United States Congress 2007). This definition, which was subsequently adopted verbatim into the California LCFS (OAL 2010), indicates that other indirect GHG emissions besides those from land-use change should be counted in each fuel’s life cycle.

In its analysis for the Renewable Fuel Standard (RFS2), USEPA estimated changes in indirect GHG emissions (and sequestration) from the following categories:

1. land clearing and conversion (above- and belowground biomass, soil carbon, foregone sequestration)

2. tillage (conversion to no-till agriculture is awarded carbon sequestration credit)

3. fertilizer and on-farm energy use (i.e., emissions are added or subtracted based on average practices in each country where changes in crop production occur)

4. methane from rice and livestock production

5. above- and below-ground carbon in forests

In its current analysis, CARB considers only item 1, ILUC emissions. Items 2 through 4 are discussed in the next sections.

7.1 Emissions Associated with Market Mediated Effects

When a model like GTAP is shocked for an additional demand for corn to satisfy biofuels demand, it results in increased process for the primary commodity shocked and then the model solves for a new equilibrium condition. This is usually met through some increase in production and rationing of demand from other sectors. It is this rationing of demand in other sectors that can have GHG emission impacts that have been overlooked.

Two areas where there may be significant GHG impacts of reduced consumption are:

- Livestock emissions
- Rice production emissions
- Crop switch

The changes can be positive or negative and there can be regional differences. Looking at the EPA RFS2 analysis, which did attempt to calculate these emissions, the results were significant for some biofuels (~25% of ILUC for soybean biodiesel) and very small for other fuels.

7.1.1 Livestock emission factors

Agricultural emissions account for about 32% of total anthropogenic emissions. Livestock emissions account for about 42% of these emissions in two major categories:

- Enteric fermentation (~34% of total ag emissions)
- Manure (~8% of total ag emissions) and indirect emissions from manure management highly variable and substantial.

Changes in livestock population should directly impact both of these livestock emission sources. The results from the EPA analysis for changes in livestock emissions are shown in the following table.

	g CO2eq/MJ
Corn Ethanol	-0.27
Soybean Biodiesel	-8.07
Sugar Cane Ethanol	-0.12

It should be possible to extract changes in livestock populations from the GTAP model runs. Using this data and regional emissions derived from the EPA[18], or from the UNFCCC Annex 1 countries; it is possible to calculate the indirect GHG emissions from changes in livestock populations.

7.1.2 Rice cultivation

There is a similar situation for rice production emissions. Rice emissions account for 11% of agricultural emissions. The EPA RFS2 emission impact from changes in rice cultivation are shown in the following table.

	g CO2eq/MJ
Corn Ethanol	1.78
Soybean Biodiesel	-5.45
Sugar Cane Ethanol	0.46

Same basic approach would be taken to quantifying these emission changes. Take the change in rice production from GTAP, multiply by the rice emissions per GTAP region. These can be obtained from the EPA or UN FCCC inventories for Annex 1 countries.

7.1.3 Crop switch

A more complex issue is the change in emissions from land that remains in the same land use category, such as cropland remaining cropland. GHG emissions per acre are significantly

[18] US EPA. Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990-2020. http://www.epa.gov/climatechange/economics/downloads/GlobalAnthroEmissionsReport.pdf

different between crops, rotation and management practices as shown in the following Figure 7.1[19].

