Land Use Change Greenhouse Gas Emissions of European Biofuel Policies Utilizing the Global Trade Analysis Project (GTAP) Model

August 30, 2013

By:

Thomas Darlington and Dennis Kahlbaum
Air Improvement Resource, Inc.

Don O'Connor
(S&T)^2 Consultants Inc.

Steffen Mueller, PhD
University of Illinois, Chicago

Table of Contents

Executive Summary

In 2009, the European Union implemented a policy of increasing renewable fuel use to a mandatory 10% of road transport energy use by 2020. The policy was based on expected greenhouse gas emission reductions from biofuels anticipated at that time. Around the time the policy was released, some researchers began questioning whether biofuel use actually brought about emission reductions, and raised concerns as to whether land use conversions from other uses (for example, pasture or forest) to cropland reduced the biofuel greenhouse gas benefit. Research was underway in the US at the same time and was utilized by the State of California in developing their Low Carbon Fuel Standards, as well as by the United States Environmental Protection Agency in implementing the Renewable Fuel Standard (RFS).

The European Union has been studying land use change emissions allegedly brought on by biofuel policies for the past several years. In 2011, the International Food Policy Institute (IFPRI) released a study of land use emissions for a number of different first generation biofuels. The IFPRI study estimated land use emissions for biodiesel made from palm, rapeseed, soybean, and sunflowers. In addition, it examined ethanol from maize, wheat, sugar beets, and sugarcane. The IFPRI study used an 8.6% biofuel target in 2020, under the assumption that the other 1.4% would come from other types of renewable energy.

Land use emissions are generally stated in grams of CO_2 equivalent per Megajoule of biofuel, or gCO_2e/MJ. The EU uses a 20-year period to sum the emissions due to land conversion, and also biofuel production on the converted land. The emissions have to be estimated over an extended period because some emissions are released slowly, while other emissions are released more quickly. Economic equilibrium models are used to determine the amount of land converted, where the land is converted, and what type of land is converted (forest, pasture, cropland, etc.). The economic modeling on land converted has to be united with estimated emission rates for the types of land converted, to produce the emissions estimate. The IFPRI effort used an economic model called MIRAGE. The biodiesel emissions from the IFPRI study were in the range from 52-56 gCO_2e/MJ and the ethanol emissions ranged from 7-14 gCO_2e/MJ.

The European Biodiesel Board (EBB) reviewed the IFPRI extensively and had a number of concerns with the study including the yield of crops on new land, the high proportion of forest converted, the high degree of substitutability between oilseeds, and the poor mass balance for the oilseed sector (oil and meal production was less than the quantity of seed crushed). Recently, EBB initiated additional work on land use emissions of biofuels using updated economic modeling, which is the subject of this study. This study used an updated economic general equilibrium model developed by Purdue University called the Global Trade Analysis Project, or GTAP. The MIRAGE model used previously utilizes the GTAP database modified by IFPRI. **GTAP has been used in the U.S. to estimate land use changes by the State of California for its Low Carbon Fuel Standard. The model is undergoing constant development and peer review.**

A version of the model was developed for this particular work to estimate land use changes as a result of European biofuel policy (the model has been used a number of times in the past for this purpose as well). Modifications to the model for this work included disaggregation of oilseeds into soybeans, palm, rapeseed, and other oilseeds. Coarse grains were also split into sorghum and other coarse grains. We united the GTAP modeling results of land use changes by region with the IFPRI study's emission rates for each of the land types that are converted, to facilitate direct comparison of the emission results between the two studies. We used the same 8.6% biofuel target in this study.

The results of this study using the latest version of GTAP show that this current study projects less land would be converted for EU biofuels production. The reductions in cropland for the different biodiesel feedstocks ranged from 18% less to 70% less compared with the IFPRI2011 study. The latest version of GTAP uses higher yields on converted land than the IFPRI analysis. The percent of this new cropland that comes from forest was estimated for the different biodiesel feedstocks in the 10-23% range. The IFPRI study estimated that 40%+ of the new cropland came from converted forest. The lower forest conversions for this analysis are the result of adding a new land category of cropland-pasture in the US and Brazil, and an improved method and data in GTAP for determining the proportion of forestland and pasture converted to crops.

The emissions comparison for the feedstocks studied for the 8.6% biofuel target is shown in Table ES-1. The emissions for this study for the biodiesel feedstocks are 48-79% lower than the estimates from the IFPRI2011 study. Again, the two most significant reasons for this are (1) less land converted per 1000L of biofuel, and (2) less predicted forest converted. Another reason is the better representation of the biodiesel industry in the GTAP model compared to the MIRAGE model. For ethanol, this study showed lower wheat ethanol emissions, but significantly higher beet emissions than the IFPRI2011 study.

Table ES-1. Percent Change in Land Use Emissions from IFPRI2011 Study

Biofuel	% Change from IFPRI2011 Study
Palm Biodiesel	-56%
Rapeseed Biodiesel	-65%
Soybean Biodiesel	-50%
Other Biodiesel	-79%
Wheat Ethanol	-33%
Sugar Beet Ethanol	+136%

While these new emissions are lower than the IFPRI2011, there are a number of reasons why the values are still very likely high. First, a new category of land has been added to the GTAP model for the US and Brazil – a category called cropland pasture. This is land that was previously in crops, but has now been turned (at least temporarily) into pasture. It would be backed to crop production if crop demand increased. The addition of this land to the US and Brazil reduced the estimated forest and pastureland converted in both areas, thereby reducing biofuel land use emissions. **The estimated land use emissions from biodiesel would further be reduced if the GTAP model were improved to include**

information on cropland pasture in the EU and Canada, but this could not be accomplished in time for this study.

