Cerulogy

Understanding the indirect land use change analysis for CORSIA

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1. Introduction

The International Civil Aviation Organization's "Carbon Offsetting and Reduction Scheme for International Aviation" (CORSIA) includes the option for airlines to meet their emission reduction obligations by using alternative aviation fuels (AAF[1]) that are calculated to have a lower greenhouse gas emissions footprint than the fossil jet fuel they replace. Part of the assessment of greenhouse gas emissions performance is the calculation of an indirect[2] land use change (ILUC) emission factor for AAF produced from agricultural crops, including energy crops such as grasses and short rotation coppice. This ILUC factor is intended to characterise the changes in biomass and soil carbon stocks that occur as agricultural production expands to meet new demand for biofuel feedstocks, potentially resulting in the conversion of natural land, pasture or forests to cropping.

The development of ILUC factors for CORSIA was taken on by a dedicated subgroup of experts working through ICAO's Committee on Aviation Environmental Protection (CAEP), representing the ICAO member states, the aviation industry and the International Coalition for Sustainable Aviation. As part of this process, the U.S. and EU delegations supported ILUC modelling using two analytical frameworks, the 'GTAP-BIO' and 'GLOBIOM' models. ILUC factor results from these modelling exercises have become the basis for the default values proposed for CORSIA. The assumptions used in that analysis are documented in a published lifecycle assessment report[3]. ILUC modelling for aviation involves developing a baseline that provides an equilibrium characterisation of global land use without demand for AAF, and then adding some amount of additional AAF consumption and allowing the model to iterate to a new equilibrium, which will normally involve responses including expansion of land use, changes in productivity, and reductions in consumption of biofuel feedstocks in other sectors.[4]

The GTAP-BIO model is a 'general equilibrium' modelling framework developed by researchers at Purdue University in the U.S. using the Global Trade Analysis Project (GTAP) database of global economic and trade data. As a general equilibrium model with global scope, GTAP-BIO provides a characterisation of the entire global economy, though with an emphasis on capturing details relevant to the biofuel industry. GTAP considers 19 regions, each divided into a number of agro-ecological zones (AEZs) that have comparable biophysical characteristics. GTAP-BIO works in terms of dollar denominated financial data (e.g. land rents, value of produced goods, value of trade etc.) with relationships between terms determined by economic equations. GTAP is a static model, meaning that results are output for a single point in time. Versions of GTAP-BIO have previously been used for ILUC analysis in the California Low Carbon Fuel Standard and for a series of academic and working papers. Prior to the ICAO work, the model had primarily been used to analyse the impact of biofuel demand in the U.S.

The GLOBIOM model (Global Biosphere Management Model) is a 'partial equilibrium' model developed by researchers at the International Institute for Applied Systems Analysis (IIASA) in

1 The CORSIA documentation uses the acronym 'SAF' for 'sustainable aviation fuel', AAF is used here so as not to pre-empt the assessment of whether fuels are in fact sustainable.

2 Sometimes also referred to as 'induced' land use change.

3 CORSIA supporting document: CORSIA Eligible Fuels – Life Cycle Assessment Methodology bit.ly/CORSIA_LCA

4 Cf. A Guide for the Perplexed to the Indirect Effects of Biofuels Production, bit.ly/guidefortheperplexed

Austria. As a partial equilibrium model with global scope, GLOBIOM provides a characterisation of the global agricultural, livestock and forestry sectors, and has been developed to include the bioenergy sector. GLOBIOM considers each EU Member State individually, and 29 other regions. GLOBIOM models with a higher resolution than GTAP, dividing the world into a coarse grid comprising over 10,000 grid cells. GLOBIOM works in terms of biophysical characteristics and processes (e.g. land areas, physical yields, specific farming models, livestock diets) with relationships between terms determined by a combination of economic and biophysical equations. GLOBIOM is a dynamic model, meaning that results are output showing a development over time. A version of GLOBIOM has previously been used in ILUC analysis for the European Commission[5], and GLOBIOM is from the same family of models as the FASOM model used by the U.S. EPA to assess ILUC within the U.S. in analysis for the Renewable Fuel Standard.