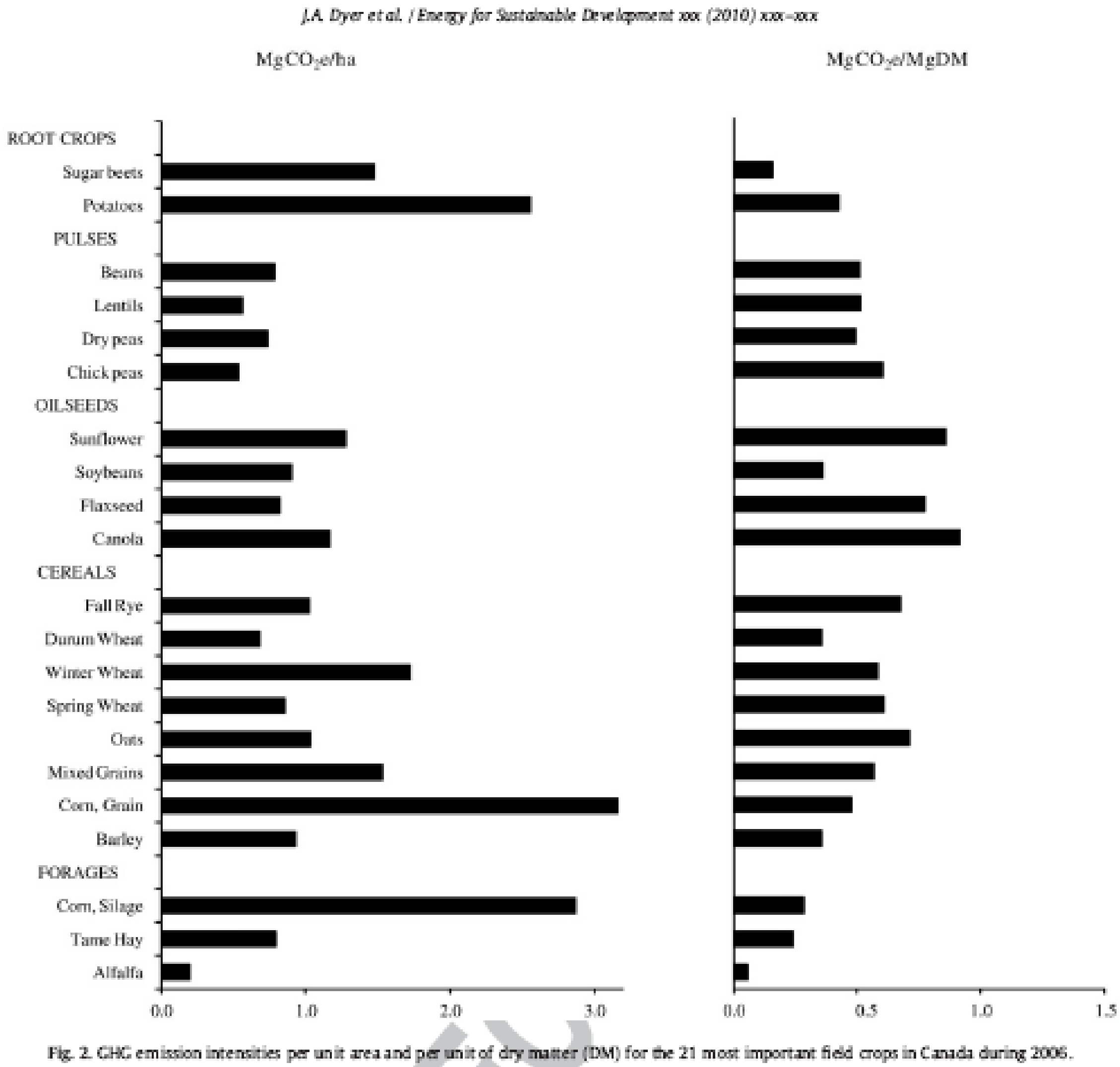

Figure 7.1. GHG emission increases per unit area and per unit of dry matter (DM) of the 21 most important field crops in Canada during 2006. s

The total GHG emissions from cropland therefore depend on the crop mix and field management practices. The assumption that has effectively been made, that there are no GHG impact of cropland remaining cropland, is obviously not correct. The issue is that some of the crop shifting is driven by the availability of co-products, whereas other crop shifting is caused by demand changes resulting from changes in prices. In the direct GHG analysis, we already attempted to

[19] Dyer JA, et al, The impact of increased biodiesel production on the greenhouse gas emissions from field crops in Canada, Energy for Sustainable Development (2010), doi:10.1016/j.esd.2010.03.001

put a GHG values on those co-products, so there is some overlaps between the GHG change from crop shifting and the GHG benefits from the direct analysis of co-products.

It is not clear how this could be resolved in the short term. An additional complexity is that GTAP probably does not provide enough detail on the various crops, as there is too much aggregation, barley and corn are aggregated as coarse grains, but have very different emissions per acre.

7.2 Emissions Changes Associated with Agricultural Practices

In the RFS2 analysis, EPA projected changes in emissions from fertilizer use, on-farm energy use, and production of rice and livestock, both domestically and internationally. Domestically, EPA relied on FASOM for these projections, while internationally, cropping changes were combined with estimates of average input and emission rates for each country.