Another type of land not included in GTAP is temporary fallow. Temporary fallow could be due to agronomic practices or due to a lack of markets. Between 1992 and 2007, the European Union had programs that provided economic incentives to leave land fallow (set aside programs). Producers were paid to leave productive land fallow to try to manage the supply and support prices. There was also fallow land that was not part of the incentive programs. In 2004, there were 9.1 million ha of fallow land in the EU. The economic incentives for fallow land are no longer in place and some of this land has come back into production. **There are no land use change emissions associated with this land, in fact there could be positive emission benefits as more carbon is added to the soils when fields are continually cropped than when they include a fallow period in the rotation.**

While due to the time restriction it was not possible to include fallow land (or cropland pasture outside of the US and Brazil) within the GTAP model as a separate land category for this work, it was possible to adjust some of the GTAP parameters to simulate the increased production of a crop without any increase in cropland. This is one way to simply utilize some of the cropland that is currently fallow or in cropland pasture. There is also evidence that little or no forest is being converted in the EU, US, or Canada. We have estimated land use emissions for the biofuels utilizing fallow land, and with and without forest conversions in the EU, US, and Canada. The results are shown in Table ES-2.

Table ES-2. Impact of Utilizing Fallow Land on Land Use Emissions (gCO_2e/MJ)		
Feedstock/biofuel	With Fallow, Forest	With Fallow, no Forest
Rapeseed biodiesel	4.66	2.33
Soybean biodiesel	16.22	15.63
Palm biodiesel	24.13	15.19
Other Biodiesel	3.32	2.95
Wheat Ethanol	3.25	1.44
Beet Ethanol	6.84	4.74

Including fallow land results in rapeseed LUC emissions to 4.66 gCO_2e/MJ. If there is no forest converted in the EU, US, and Canada (and there is evidence that forest has been increasing in those regions), then the emissions drop to 2.33 gCO_2/MJ. The results for soybean and palm biodiesel are higher, and the results for wheat and beet are also less than 10 gCO_2e/MJ. The change in total cropland is less than 10% of the fallow land that is available in the EU, and is less than half the reduction in fallow land seen in the EU between 2005 and 2010.

This work has found that indirect land use emissions calculated using the latest version of GTAP are much less than those calculated by IFPRI2011. There are two primary reasons for the lower emissions. The first is that less land is required in the new GTAP, mostly the result of higher yields on new cropland than was assumed by IFPRI, and the second is that less forestland is converted. Estimated forest conversions have been reduced through the addition of cropland pasture in the US and Brazil, and updated methods of determining the proportion of both forest and non-forest land to cropland. This work has also found that there are limitations in accessing fallow land directly in the GTAP model, but when another parameter is altered that simulates using fallow land, and the equivalent of 40% of the EU fallow land that has been put into production between 2005-2010 is used by the model (using none of the fallow land anywhere else in the world), the LUC emissions drop dramatically.

There is a very strong reason to believe that the indirect emissions would be even lower if GTAP was further enhanced to be able to more accurately reflect the availability of fallow land and cropland pasture in more regions than just the United States and Brazil. The reduction in ILUC emissions could be significant with these enhancements. Other GTAP model enhancements that need to be considered include further tuning of the factor that selects the quantity of land converted from forest versus pasture. This would also consider the regional restrictions that have effectively stopped forest land conversion in the EU, the United States and Canada.

Since GTAP only provides the quantity and types of land that are converted, information on the carbon contents of the converted land could be also be improved. Consideration of the actual carbon loss (or gain) from putting cropland pasture and fallow land back into crop production should be evaluated. The importance of this factor increases as the GTAP model has better access to this land. Further improvements will come from developing biophysical soil carbon models to derive feedstock specific emissions factors as was done in the US with the current Argonne CCLUB model. Not all of the carbon stored in forests is lost when forests are harvested; some of the carbon is stored in the harvested wood products.

There has also been research that shows that the simple accounting for the impact of time on the emissions may not be the most appropriate approach that could be used. Alternative approaches could lead to lower emission estimates.

The initiative to perform the present study emerged in February 2013 to provide additional information to policy makers in frame of the policy debate amending Renewable Energy Directive and the Fuel Quality Directive in Europe. This research work was entrusted to the authors by the European Biodiesel Board (EBB), the European Oilseed Alliance (EAO) and the EU Vegetable Oil and Protein-meal Industry (FEDIOL) as joint committers. It is meant to add and improve ILUC knowledge inside the scientific Community as well as governments, European civil servants at the European Commission, Members of the European Parliament and is designed to foster greater understanding of economic modeling applied to biofuels. The GTAP model is a general equilibrium tool used by an International network of researchers to assess patterns due to economic policy-making.

1.0 Introduction

The European Union (EU) is considering amending its current biofuel policy. The current policy, adopted in 2009, calls for 10% transportation renewable energy target (by energy content) by calendar year 2020. Among the options currently being considered is a cap for biofuels at 5%.

One of the reasons frequently cited for the need to amend the biofuels policy is the estimated emissions associated with land use changes brought about by the expansion of feedstocks used to produce biofuels. A study of land use change emissions was completed in 2011 by the International Food Policy Institute (IFPRI) for the Directorate General for Trade of the European Commission. [1] A number of biofuels stakeholders including the European Biodiesel Board (EBB) expressed concerns with this study. [2]

Estimating emissions due to land use changes using economic models, and predicting the types of land that would be impacted, is a field of much continuing research. A recent (2012) extensive review of the various land use estimates and models used to estimate land use changes by Wicke et al concluded, "despite recent improvements and refinements of the models, this review finds large uncertainties, primarily related to the underlying data and assumptions of the market-equilibrium models. Thus there is still considerable scope for further scientific improvements of the modeling efforts." [3]

Recognizing the need for additional work on land use changes in the EU and the discussion about possibly modifying biofuel targets, EBB contracted with Air Improvement Resource, Inc. to perform additional LUC modeling. AIR was assisted by by Don O'Connor of $(S\&T)^2$ Consultants, and by Steffen Mueller, University of Illinois, Chicago.

This study evaluates land use changes for several biofuel pathways and policies in the EU using the latest modified version of the Purdue Global Trade Analysis Project (GTAP) model for biofuel analysis (GTAP-BIO). The results obtained from this modeling practice are compared with the IFPRI2011 study.

This report is organized in the following sections:

- Background
- Biofuel Scenarios Evaluated
- Modeling Framework
- Results – Land Use Changes using GTAP7
- Results – Land Use Change Emissions
- Discussion

2.0 Background

The European Commission has undertaken a number of land use modeling studies to try to understand the potential impacts of the EU biofuels policy on global land use change. These studies were designed to help the Commission develop a report for the European Parliament and to the Council, reviewing the impact of indirect land use change on greenhouse gas emissions and addressing ways to minimise that impact (article 19.6 of the Renewable Energy Directive (2009/28/CE)) and article 7d.6 of the Fuel Quality Directive (2009/30/CE)).