Modelling was done with both models for seventeen AFF pathways utilising ten feedstocks. The conversion technologies considered are:

1. Hydroprocessed esters and fatty acids (HEFA) with vegetable oil as feedstock
2. Alcohol-to-jet with either starches and sugars or cellulosic material as feedstock
    a. via fermentation to ethanol
    b. via fermentation to isobutanol[6]
3. Synthesized iso-paraffins (SIP) with sugars as feedstock
4. Fischer-Tropsch (FT) synthesis following gasification, with cellulosic material as feedstock.

The calculated emissions are divided across 25 years – this is a little longer than the EU convention of 20 years, tending therefore to give slightly lower ILUC factors, but a shorter period than the 30 year convention in the U.S. Materials that might be characterised as wastes, residues or by-products of other processes were not assessed. This was on the basis that the ILUC impact of using such materials was assumed to be low, although other analysis suggests that in fact the indirect emissions from using some such materials could be very significant[7].

As part of the process the two sets of modellers spent time comparing outcomes and model inputs with a view to reconciling and/or aligning some data and assumptions, and with the aim of reducing the gap between output ILUC factors. The documentation notes that while the final model results for starch and sugar pathways are relatively close, there are still considerable differences in estimated ILUC factors for some vegetable oils and cellulosic crops.

Based on consideration of the two sets of modelled results, CAEP then assigns default ILUC factors to each pathway. Where the two models give similar answers (within 8.9 gCO_2e/MJ of each other, which is 10% of the agreed baseline GHG intensity for fossil kerosene) the average is taken of the two results. If however the discrepancy is larger, then the lower of the two GHG intensity results is taken, adjusted upwards by a small increment of 4.45 gCO_2e/MJ. The implication of this methodological choice is that where one model gives a much lower result

5 bit.ly/GLOBIUM-ILUC

6 Fermentation to ethanol is the norm for both first and second generation biofuels in the road sector, fermentation to isobutanol is a more advanced process.

7 See e.g. bit.ly/cerulogy_wastenot, bit.ly/ICCT_REDII

than the other, the model giving the higher result is more or less ignored. This decision imposes a significant optimism bias on the final agreed default ILUC values.

2. Food-based AFF

The results reported for food-based AFF are listed in Table 1, and displayed in Figure 1.

Table 1. CORSIA ILUC values for food-based AFF

Region	Feedstock	Conversion Process	GTAP-BIO	GLOBIOM	Default ILUC
USA	Corn	Alcohol (isobutanol) to jet (ATJ)	22.5	21.7	**22.1**
USA	Corn	Alcohol (ethanol) to jet (ATJ)	24.9	25.3	**25.1**
Brazil	Sugarcane	Alcohol (isobutanol) to jet (ATJ)	7.4	7.2	**7.3**
Brazil	Sugarcane	Alcohol (ethanol) to jet (ATJ)	9	8.3	**8.7**
Brazil	Sugarcane	Synthesized iso-paraffins (SIP)	14.2	8.4	**11.3**
EU	Sugar beet	Synthesized iso-paraffins (SIP)	20.3	20	**20.2**
USA	Soy oil	Hydroprocessed esters and fatty acids (HEFA)	20	50.4	**24.5**
Brazil	Soy oil	Hydroprocessed esters and fatty acids (HEFA)	22.5	117.9	**27**
EU	Rapeseed oil	Hydroprocessed esters and fatty acids (HEFA)	20.7	27.5	**24.1**
Malaysia & Indonesia	Palm oil	Hydroprocessed esters and fatty acids (HEFA)	34.6	60.2	**39.1**

Notes: Numbers in the 'default ILUC' column are coded from red for positive to green for negative values (negative values only appear for energy crop based fuels, see Table 2). Numbers in the model-specific columns (GTAP-BIO and GLOBIOM) are colour coded from green for values lower than the default, red for numbers higher than the default.