These same two approaches are available to CARB for use with GTAP. GHG emission factors are available for use in GTAP, both for CO_2 and non-CO_2 emissions[20] allowing the model to estimate marginal GHG changes that are consistent with estimates of ILUC emissions. (We note that while FASOM has much finer resolution, it also has much more limited scope, being a domestic, partial equilibrium model. Neither model is ideal for the task at hand.)

7.2.1 Tillage changes

In its modeling for RFS2, the US EPA combined two economic models: FASOM was used to model the US, and FAPRI was used for the rest of the world. The FASOM model estimates GHGs associated with agriculture and forestry, including soil carbon sequestration assumed to be associated with a transition from conventional tillage (CT) to no-tillage (NT). FASOM also projects changes in carbon stocks associated with forestry, though these projections include large unexplained anomalies (Plevin et al. 2010a).

Experimental data performed by several researchers indicate that in some cases carbon sequestration can potentially occur due to changes in field management practices (e.g., tillage) especially when switching from intensive tillage methods to no-till. Carbon sequestration rate is dependent upon a number of factors including crop, yield, rotation, tillage practices and timing, climatic effects, etc. One set of long-term field experimental data (West and Post 2002) indicate carbon sequestration rates have increased when changing from conventional tillage to no-till field management practices especially in the 0-30 cm soil depth (~1 foot). Work by Angers and Erikson-Hamel (2008) showed significant differences in soil organic carbon (SOC) stocks between intensive tillage systems and no-till situations occur at the soil surface but can also at

[20] See https://www.gtap.agecon.purdue.edu/models/energy/Land_Use/

depth, which further highlights the importance of taking into account the whole soil profile when comparing soil C stocks.

However, others have found assumed carbon sequestration benefits of no-tillage over conventional tillage may really only occur at the shallow depths (less than 30 cm) (Baker et al. 2007; Batlle-Bayer, Batjes, and Bindraban 2010; Gál et al. 2007; Luo, Wang, and Sun 2010; Yang et al. 2008). Baker et al. (2007) even concluded that while "there are other good reasons to use conservation tillage, evidence that it promotes C sequestration is not compelling." VandenBygaart and Angers (2006) found high variability in SOC stocks often makes it difficult to detect differences induced by management practices and at greater depths the effect of tillage (field management) Intensive tillage (sometimes full inversion) and no-till have been shown in limited experimentation to result in different redistributions of SOC in the soil profile and consequently, the net effect of switching tillage practices to no-till on total C stocks is sometimes difficult to predict. Much is still unknown at this point concerning actual carbon sequestration in soils and its effect on climate change.[21]

FASOM incorporates from DAYCENT emission factors for soil GHG fluxes. The specifics of these factors and where exactly they are applied have not been documented by USEPA. Page: 36 It is understood that the impact of no tillage on N2O emissions is a function of soil type and climatic conditions. Basically conditions that promote high N2O emissions (high moisture and saturated soils) will see a short term increase in N2O emissions. Soils that have low N2O emissions can see a decrease in N2O with a switch to no tillage. Six et al. (2004) concluded that conversion to no-till can increase N_2O emissions for decades, resulting in a net increase in global warming potential—even assuming no-tillage results in carbon sequestration—yet it's unclear whether FASOM accounts for this. The large CO_2e benefit FASOM assigns to conversion to no-till seems to indicate that this N_2O increase is not included. As far as we know, EPA did not account for tillage changes outside the US.

GTAP doesn't represent tillage and therefore is silent on the matter. However, given the recent findings challenging the soil carbon benefits of reduced tillage, we do not recommend including this effect at this time. However, in the context of an uncertainty analysis, it would be appropriate to represent a range of outcomes based variation in assumption about the incidence of tillage reduction and the resulting changes in soil carbon.

Finally, it is important to look at consistent depth levels between soil carbon releases during land conversion and subsequent carbon sequestration from till/no till practices. In general, the assessed soil carbon depth should be the same as the assessed till/no till depth.

7.2.2 Fertilizer use and N_2O emissions

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[21] Several experts' opinions within the subgroup are divided on this issue. Thus, we expect to come back and revise the discussion here in the final revision.