One of the studies was prepared by the International Food Policy Research Institute (IFPRI) of Washington DC and published in October 2011. [1] This study was a follow-up study to a report published in March 2010 by the same group. The IFPRI2011 ILUC values for the different biofuel feedstocks served as the central source of ILUC emission estimates used by the Commission.

IFPRI utilized the MIRAGE model to calculate induced land use changes due to EU biofuel targets. MIRAGE is a computable general equilibrium (CGE) model which has been originally developed at CEPII (the French Center for Research and Studies on World Economy) for trade policy analysis. IFPRI has modified this model to address the potential economic and environmental impact of biofuels policies. The MIRAGE model relies on the Global Trade Analysis Project (GTAP) database version 7, which represents the global economy in 2004. Since the standard GTAP databases do not represent explicitly biofuel activities, IFPRI has made some modifications in the original GTAP database to introduce biofuels in this database and represent the link between crop and biofuel industries. The IFPRI2011 study results derived from the MIRAGE model are summarized in Table 1.

Table 1. Crop Specific Land Use Change Coefficients

Biofuel	Feedstock	Land Required Ha/1000 litres	GHG Emissions gCO_2e/MJ
Biodiesel	Palm	0.0682	54
	Rapeseed	0.1392	54
	Soybean	0.1378	56
	Other	0.1749	52
Ethanol	Wheat	0.0293	14
	Maize	0.0186	10
	Sugar Beet	0.0087	7
	Sugarcane	0.0312	13

For the combined biofuels, the source of the new land was 42% from pasture, 42% from managed and primary forest, and 16% from grassland and savannah.

3.0 Biofuel Scenarios Evaluated

The IFPRI2011 study examined the land use effects of an 8.6% penetration of biofuels by 2020. This corresponds to 27.2 million tons of oil equivalent (Mtoe) of first generation land-using ethanol and biodiesel by 2020 assuming continual growth in demand for transportation fuel. The remaining 1.4% was assumed to come from other types of renewable energy, including waste products (used cooking oil and tallow biodiesel). The study further assumed that in 2020, 72% of produced biofuels would be biodiesel and the rest (28%) would be ethanol. We do some limited sensitivity analysis on the impact of different growth assumptions.

This current study is also assuming an 8.6% penetration of biofuels by 2020. Ethanol may expand to more than the 28% of biofuel assumed by IFPRI because the 1.4% from other sources primarily affects biodiesel production. Therefore, this study is also evaluating both rapeseed and palm oil at one-half of the increases calculated for the case of an 8.6% target.

We are assuming a status quo trade policy. In the case of sugar beet ethanol, we include the impact of the 2006 change in EU sugar policy that results in lower sugar beet for sugar production in the EU.

The GTAP model used in this research does not evaluate ethanol produced from maize or sugar cane in the EU. Instead, it simulates ethanol produced from wheat and sugar beets. Therefore, we have replaced the maize volume with wheat and the sugar cane volume with sugar beets.

The GTAP modeling “shocks” for each feedstock for these policies are developed further in section 4.2.

4.0 Modeling Framework

4.1 GTAP7[1]

To evaluate induced land use changes due to the EU biofuel targets, the GTAP-BIO model has been modified and used. The model is a Computable General Equilibrium model and frequently has been used to assess the economic and environmental consequences of biofuel production and policy [4-11]. The model used in this research is an extended version of the model developed by Taheripour and Tyner [9]. The new model used in this analysis (and its database) extends the space of agricultural commodities, vegetable oils and their meals, and biofuels.

The database of the new model disaggregates oilseeds into soybeans, palm, rapeseed, and other oilseeds. In addition, it splits the standard GTAP crop category of coarse grains into two groups of sorghum and other coarse grains. To disaggregate crop commodities, we first collected data on harvested area and crop production for new crops by region and by crop at a global scale from the SAGE database [5]. This is the most trusted database in this field. The Food and Agricultural Organization (FAO) of the United Nations (UN) also uses this source of data.

In general, the database used in this work represents crop activities under 12 different crop categories of: paddy rice, wheat, sorghum, other coarse grains, soybeans, palm, rapeseed, other oilseeds, sugar crops, other crops, Conservation Resource Program, or CRP (only for US), and cropland pasture (only for US and Brazil). Tables 2 and 3 show global harvested areas and crops produced in 2004 by region. The new GTAP database provides similar data items for the 19 regions of the model by Agro Ecological Zone (AEZ).

This data set is used to disaggregate the standard GTAP crop categories of *"gro"* and *"osd"* into: sorghum, other coarse grains, soybeans, palm, rapeseed, and other oilseeds. The *SplitCom* program developed at Monash University [13] is used to accomplish the separation. Notice that the original GTAP database version 7 does not accurately represent values of oilseeds produced in China, Malaysia and Indonesia, India, and Brazil. As we did in our earlier work in this area, prior to the split process, we used the *GTAPAdjust* program [14] and made proper adjustments in the original database to fix values of oilseeds produced in these regions. Then the *SplitCom* program was used sequentially to introduce new crop activities into the database one-by-one.

A similar process is used to split the standard GTAP vegetable oil industry (*vol*) into new vegetable oil industries of: soybean oil (*vol-soy*), palm oil (*vol-palm*), rapeseed oil (*vol-rape*), and other oils (*vol-oth*). In general, the original *vol* industry of GTAP covers a wide range of economic activities. This industry produces crude and refined vegetable oils; animal and vegetable fats; and all types of oilseed meals, oil cakes, and other

[1] This section, along with the updated model was provided by Professors Farzad Taheripour and Wally Tyner. They did not participate in the analysis provided in this report other than through provision of the model.

products resulting from the extraction of vegetable oils and fats. This industry buys all types of oilseeds and animal fats along with other inputs and sells its products mainly to the livestock and processed livestock industries, food industries, processed animal feed industries, chemical industries, services (restaurants and fast food), and households. It is important to highlight the fact that the *"vol"* industry captures values of a wide range of commodities such as vegetable oils, animal fats and meal products.