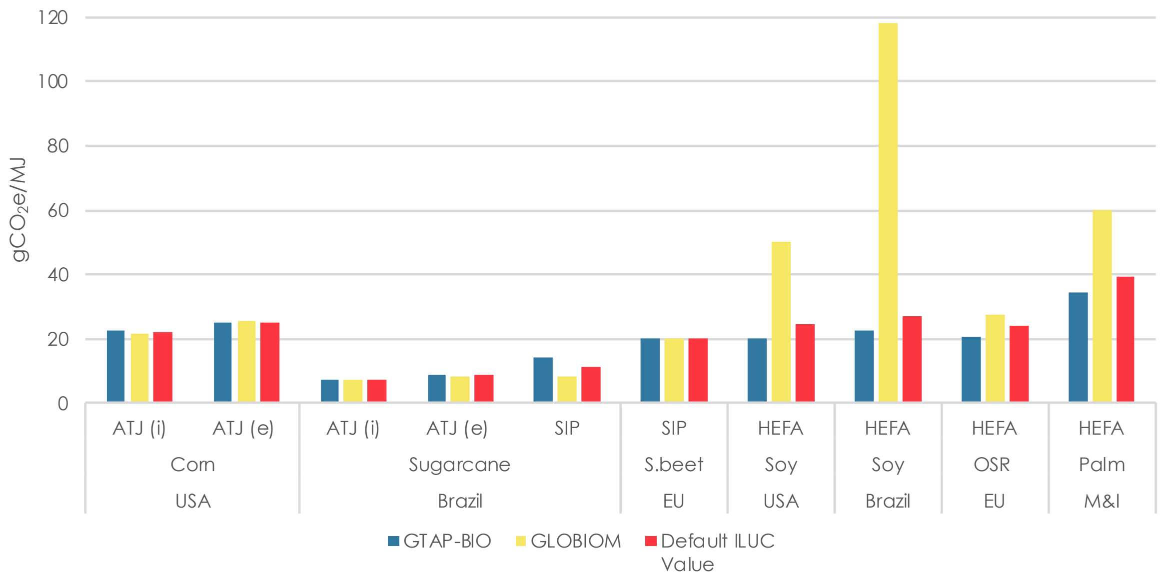

Figure 1. CORSIA ILUC values for food-based AFF

Notice that in the agreed default values:

- Sugar-based fuels are assigned a relatively low ILUC value, which is broadly consistent with previous ILUC analysis for the EU Commission;
- Corn based fuels from the U.S. are assigned a result just over 20 gCO_2e/MJ, similar to the current California LCFS assumption;
- Oil-based fuels are assessed as having the highest associated ILUC, as in previous EU work, but the assigned ILUC factors are somewhat below those quoted in the RED II, or given in previous GLOBIOM analysis for the European Commission;
- The GLOBIOM results for soy and palm oil HEFA are significantly higher than the respective agreed defaults. If the GLOBIOM result had been used as the default, both of these fuels would be assessed as having a higher GHG intensity than fossil jet fuel.

3. Cellulosic AFF

The results reported for cellulosic AFF are listed in Table 2, and displayed in Figure 2.

Table 2. CORSIA ILUC values for cellulosic AFF

Region	Feedstock	Conversion Process	GTAP-BIO	GLOBIOM	Default ILUC
USA	Miscanthus	Fischer-Tropsch (FT)	-37.3	-10.6	**-32.9**
USA	Miscanthus	Alcohol (isobutanol) to jet (ATJ)	-58.5	-8.7	**-54.1**
EU	Miscanthus	Fischer-Tropsch (FT)	-9.3	-26.5	**-22**
EU	Miscanthus	Alcohol (isobutanol) to jet (ATJ)	-16.6	-35.5	**-31**
USA	Switchgrass	Fischer-Tropsch (FT)	-8.2	2.5	**-3.8**
USA	Switchgrass	Alcohol (isobutanol) to jet (ATJ)	-18.9	10.2	**-14.5**
USA	Poplar	Fischer-Tropsch (FT)	-9.6	-0.6	**-5.2**

Notes: Numbers in the 'default ILUC' column are coded from red for positive to green for negative values (positive values only appear for energy crop based fuels, see Table 1). Numbers in the model-specific columns (GTAP-BIO and GLOBIOM) are colour coded from green for values lower than the default, red for numbers higher than the default.