N_2O emissions from soils are an important part of the lifecycle GHG emissions for all biofuels. Most analyses of the issue utilize at least part of the methodology recommended by the Intergovernmental Panel on Climate Change (IPCC). Recently, in a paper by Crutzen et al[22], it has been suggested that this methodology may significantly underestimate these emissions by a factor of three to five and that as a result the lifecycle GHG emissions of biofuels may not be less than petroleum fuels.

It is important to understand that the methodology employed by Crutzen and that of the IPCC are very different and cannot be directly compared. The Crutzen approach has been described as a "top down" method and the IPCC is very much a bottom-up approach.

The Crutzen top approach estimated the global N_2O emissions from the atmospheric concentrations of N_2O and estimated the portion that was attributable to agricultural soils by eliminating the estimated contributions from other sources. This was then compared to nitrogen fertilizer application rates to arrive at a value of about 3.4 to 4.6%. The range caused by uncertainty in the individual values. Top down approaches that are based on elimination can be very sensitive to the accuracy of the values being eliminated. It has been suggested that the Crutzen paper missed some sources such as biomass combustion, livestock, and even transportation. The range may be only 2.8 to 4.2% if these additional sources are included.

The IPCC bottom-up approach is based on field measurements of N_2O from a large number of studies around the world. The IPCC Tier 1 value of 1% is also widely misunderstood, as this is the average for the direct emissions only. The IPCC also has estimated for indirect effects and for emissions at later stages of the lifecycle. For example, when the straw that is also produced with grain or oilseeds is returned to the soil, further N_2O emissions are created that are in addition to the original estimate of 1%. The next years crop would use a portion of this nitrogen and the straw from that crop would also decompose and release some N_2O, and so on. If the feedstock is used to feed an animal there are additional emissions of the nitrogen when the manure from the animal is returned to the soil, and so on through the cycle. There are also indirect emissions when some of the nitrogen is leached from the soil.

When the total soil N_2O emissions from the IPCC approach are calculated the range of values produced 0.6 to 3.5%, which has some overlap with the Crutzen values. It is widely recognized by soil scientists that the emission factors is a function of soil composition and climatic conditions. Many countries, including Canada and the United States, use a more detailed approach to estimating N_2O emissions from agricultural soils than the IPCC Tier approach. In Canada, this more detailed approach results in direct emission factors in the range of 0.5 to 1.7% and a total emission factor of 3.8%. Lifecycle studies that are well done will use N_2O emission factors that are appropriate for the region and system being modelled.

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[22] PJ Crutzen ***et al, Atmos. Chem. Phys. Discuss***., 2007, **7**, 11191

Most biofuel pathways produce more than just biofuel and have a co-product animal feed that some of the emissions must be attributed to. If the GHG emissions for producing the crop increase then the GHG emissions avoided by the use of the substitute animal feed also increase. Thus there is not necessarily a direct relationship between the total lifecycle emissions and the N_2O emission rate from fertilizer application.

7.3 Recommendations

None at this point.

8 Non-Kyoto Climate Active GHG and Aerosol Emissions

LCA typically considers only one category of climate effects—direct greenhouse gases. Within this category, LCA studies generally consider at most six gases (or groups of gases) defined in the Kyoto Protocol as contributing to global warming effects: CO_2, methane (CH_4), nitrous oxide (N_2O), hydroflourocarbons (HFC), perflourocarbons (PFC), and sulfur hexafluoride (SF_6). Fuel cycle models typically consider only the first three gases, on the presumption that little or no HFC, PFC, or SF_6 is emitted in the life cycle of transportation fuels (USEPA, 2009b, p. 302). The standard approach for aggregating climate effects is to sum the emissions of these "big three" gases—CO_2, CH_4, and N_2O—weighted by the latest IPCC global warming potential values (e.g., Forster et al. 2007) using a 100-year time horizon (CARB 2009; USEPA 2010; Wang 1999, 2009).