In a recent paper Laborde and Valin [15] argued that the GTAP database undermines the links between the vegetable oil and oilseed industries and that it overestimates implicit prices of vegetable oils. We accept the first part of this argument. Indeed we were aware of this deficiency and it has been fixed in our earlier databases developed for the GTAP-BIO model. However, it seems that theses authors neglected the fact that the GTAP *"vol"* industry not only represents produced vegetable oils but it also represents values of produced animal fats and all types of meals mentioned above. Of course if one divides values presented by the *"vol"* industry by the amounts of vegetable oil produced, they will get an inflated implicit oil price and will reach an invalid conclusion.

To improve accuracy of our database we investigated the regional input/output tables of the original GTAP database and corrected the links between the oilseeds and vegetable oil industries using the *GTAPAdjust* program. In this process we also calculated the values of oilseeds, vegetable oils, animal fats, and meals by region using available databases and adjusted their corresponding values in GTAP, if we observed inconsistencies. As mentioned above, the final database covers four distinct vegetable oil industries of soybean oil (*vol-soy*), palm oil (*vol-palm*), rapeseed oil (*vol-rape*), and other oils (*vol-oth*). Each vegetable oil industry provides two commodities: vegetable oil and meal. Table 4 represents the shares of oils and meals in each vegetable oil industry.

These vegetable oil industries provide feedstock for four biodiesel industries of soybean biodiesel (biod-soy), palm biodiesel (biod-palm), rapeseed biodiesel (biod-rape), and other biodiesel (biod-other). In addition to these biodiesel sectors, the model represents corn ethanol (mainly US), sorghum ethanol (mainly US), wheat ethanol (mainly EU), sugar cane ethanol (mainly Brazil), and sugar beet ethanol (mainly EU). Taheripour et al. and Taheripour and Tyner [16,17] explained the production processes and cost structures for these biofuel industries except for sugar beet.

To model sugar beet production in EU, available research in this area was examined [18-20]. These resources represent several production technologies with different cost structures. In the absence of reliable resources on the cost structure of the sugar beet ethanol industry in EU, a Meta cost structure was defined based on the available resources in this area. In this structure the sugar beet cost share is about 60%, and the share of other inputs including the primary and intermediate inputs is about 40%. This industry buys sugar beet and produces ethanol. The returns on co-products are used to pay a portion of production costs. Hence, non-feedstock costs represent net costs of production.

Production of biodiesel will affect the price of vegetable oils and oilseed meals. For example, an increase in the demand for rapeseed biodiesel could increase the demand for other types of vegetable oils. This will encourage households and producers (e.g food producers) to move away from rapeseed oil consumption to other types of vegetable oils. This substitution could reduce the demand for rapeseed oil and increase the demand for other types of vegetable oils. To model this behavior, following Tyner et al. [21], a new nest is added to the GTAP-BIO model which facilitates substitution among alternative types of vegetable oil at household and firm levels.

Due to the substitution among vegetable oils, an increase in one type of biodiesel increases the demand for all types of vegetable oils, which leads to increases in their supplies. This increases the supply of all types of oilseed meals and reduces their prices. This affects the relative prices for animal feed products. The GTAP-BIO model captures these substitutions using a multi-level nesting structure which models demand for feed items as shown in Figure 1.

Table 2. Global harvested area by region and crop (figures are in 1000 hectares)

Region / Crop	Paddy Rice	Wheat	Sorghum	Other Coarse Grains	Soybeans	Palm	Rapeseed	Other Oilseeds	Sugar Crops	Other crops	CRP land	Cropland Pasture	Total
USA	1,346	20,222	2,637	32,575	29,930	0	338	1,569	909	38,464	14,046	25,024	167,059
EU27	432	26,576	107	33,739	387	0	4,553	8,946	2,231	38,758	0	0	115,729
BRAZIL	3,733	2,807	931	12,948	21,539	55	34	640	5,632	14,510	0	23,573	86,403
CAN	0	9,389	0	6,773	1,174	0	4,867	862	14	10,435	0	0	33,514
JAPAN	1,701	213	0	105	137	0	1	9	91	1,929	0	0	4,185
CHIHKG	28,616	21,626	570	28,801	9,582	47	7,272	7,323	1,583	55,421	0	0	160,840
INDIA	41,907	26,595	9,331	19,974	7,571	0	5,428	14,535	3,938	57,521	0	0	186,799
C_C_Amer	699	524	2,177	10,162	108	178	1	801	1,953	10,084	0	0	26,687
S_o_Amer	2,134	7,357	911	6,707	17,341	328	49	2,602	1,235	17,921	0	0	56,585
E_Asia	1,584	242	14	692	385	0	1	60	0	1,874	0	0	4,852
Mala_Indo	12,604	0	0	3,381	565	6,722	0	3,720	432	8,575	0	0	35,999
R_SE_Asia	30,978	96	36	5,493	566	326	0	6,984	1,966	13,719	0	0	60,163
R_S_Asia	15,261	11,414	309	3,278	24	0	665	1,513	1,343	9,906	0	0	43,712
Russia	125	22,920	26	17,422	555	0	232	4,884	790	34,274	0	0	81,229
Oth_CEE_CIS	309	32,249	47	21,114	492	0	260	6,381	1,293	32,853	0	0	94,998
Oth_Europe	0	171	0	311	3	0	24	5	19	628	0	0	1,160
MEAS_NAfr	1,350	18,081	749	9,904	99	0	139	3,951	513	15,148	0	0	49,933
S_S_AFR	7,660	2,917	21,918	50,336	1,118	4,513	70	15,894	1,243	70,123	0	0	175,792
Oceania	67	13,439	735	6,154	27	85	1,379	324	456	19,515	0	0	42,181
Total	150,504	216,838	40,498	269,868	91,602	12,255	25,312	81,002	25,640	451,657	14,046	48,597	1,427,818

Table 3. Global crop production by region and crop (figures are in 1000 metric tons)