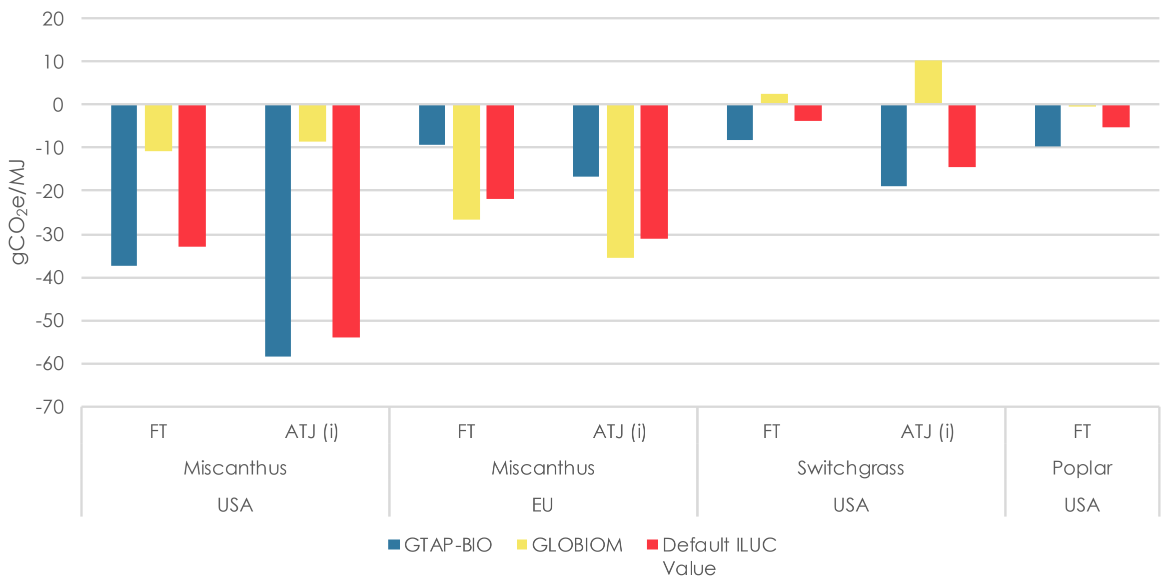

Figure 2. CORSIA ILUC values for cellulosic AFF

The results for these energy crops are lower than those for food-based AFF, which is consistent with most previous analyses[8]. The default ILUC values agreed are all in fact negative, meaning that the modelling suggests that additional carbon sequestration by energy cropping in biomass and soils will be larger overall than any associated carbon emissions from land use changes. This reflects the types of land that the models assume would be converted. For the miscanthus energy crop in particular the assumed negative ILUC factors are large, with a value of -54 gCO_2e/MJ adopted for the case of the cellulosic alcohol to jet pathway due to assumptions in GTAP that the majority of land conversion to miscanthus is from cropland pasture, and that this results in large carbon stock increases.

4. What might explain differences between GTAP-BIO and GLOBIOM?

The GTAP-BIO and GLOBIOM models reflect very different approaches to modelling potential developments in the agricultural economy, and thus it is not surprising that they do not estimate exactly the same impacts from expanded biofuel use. In fact, even where the ILUC factor results from the two models are relatively similar, the actual land use responses being modelled are quite different – if anything, the difference between the models is larger than it may appear from considering only the reported ILUC factors. Below we discuss differences in the way the agricultural economy is considered in the models that could explain some of the discrepancy – note though that there could also be more subtle differences that emerge from the mathematics in the two models that would be harder to identify and explain.