However, several other compounds emitted over fuel life cycles are climate-active: carbon monoxide (CO), non-methanol volatile organic compounds (NMVOC), sulfur oxides (SO_X) oxides of nitrogen (NO_X), black carbon (BC), and organic carbon (OC) all affect climate, though their global warming effects are in some cases variable over time, space, and chemical conditions, and in general, uncertain (Delucchi 2003; Forster et al. 2007; Kammen et al. 2007; Larson 2006; Sanhueza 2009). Despite the variability and uncertainty, an important question is whether inclusion of these emissions has the potential to alter the preference order of alternative fuels with respect to their effects on climate. Table 8.1 lists CO_2-equivalent global warming potentials for the three well-mixed GHGs and shorter-lived species.

Table 8.1. GWP_{20} and GWP_{100} CO_2 equivalence factors for various substances.

Substance	GWP_{20}	GWP_{100}
CO_2	1 [a]	1 [a]
CH_4	72 [a]	25 [a]
N_2O	289 [a]	298 [a]
CO	10 [b]	3 [b]
SO_2		-94 [c]
NO_X		-1 [c]
NMVOC		8 [c]
BC	2200 [d]	680 [d]
OC	-200 [b]	-50 [b]

[a] Forster, Ramaswamy et al. (2007)
[b] Sanhueza (2009) (CO GWPs are for sustained releases, based on Fuglestvedt et al. (1996))
[c] Brakkee, Huijbregts et al.(2008)
[d] Bond and Sun (2005)

8.1 The Role of Non-CO_2 Emissions in Land Clearing Emission Factors

The mode of clearing (burning vs. smoldering vs. mechanical) affects the BC and CO emission factors. Table 8.2 shows emissions of trace gases and aerosols for savanna fires, in mass and as CO_2-equivalents. If only CO_2, CH_4, and N_2O are considered, the emission factor per kilogram of dry matter would be 1745 g CO_2e kg^{-1} (GWP_{100}) or 1856 g CO_2e (GWP_{20}). Inclusion of the remaining emissions shown in Table 8.2 and the GWP values shown in Table 8.1 increases these emission factors to 2346 g CO_2e kg^{-1} and 3648 g CO_2e kg^{-1}, respectively. Under a short time horizon (e.g. 20 years) black carbon can contribute more radiative forcing than the CO_2 released when burning biomass. In either timeframe, including all the emissions greatly increases the CO_2-equivalent emission factor. However, the much greater uncertainty in the global warming potential values must be taken into account.

Burning results in higher BC emission rates (shown in table), whereas smoldering (not shown) results in lower BC emissions but higher CO emissions. (Ward 1991 discusses the different types of fires and combustion efficiencies.)

Table 8.2. Emissions of trace gases and aerosols for savanna fires, in mass (g kg^{-1}) and as CO_2-equivalents (g CO_2e kg^{-1}).

		100-year GWP			**20-year GWP**		
Emission	**g/kg dm**[a]	**EF**	**g CO_2e/kg**	**Contribution**	**EF**	**g CO_2e/kg**	**Contribution**
CO_2	1640	1[b]	1640	70%	1[b]	1640	45%
CO	65	3[e]	195	8%	10[e]	650	18%
CH_4	2.4	25[b]	60	3%	72[b]	173	5%
NMHC	3.1	8[c]	25	1%	*8*[c]	25	1%
NO_X	3.1	-1[c]	-3	0%	*-1*[c]	-3	0%
N_2O	0.15	298[b]	45	2%	289[b]	43	1%
BC	0.8	680[d]	544	23%	2200[d]	1760	48%
OC	3.2	-50[e]	-160	-7%	-200[e]	-640[e]	-18%
Total			2346	100%		3648	100%

[a] Delmas, Lacaux et al. (1995)
[b] Forster, Ramaswamy et al. (2007)
[c] Brakkee, Huijbregts et al. (2008) – only 100-year GWP was reported.
[d] Bond and Sun (2005)
[e] Sanhueza (2009)