Region / Crop	Paddy Rice	Wheat	Sorghum	Other Coarse Grains	Soybeans	Palm	Rapeseed	Other Oilseeds	Sugar Crops	Other crops	CRP land	Cropland Pasture	Total
USA	10,540	58,697	11,523	308,257	85,014	0	613	3,348	59,034	784,072	56,746	104,849	1,482,692
EU27	2,902	149,296	544	172,391	1,106	0	15,445	19,527	132,834	849,211	0	0	1,343,255
BRAZIL	13,277	5,819	2,159	42,697	49,550	550	57	3,574	415,206	85,885	0	41,242	660,015
CAN	0	24,796	0	25,983	3,044	0	7,674	859	744	114,799	0	0	177,897
JAPAN	10,912	860	0	222	163	0	1	21	5,843	58,711	0	0	76,733
CHIHKG	180,523	91,952	2,341	138,348	17,404	675	13,182	18,151	96,902	762,317	0	0	1,321,794
INDIA	124,697	72,156	6,681	26,311	6,876	0	6,291	18,252	233,862	269,316	0	0	764,443
C_C_Amer	2,244	2,332	7,452	26,089	181	2,724	2	2,397	121,508	85,743	0	0	250,672
S_o_Amer	11,102	19,734	3,260	26,839	37,315	5,617	84	4,621	98,798	250,761	0	0	458,130
E_Asia	9,107	323	22	2,286	489	0	1	48	0	24,659	0	0	36,935
Mala_Indo	56,353	0	0	11,297	724	130,307	0	18,501	27,905	49,751	0	0	294,837
R_SE_Asia	110,635	125	93	14,695	746	5,404	0	20,462	122,045	96,325	0	0	370,531
R_S_Asia	51,374	24,535	188	6,107	23	0	612	3,006	64,244	41,519	0	0	191,607
Russia	471	45,413	44	30,304	555	0	276	4,918	21,848	273,219	0	0	377,048
Oth_CEE_CIS	1,232	66,645	90	59,147	911	0	338	7,399	39,400	268,130	0	0	443,291
Oth_Europe	0	936	0	1,568	7	0	71	14	1,456	17,087	0	0	21,138
MEAS_NAfr	9,175	41,418	1,487	18,529	246	0	268	4,300	35,285	202,178	0	0	312,885
S_S_AFR	12,628	5,253	19,971	59,586	1,118	16,567	61	14,201	65,155	316,272	0	0	510,812
Oceania	554	22,224	2,013	10,613	60	1,250	1,546	786	37,436	219,891	0	0	296,371
Total	607,726	632,514	57,866	981,266	205,530	163,094	46,521	144,384	1,579,505	4,769,844	56,746	146,091	9,391,086

Table 4. Share of oils and meals in total sale values of vegetable oil industries by region

Region	Vol-Soy			Vol-Palm			Vol-Rape			Vol-Oth		
	Oil	Meal	Total	Oil	Meal	Total	Oil	Meal	Total	Oil	Meal	Total
1 USA	44.6	55.4	100.0	-	-	100.0	58.1	41.9	100.0	63.9	36.1	100.0
2 EU27	67.5	32.5	100.0	91.9	8.1	100.0	83.4	16.6	100.0	79.5	20.5	100.0
3 BRAZIL	62.7	37.3	100.0	92.2	7.8	100.0	79.8	20.2	100.0	80.1	19.9	100.0
4 CAN	53.5	46.5	100.0	-	-	100.0	71.1	28.9	100.0	68.0	32.0	100.0
5 JAPAN	55.4	44.6	100.0	-	-	100.0	73.1	26.9	100.0	72.7	27.3	100.0
6 CHIHKG	48.1	51.9	100.0	63.2	36.8	100.0	66.0	34.0	100.0	67.2	32.8	100.0
7 INDIA	71.1	28.9	100.0	88.7	11.3	100.0	77.1	22.9	100.0	77.3	22.7	100.0
8 C_C_Amer	59.5	40.5	100.0	89.8	10.2	100.0	78.3	21.7	100.0	77.5	22.5	100.0
9 S_o_Amer	66.5	33.5	100.0	92.2	7.8	100.0	80.0	20.0	100.0	78.6	21.4	100.0
10 E_Asia	55.0	45.0	100.0	-	-	100.0	65.5	34.5	100.0	66.4	33.6	100.0
11 Mala_Indo	61.9	38.1	100.0	90.5	9.5	100.0	-	-	100.0	77.1	22.9	100.0
12 R_SE_Asia	63.1	36.9	100.0	92.5	7.5	100.0	-	-	100.0	80.4	19.6	100.0
13 R_S_Asia	68.9	31.1	100.0	-	-	100.0	72.5	27.5	100.0	72.7	27.3	100.0
14 Russia	67.1	32.9	100.0	-	-	100.0	81.5	18.5	100.0	81.8	18.2	100.0
15 Oth_CEE_CIS	67.4	32.6	100.0	-	-	100.0	80.6	19.4	100.0	80.2	19.8	100.0
16 Oth_Europe	70.2	29.8	100.0	-	-	100.0	81.2	18.8	100.0	80.6	19.4	100.0
17 MEAS_NAfr	69.7	30.3	100.0	-	-	100.0	82.1	17.9	100.0	77.5	22.5	100.0
18 S_S_AFR	72.5	27.5	100.0	92.0	8.0	100.0	79.5	20.5	100.0	79.9	20.1	100.0
19 Oceania	69.6	30.4	100.0	-	-	100.0	83.2	16.8	100.0	82.6	17.4	100.0