4.1. Productivity

The two models have very different approaches to assessing agricultural productivity. GLOBIOM considers productivity primarily by modelling specific farming systems for each crop, some more productive than others (e.g. increased irrigation rates). When prices increase, farmers can switch to more productive farming systems, increasing average yields. GLOBIOM also assumes underlying trends of increasing yields and increasing multicropping that are not affected by prices. GTAP-BIO, in contrast, does not directly consider farming systems but includes a mathematical relationship by which increased prices lead to increased productivity[9]. It also includes regional assumptions about the contribution of multicropping to meeting increased demand[10]. When all these effects are considered together, GTAP-BIO probably assumes a stronger overall productivity response than GLOBIOM does for most or all pathways.

4.2. Food versus fuel

For the vegetable oils in particular, GTAP-BIO assumes a much larger reduction in consumption

8 Cf. bit.ly/energycropILUC

9 Setting an appropriate parameter for this effect has proved contentious, and some commentators have argued that the strength of the yield response modelled in GTAP is not justified by assessment of historical data (see e.g. bit.ly/yieldelasticity).

10 This multicropping response was only added to GTAP-BIO relatively recently, and is not supported by any robust analysis of how strongly rates of multicropping actually respond crop prices.

by other sectors of the economy than is assumed in GLOBIOM. For example, the net increase in palm oil production shown by GTAP-BIO is less than half that shown in GLOBIOM for the same increase in palm oil HEFA production. A decrease in consumption helps reduce the resulting ILUC factor but could imply negative welfare impacts (reduced food consumption and reduced disposable income). The extent to which biofuel demand affects consumption of foodstuffs by people and feedstuff by livestock has been a controversial question in the biofuel debate.

4.3. Livestock

For the soy pathways in particular, there is an effect referred to as the 'livestock rebound effect' which results in a significant difference between modelled results. The livestock rebound occurs because soybeans are processed into two co-products – soy oil and soy meal. The oil can be used for AFF production, while the meal is used as a livestock feed. Increasing soybean production for the sake of the oil therefore brings additional meal onto the market as a co-product, reducing global livestock feed prices. In GLOBIOM, this reduction in feed price is modelled as driving an uptick in livestock farming for meat and dairy production, which in turn leads to additional demand for complementary livestock feed materials such as coarse grains. In contrast, GTAP-BIO assumes that at the global level the extra soy meal tends to replace other feedstuffs. The difference in outcomes may partly reflect the different modelling of the livestock sector – GLOBIOM considers livestock industries in more explicit detail, with explicit modelling of feed rations.

4.4. Trade

The models have different underlying representations of global trade, so that land use impacts from an AFF production increase in one region may lead to different geographic distribution of land use changes. They also have different underlying approaches to estimate the degree to which similar products may be substituted with each other. For example, GLOBIOM models larger transmission of increased soy oil demand to the palm oil market, and therefore more land use change in Southeast Asia in response to soy HEFA production than is seen in GTAP-BIO.

4.5. Ease of land conversion

The models use different land categories, and have different assumptions about how 'easily' land of a given type may be converted to cropping. Perhaps the two largest differences emerge from the importance in GTAP-BIO of a land category referred to as 'cropland pasture', and the importance in GLOBIOM of the category 'other natural land'. In GTAP-BIO, the cropland pasture category (only included for Brazil, Canada and the U.S.) represents former cropland that is currently pastured but which it is assumed will be readily converted back to cropping with relatively low carbon cost. Cropland pasture conversion with low associated carbon emissions is the largest land conversion response in all GTAP-BIO modelling for AFF production in the U.S. or Brazil. Despite the importance of this in the model, there is very little evidence to support the assumption that this land category plays such a dominant role in adjustments to increased feedstock demand[11], and there is no direct equivalent to this category in GLOBIOM. In GLOBIOM, in contrast, there is an 'other natural land' category that

11 Cf. bit.ly/GTAP_ILUC

represents land with unmanaged vegetation having a lower carbon stock than forest land, which plays a large role in most of the pathway analyses. This land category in turn is not represented in GTAP-BIO, and indeed the GTAP-BIO model does not consider the case that land with no existing economic use is converted to cropping.