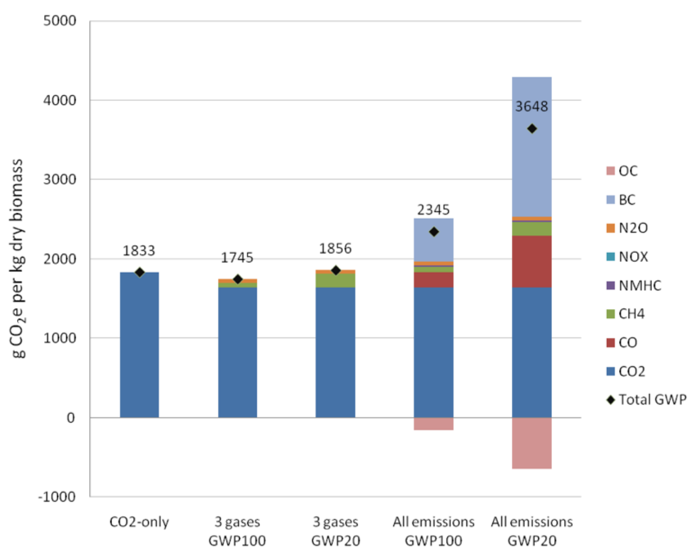

Figure 8.1. Savana burning emission factor

Black Carbon is emitted from land use change, but also from the combustion of fuels including gasoline and diesel. In fact, Jacobson points out that considering black carbon emissions (under California's LEVII standards for PM at 0.01 g/mi) diesel would warm climate more than gasoline emissions (2002) on a full life cycle basis. Including black carbon as part of the LCFS analysis will a) increase the GWI for the gasoline and diesel reference fuels and b) alter the perceived environmental benefits between fuels.

8.2 Recommendations

- Non-Kyoto climate forcing gases and particles can contribute to large uncertainties and significantly increase the estimated impacts of biofuel LUC emissions.
- The use of these non-Kyoto gases would also require that the lifecycle GHG emissions of the gasoline and diesel reference fuels would need to be re-evaluated.
- Sensitivity analysis (short-term) and uncertainty analysis (long-term) should be performed to explicitly consider the effects of non-Kyoto climate forcing gases and particles.

9 Uncertainty Analysis

Estimates of ILUC emissions require linking together various sets of uncertain data using imprecise models. To understand the uncertainty in the final estimate of ILUC emissions requires propagation of uncertainty through the combined economic-ecosystem model.

9.1 EPA's Uncertainty Analysis

In their regulatory impact analysis for RFS2, USEPA (2010) compared frequency distributions for biofuels with the required reduction thresholds, but these distributions included only uncertainties in the remote sensing and carbon accounting portions of the model. Figure 9.1 is taken from the Regulatory Impact Analysis for RFS2, showing a frequency distribution for the percentage reduction in corn ethanol GWI versus the required 20% reduction threshold. This distribution is based on a Monte Carlo simulation that considers as uncertain remote sensing data (and change detection) and numerous parameters required to model emission factors. The analysis treats economic model output as certain. As a result, distributions such as that shown in this figure are not appropriate for the purpose of determining the probability of compliance.