Source: Authors' estimate

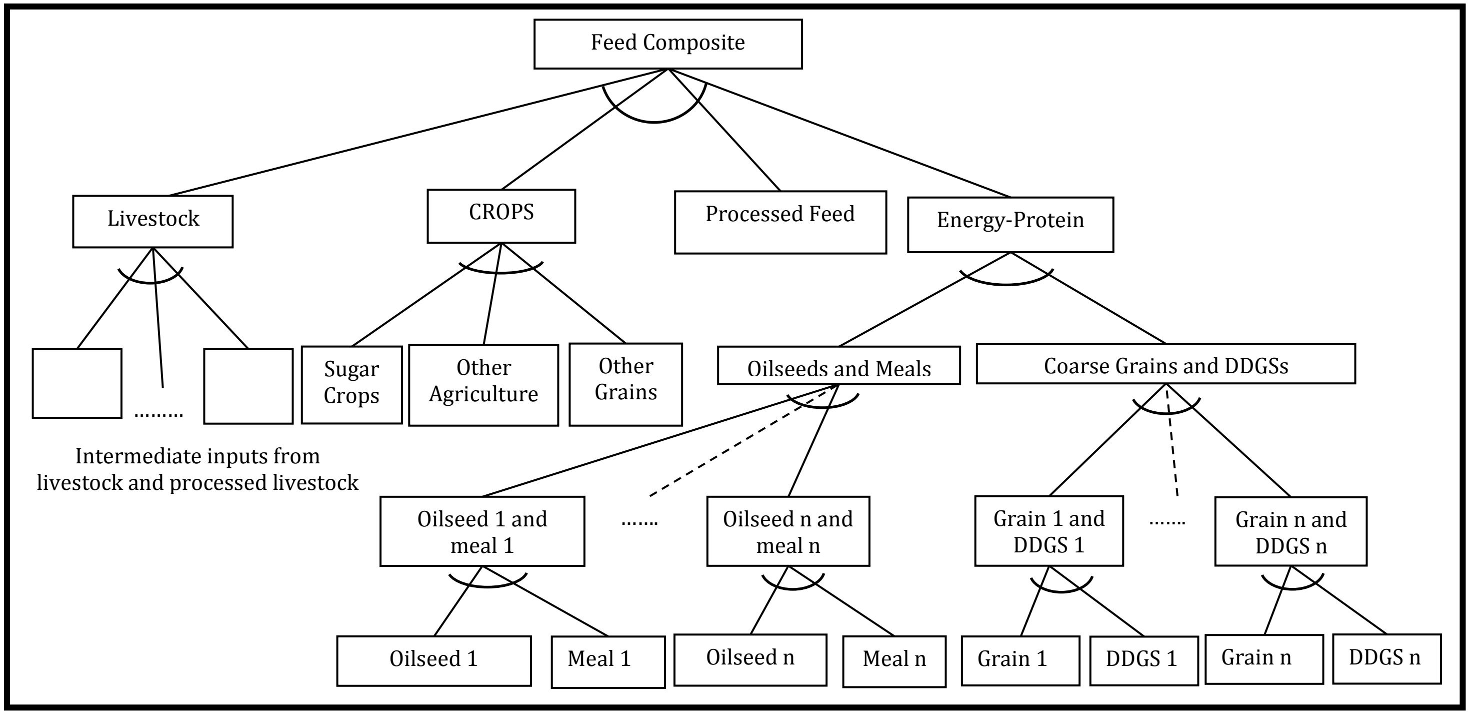

Figure 1. Structure of nested demand for feed in livestock industry

4.2 Size of Feedstock Shocks to GTAP for Policies Evaluated

GTAP7 utilizes economic data from the 2004 calendar year. For biofuels consumed in Europe, the model assumes that biodiesel can be produced from soybeans, rapeseed, palm oil or other feedstocks (such as sunflower). For ethanol produced in the EU, the model assumes the feedstock is either sugar crops (mainly beets) or wheat. In the GTAP model used in this research it is assumed that in the EU region ethanol is produced from sugar beets and wheat. The 2004 volumes of biofuels produced in the EU assumed in the GTAP-BIO database used in this research are shown in Table 5.

Table 5. GTAP 2004 Biofuel Volumes in European Region

Biofuel	Feedstock	Volume (G L/yr)
Biodiesel	Soybean	0.389
	Rapeseed	1.592
	Palm	0.058
	Other	0.157
Ethanol	Beet	0.114
	Wheat	0.414

This study is examining the land use effects of expansion of the above volumes to 8.6% of transport fuel consumed (by energy content) by 2020. To perform GTAP modeling of land use effects, we must estimate the percentage increases in these feedstocks by 2020, which can be estimated from the predicted volumes of various feedstocks by 2020 and the volumes in Table 5.

The IFPRI2011 study examined 8.6% biofuels. The IFPRI incremental biofuel volumes added to the IFPRI baseline were 10 Mtoe of biodiesel and 5.5 Mtoe of ethanol. The expected feedstock mixes of these volumes in 2020 were also obtained from the IFPRI2011 study and are shown in Table 6.

Table 6. Biofuel Feedstock Percent Expected in 2020		
Biofuel	Feedstock	No trade liberalization, biofuel percent
Biodiesel	Palm	24
	Rapeseed	56
	Soybean	14
	Other	6
	Total biodiesel	100
Ethanol	Wheat	32
	Sugar Beet	68
	Total ethanol	100

Using the expected amounts of biodiesel and ethanol in 2020, and the percent from each feedstock, we estimate the biofuel volumes by feedstock and the percent increases from the GTAP2004 levels for the 8.6% biofuel policy in Table 7 (biodiesel) and Table 8 (ethanol). Some estimates put the total biodiesel production in 2004 at about 1.99 Mtoe. The use of 1.754 Mtoe in GTAP is close to this, and differences in this number are not expected to adversely affect the results.

Table 7. Biodiesel Shocks by Feedstock Type for 8.6% Policy							
Feedstock	GTAP 2004 (G gal)	GTAP 2004 (Mtoe)	2020 Percent	2020 Volume (Mtoe)	2020 Volume (G gal)	2020 Volume (G L)	% GTAP Shock
Soy	0.103	0.311	14%	1.646	0.544	2.110	430%
Palm	0.015	0.047	24%	2.821	0.933	3.617	5957%
Rapeseed	0.421	1.272	56%	6.582	2.178	8.439	418%
Other	0.042	0.126	6%	0.705	0.233	0.904	461%
Total	0.580	1.754	100%	11.754	3.889	15.070	

Table 8. Ethanol Shocks by Feedstock Type for 8.6% Policy							
Feedstock	GTAP 2004 (G gal)	GTAP 2004 (Mtoe)	2020 Percent	2020 Volume (Mtoe)	2020 Volume (G gal)	2020 Volume (G L)	% GTAP Shock
Wheat	0.109	0.331	32%	1.89	0.627	2.429	473%
Sugar Beet	0.030	0.091	68%	4.03	1.332	5.162	4340%
Total	0.139	0.422	100%	5.92	1.959	7.592	

While the size of shocks (that is, the percent increases from 2004 for each biofuel) have been developed to be as close as possible to the IPFRI study there are some differences in the two modeling approaches. IFPRI forecast a business as usual scenario in 2020 and then applied the biofuel shock on top of that. In this modeling, the volume of the incremental shock is applied to the 2004 data that is in GTAP. There is no business as usual forecast to 2020 but the shocks are based on the 2020 forecast fuel demand from the IFPRI2011 study.