4.6. Carbon sequestration by energy crops

GTAP-BIO models high rates of additional carbon sequestration by cellulosic energy crops compared to GLOBIOM, resulting in large negative ILUC values for miscanthus based fuels in particular. This partly reflects higher assumptions for the soil organic carbon sequestered by energy crops, but more importantly reflects the difference in assumptions about the type of land converted. In the U.S., GTAP-BIO assumes that almost all energy cropping occurs on converted cropland pasture, which is assumed to have low soil carbon stocks, so that there is a large gain from energy crop establishment. GLOBIOM, in contrast, models conversion of land primarily from the categories ‘other natural land’ and ‘abandoned land’ – both assumed to have more starting soil carbon than cropland pasture, so that energy crop establishment yields a lower net carbon benefit.

4.7. Model scope

The GTAP-BIO model includes adjustments across the whole of the economy, while GLOBIOM considers only the agriculture and forestry sectors. There may be responses to increased biofuel use that emerge in the modelling of other sectors (such as food processing) that reduce ILUC outcomes, but this is difficult to assess given the published results.

5. What might explain differences between the CORSIA GLOBIOM analysis and previous GLOBIOM analysis for the EU?

The ILUC analysis for CORSIA shows differences between GTAP-BIO and GLOBIOM modelling, but significant differences are also seen between the new results and previously published ILUC estimates made for the European Commission.[12] Previous results do however remain within the range identified in Monte Carlo sensitivity analysis using GLOBIOM, documented in section 6.3 of the CORSIA LCA report.

5.1. Time horizon

The previous GLOBIOM analysis for the EU amortised emissions over 20 years, whereas the new analysis amortises over 25 years. This reduces most of the reported ILUC factors by 20% (with the exception of pathways where peat emissions play an important role, as these are continuous and are not divided by the amortisation period).

12 bit.ly/GLOBIUM-ILUC

5.2. Peat conversion

Two important changes from the earlier modelling is in the treatment of peat emissions associated with palm oil expansion in Malaysia and Indonesia. Firstly, the fraction of new palm oil expansion in Indonesia assumed to be associated with peat conversion was cut from 34% to 20%. Secondly, the assumed rate of carbon loss associated with peat drainage was cut by over a third from 61 tonnes of carbon dioxide per hectare per year (tCO_2e/ha/yr) to 38 tCO_2e/ha/yr (this value was also imposed in the emission factors used for GTAP-BIO, reduced from 95 tCO_2e/ha/yr). The downward revision in the assumption for palm oil expansion on peatland in Indonesia reflects consideration of a similar range of literature to that assessed by the European Commission for the delegated act on high ILUC-risk biofuels[13], but came to a slightly different conclusion, assuming 20% of expansion on peat as compared to 25% assumed by the Commission.[14] The rate of expansion onto peat in Malaysia was not amended from the previous 34% assumption, although the Commission work on high ILUC-risk suggested a slightly higher value of 36%.

The revision in the peat emissions factor primarily reflects two changes. Firstly, the adoption of a value of 55 tCO_2e/ha/yr from the IPCC for typical emissions from a plantation on peat soil to replace values based on other scientific literature, and secondly attributing part of the ongoing peat emissions to previous disturbances. The chosen value of 55 CO_2e/ha/yr is the average IPCC value across palm and acacia plantations, and is higher than the IPCC value for palm plantations specifically (which is 40 CO_2e/ha/yr). The use of IPCC values is understandable for analysis by ICAO as a UN body, but it should be noted that the development of the current IPCC value for emissions from plantations on peat was somewhat controversial, and it was challenged (unsuccessfully) by Wetlands International, who argued a higher value was appropriate. In particular, the IPCC value ignores accelerated emissions that occur in the first five years after initial peat drainage, although in some cases these accelerated emissions would have already occurred before plantation establishment.