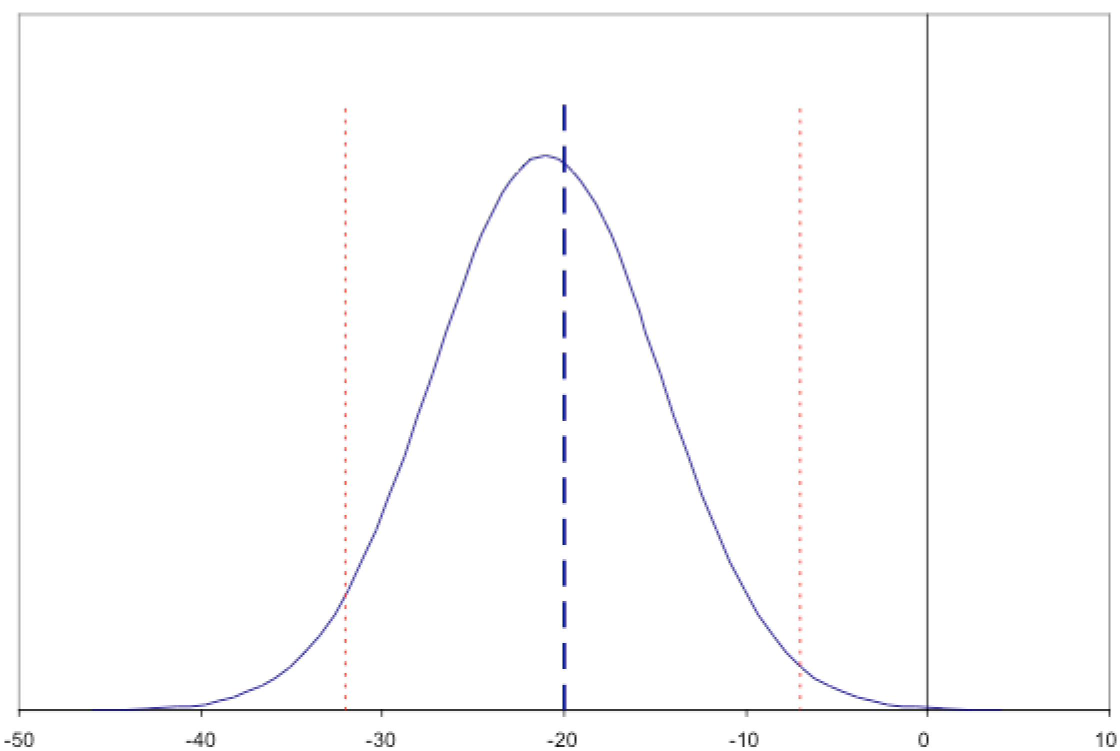

Figure 9.1. Distribution of 2022 corn ethanol GWI reduction relative to 2005 gasoline (for natural gas fired facilities producing 63% dry and 37% wet DGS, with fractionation). (Source: USEPA 2010, PDF p. 480).

Hertel et al. (2010a) incorporated into GTAP probability distributions for the emission factors for each type of land conversion in each GTAP region and combined these with distributions around key elasticity parameters using GTAP's Systematic Sensitivity Analysis (SSA) feature. The details of this analysis are available in the supporting materials for that paper (Hertel et al. 2010b). The SSA is based on the Gaussian Quadrature method, which requires far few model runs than do Monte Carlo type methods, but SSA is subject to several important limitations. First, SSA assumes that input distributions are approximately normal. It's unclear whether this is true for economic model parameters, but it is almost certainly false for emission factors. Second, SSA produces only a mean and standard deviation as output, and thus is unable to represent skewed output distributions. Based on a reduced-form model of ILUC, Plevin et al. (2010b) generate output distributions that are all heavily skewed, with long right tails. Thus the SSA may underestimate both the median and breadth of the output distributions.

As a long-term goal, we recommend that CARB develop a stochastic analysis using a similarly unified model in which emission factor uncertainties are incorporated into GTAP. To enable this, we recommend developing a stochastic model combining remote sensing uncertainties with emission factor uncertainties, much as USEPA has done, to use in place of the distributions generated for the Hertel et al. analysis. In the near term, the distributions around emission factors can be used with GTAP's SSA, which, despite its limitation, is better than no analysis of uncertainty. In the long run, however, a more robust analysis would use Monte Carlo analysis to allow for asymmetrical distributions.

9.2 Recommendations

Short-term:

- Use range of uncertainties reported in the datasets/literature for biomass and soil C stock values and factors fors emission factors.
- Use sensitivity analysis or scenario analysis to illustrate the importance of the consideration of certain parameters, such as HWP, other non-land conversion emissions, non-Kyoto climate forcing gases and particles.
- Use parametric analysis to estimate effect of specific time profile to examine emissions over time or scenario analysis to consider different approaches to handling time, (e.g., simple amortization, cumulative radiative forcing, discounting).

Long-term:

- Include probability distributions for all uncertain parameters.

- Propagate uncertainty using Monte Carlo simulation.
- Use global SA (uncertainty importance analysis) to identify which parameters drive overall variance.

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- Biomass Carbon Stock: Holly Gibbs (lead author), Steffen Mueller (Sohngen EF)
- Soil Carbon Stock: Sahoko Yui (lead author), Holly Gibbs, Sonia Yeh
- Peatlands Emissions: Sahoko Yui (lead author), Sonia Yeh
- Emission Factors: Susan Tarka Sanchez
- Long-term Carbon Storage in Harvested Wood Products (HWPs): Steffen Mueller (US forest products), Sonia Yeh (general discussion)
- Fertilizer Use and N2O Emissions: Don O'Connor
- Other Non-Land Conversion Emissions: Don O'Connor (lead author), Richard Plevin
- Non-Kyoto climate active GHG and aerosol emissions: Richard Plevin
- Uncertainty Analysis: Richard Plevin

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