5.0 Results

5.1 GTAP Land Use Changes

5.1.1 Biodiesel Scenarios

Table 9 shows land use changes in ha/1000L for the four biodiesel scenarios for the 8.6% biofuel target. The land converted per 1000L is higher for soy and rapeseed than for palm and other.

The land use values at 8.6% are significantly less than the IFPRI2011 values, 25% less for soy, 27% less for palm, 18% less for rapeseed, and 70% less for other.

Table 9. Land Use Changes for Biodiesel Feedstocks

Feedstock	This Analysis 8.6% (ha/1000L)	IFPRI2011 Values (ha/1000L)	Percent Change from IFPRI2011 to This Analysis
Soy Biodiesel	0.1036	0.1378	-27%
Palm Biodiesel	0.0499	0.0682	-33%
Rapeseed Biodiesel	0.1138	0.1392	-34%
Other Biodiesel	0.0526	0.1749	-70%

One of the reasons for these reductions is that the yield on new land in the IFPRI modeling was assumed to be 75% of the yield on existing land in the region. In recent years GTAP has been enhanced to include yield estimates by region and AEZ that are based on the Terrestrial Ecosystem Model (TEM). This model captures first-order interactions among land use, climate, and economy. In the case of the 8.6% rapeseed shock, the average yield on new land is 89.5% of the yield on existing land. For the 8.6% palm shock, the average yield on new land is 90.5% of the existing land.[2] Another reason is the better representation of the biodiesel industry in the GTAP model compared to the MIRAGE model.[3]

5.1.2 Ethanol Scenarios

The land use changes for the ethanol scenarios are shown in Table 10. The wheat ethanol value in this study is also 15% less than the average of the wheat and corn averages from the IFPRI2011 study. The average yield on new land for the wheat scenario is 91.5% of the existing yield, this will account for a significant proportion of the reduced land requirement. For beet ethanol, however, the average of the beet and sugarcane

[2] The yield on new land was calculated from the ETA (elasticity of effective hectares with respect to harvested area) data in the model. This is available by AEZ and country. We took the weighted average using the change in crop area for each AEZ and country. The range represents separate weighted averages for rapeseed, wheat, and palm.

[3] In the MIRAGE model, the masses of oil and meal did not add to 100% of uncrushed oilseed mass.

IFPRI2011 values is 75% lower than this study. This difference is in part driven by the IFPRI beet value of 0.0087, which is much lower than sugarcane.

Table 10. Land Use Changes for Ethanol Feedstocks			
Feedstock	8.6% (ha/1000L)	IFPRI2011 Values (ha/1000L)	Percent Change from IFPRI2011 to This Analysis (8.6%)
Wheat Ethanol	0.0230	0.0240[1]	-4%
Sugar Beet Ethanol	0.0708	0.0196[2]	+261%

[1] Average of maize (0.0186) and wheat (0.0293)
[2] Average of beet (0.0087) and sugar cane (0.0312)

5.1.3 Fraction of Forest Converted

The overall emissions due to land use changes are driven by the percentage of forest converted, because forest generally has much higher carbon emissions than pasture or cropland/pasture (peat is even higher than forest). Therefore, it is instructive to evaluate the percent of forest converted to other uses (such as pasture or cropland). In this analysis, we have computed the percent of forest converted by dividing the forest converted by the total cropland increase for each biofuel case. The results are shown in Table 16. The values are between 10% and 27%. This range is lower than the percent of forest converted in the IFPRI2011 analysis, which was in the 40 percent range.

Table 11. Percent of Forest Converted	
Biofuel	Percent of Forest Converted
Soy Biodiesel	10.1%
Palm Biodiesel	25.1%
Rapeseed Biodiesel	21.1%
Other Biodiesel	13.6%
Wheat Ethanol	24.1%
Beet Ethanol	26.7%

In earlier versions of GTAP, the land cover nest has forest, pasture, and cropland in one nest implying, everything else being equal, that the ease of transformation between forest and cropland and pasture and cropland is the same. This version employs a revised and improved nesting structure for cropland, pasture, and forest that reflects the fact that it is much easier, and less costly, to transform pasture to cropland than forest to cropland.

5.2 Emission Factors for Converted Land Types

The land use change emissions are calculated from the location and quantity of land converted, the change in carbon stocks of the converted land, and the study period. For this work, an attempt has been made to keep as many of the parameters as were used in the IFPRI study constant to be able to isolate the reasons for any different results.

Accordingly, we have used the same 20 year period to amortize carbon changes as was used in the IFPRI study, even though the standard period that has been used by CARB and the EPA is 30 years. Using a 30-year period reduces the ILUC factors by one third.

The changes in carbon stocks that have been used are the same as those used in Appendix 2 of the IFPRI report. The carbon stocks in managed forests in the IFPRI modeling differed by AEZ, but not by region. So even though the GTAP modeling contains more and different regions, the IFPRI data could be used directly with the GTAP land use change for forests. For the carbon stock in the mineral soils, there were only very small changes in the values for the same AEZ for different regions, so it was relatively easy to also develop a set of emission factors that were consistent with those used in the IFPRI study.

The peat emission factor for the land conversion in Malaysia and Indonesia was the same as that used by IFPRI, 30% of the new land is assumed to be on peat soils and the annual emission rate is 55 t CO_2/ha.

The IFPRI average emissions per hectare for each of the biofuels are shown in Table 12. These emissions are a blend of forest and pasture emissions.