Attributing part of ongoing peat emissions to previous disturbances brings the final peat emission value down from 55 tCO_2e/ha/yr to 38 tCO_2e/ha/yr, and is somewhat controversial. It implies an assumption that in many cases peat would decompose due to reduced water table height even without palm plantation establishment, for instance where there has been prior disturbance for logging. One potential criticism of this argument is that planting a palm plantation requires ongoing drainage and water table management that guarantees continued peat decomposition indefinitely, whereas in the absence of a plantation the water table could reach a new equilibrium, or indeed active steps could be taken to restore the water table and deliver additional sequestration.

Given these issues, it is not obvious that the adjusted peat emission factors are better justified than the previous values used. Using those previous values, the reported palm oil HEFA ILUC value from GLOBIOM would have been approximately 95 gCO_2e/MJ.

5.3. Forgone sequestration

GLOBIOM includes a term for 'forgone sequestration', which reflects the loss of future biomass

13 bit.ly/high-ILUC_annex

14 The Commission analysis notes that the study that leads to the 20% assessment is based on mapping that excludes some shallower peat soils (below 0.5m).

growth due to returning abandoned farmland to cropping that would otherwise return to a more natural state with increasing vegetation levels. In earlier work, it was assumed that a mix of natural vegetation characteristic of the local region would be restored if land were not returned to cropping, which may include full or partial afforestation. In the new work, it is assumed that no afforestation would occur, which is described as having the result that, "the opportunity cost accounted for is at a rather low bound of possible estimates". The explanation given for discounting the possibility of afforestation on abandoned land is that it created an asymmetry with the treatment of natural land, where carbon stocks are implicitly assumed to be in equilibrium before conversion, and that this discrepancy of treatment could result in a higher 'opportunity cost' assessment in regions with more abandoned land (implicitly favouring natural land conversion over abandoned land conversion in farming terms). The upshot is that forgone carbon sequestration is systematically underestimated against central expectations. This combined with the changes to peat emissions accounting goes some way to explain the reduction in the reported ILUC estimate for rapeseed oil HEFA.

6. Discussion

The CORSIA scheme reflects the first time that any sort of global policy driver will have been introduced to promote the use of AAF in aviation. That the AAF accounting rules for CORSIA should include elements of lifecycle analysis represents progress for those ICAO member states concerned not to treat AAF as automatically sustainable, and for the environmental community working through ICSA. Not everyone involved in the process would have been unhappy to treat AFF as automatically carbon neutral, ten years ago, it would not have been at all obvious that an ICAO process could deliver an LCA assessment including any characterisation of ILUc emissions. The documentation of the CORSIA lifecycle analysis speaks to a significant amount of research effort and political effort expended to deliver meaningful sustainability governance.

The other side of this coin is that it must be recognised that the outcomes of any ICAO process, as with any other UN body, represent a compromise. The modelling undertaken by the GTAP-BIO and GLOBIOM modelling teams has been influenced by the engagement of representative of ICAO members, of the aviation industry and of ICSA. Neither set of ILUC results is exactly what the respective modelling teams would have produced without external input and the process of model reconciliation. It is clear that some ICAO Member States have an interest in being able to report the highest GHG emissions reductions possible for favoured biofuels. In particular, the decision to base ILUC values on only the lower modelled value where models disagree introduces an obvious and significant optimism bias into the default values that is not analytically justified.

EU stakeholders will notice that the ILUC results in this study are generally lower than those generated in earlier GLOBIOM work for the EU Commission. In part this may reflect genuine modelling improvements, but to a considerable extent it is a result of the modelling team agreeing to adopt more biofuel-positive assumptions on issues including emission factors for peat and for forgone sequestration, which could reasonably be challenged. These results should therefore not be treated as automatically superseding the 2015 analysis, but as providing alternative scenarios that might be considered alongside the earlier work, with due consideration given to the relative merits of each.