Table 12. IFPRI Emissions per Hectare (tonnes CO_2 e/Ha)

Biofuel	Without peat	With Peat Emissions
Palm Biodiesel	220	565
Rapeseed Biodiesel	205	277
Soybean Biodiesel	218	290
Other Biodiesel	159	212
Wheat Ethanol	173	201
Maize Ethanol	205	227
Sugar beet Ethanol	244	341
Sugarcane Ethanol	176	176

The one deviation that we have done to the emission factors is that GTAP has a land category called cropland-pasture for the United States and Brazil. This is cropland that has been cultivated in the past for crop production but currently is used as pasture land. It has been assumed that the soil carbon losses for this land are 50% of the soil carbon losses for pasture land in the same AEZ. It is unlikely that in the few years that this land has been in perennial crops it has recovered this much soil carbon (a 20% to 25% recovery would be more reasonable), so this leads to the possibility of overstating ILUC emissions rather than understating them.

The GTAP values all result in less forestland converted than IFPRI reported. The average emissions per hectare for the two models and various feedstocks are shown in Table 13. The differences in emissions are driven by differences in the forest fraction converted, and also by a different distribution of land conversions between different regions.

Table 13. Comparison of Emissions per Hectare			
	IFPRI2011	GTAP-IFPRI EF	% Change from IFPRI2011
Biofuel	Tonnes CO_2e/ha		
Palm Biodiesel	565	331	-41.4%
Rapeseed Biodiesel	277	118	-57.4%
Soybean Biodiesel	290	82	-71.7%
Other Biodiesel	212	118	-44.3%
Wheat Ethanol	201	77	-61.7%
Sugar beet Ethanol	341	108	-68.3%

5.3 Land Use Change Emissions in gCO_2e/MJ Biofuel

5.3.1 Biodiesel and Ethanol Cases

The land use emissions for the various cases are shown in Table 14. The first column shows the values for this analysis, using an 8.6% target, and using the IFPRI emission factors. The second column shows the percent reductions in land use emissions from the IFPRI2011 report. For the biodiesel feedstocks, the values from this analysis are approximately 50-65% of the values in IFPRI2011 for palm, rapeseed, and soybean biodiesel, while other biodiesel is 79% less in this analysis. The wheat ethanol values in this analysis are also lower than the IFPRI2011 analysis. The beet ethanol values in this analysis are significantly higher than in the IFPRI2011 analysis.

Table 14. Land Use Emissions of the Biofuel Scenarios (gCO_2e/MJ)		
Biofuel	IFPRI2011 Analysis, 8.6% Target (g CO_2/MJ)	% Change from IFPRI2011 to This Analysis
Palm Biodiesel	54	-56%
Rapeseed Biodiesel	54	-65%
Soybean Biodiesel	56	-50%
Other Biodiesel	52	-79%
Wheat Ethanol	Maize:10, Wheat:14	-33%*
Sugar Beet Ethanol	Beets: 7, Sugarcane:13	+136%*

* Estimated from the average IFPRI2011 emissions

There are two primary reasons why the emissions in this analysis are less than the IFPRI2011 analysis. The first is that utilizing this most recent version of the GTAP7 model, less total land is converted per 1000L of biofuel, due to improved crop yields on newly converted land. The second reason is that the percent of forest in the new cropland utilizing this model is less than the percent of forest converted in the IFPRI2011 analysis, due to the introduction of cropland-pasture in the US and Brazil, and an improved method and data in this version of GTAP for determining the proportion of forestland and pasture converted to crops.

5.3.2 Other Cases

We examined emissions at a 50% shock for palm oil and rapeseed, plus we examined the impact of peat emissions estimate on the land use emissions of oil seeds. The 50% shocks were 2979% for palm oil, and 209% for rapeseed (one-half of the values shown in Table 7). The 50% palm oil shock land use emissions are 3% less than the full shock for palm oil, and the 50% rapeseed shock land use emissions are 15% less than the full shock. Thus, analysis of lower shocks on these oilseeds from GTAP would imply that reducing biofuel production to much lower levels than estimated in this analysis would not reduce the land use emissions on an energy basis significantly.

We also evaluated the impact of peat emissions on the land use change emissions for the biodiesel feedstocks utilizing the 8.6% target. The results are shown in Table 15. Peat has the largest impact on the palm oil emissions.

Table 15. Impact of Peat Emissions on Biodiesel LUC (% reduction form IFPRI 2011)

Biodiesel	With Peat	Without Peat
Palm	-56%	-73%
Rapeseed	-65%	-66%
Soybean	-50%	-53%
Other	-79%	-79%

5.3.3 GTAP Land Areas

In GTAP there are two layers of information on cropland; land cover and harvested area. Any land which has been cultivated in the past is included in the cropland category under the land cover header. This category of land includes all types of cropland (cultivated and idled land such as planted but not harvested, cropland pasture, CRP, or fallow). The cropland area is generally not divided into different types (except partially for the US and Brazil). The second layer is harvested area. Harvested area refers to the cropland that is harvested in the base year (i.e. 2004).

The version of GTAP used for this work has cropland-pasture for the US and Brazil and CRP area for the United States added to the harvested land layer. The model does not allow conversion of CRP land to crop production (the model keeps it under the conservation program). However, cropland-pasture which is used for grassing tasks can be converted back to crop production. Cropland-pasture in the other regions of the world and fallow land (either deliberately not planted or having a harvest failure) are not included in the harvested land layer. The model currently has no capability of accessing this land for increased crop production even though it is probably the most likely land to respond to higher crop demand and is land that could be brought into production without any land use change.

In some areas of the world two or more crops can be harvested from the same land in a given year. In these areas, the harvested land may be greater than the cropland area. While some regions may have both fallow land and double cropped land from this data we can only show the net fallow land and the net double cropped land. A summary of these lands by model region is shown in Table 16.

Table 16. GTAP Land Summary (Ha)

GTAP Region	Cropland	Harvested Area	Net Cropland not in crops	Net Double Cropped
USA	175,807,007	167,059,000	8,748,007	
EU27	124,830,687	115,729,000	9,101,687	
BRAZIL	60,724,257	86,403,000		-25,678,743
CAN	39,573,515	33,514,000	6,059,515	
JAPAN	3,680,435	4,185,000		-504,565
CHIHKG	140,644,611	160,840,000		-20,195,389
INDIA	171,418,998	186,799,000		-15,380,002
C_C_Amer	56,671,461	26,687,000	29,984,461	
S_o_Amer	58,603,527	56,585,000	2,018,527	
E_Asia	5,190,174	4,852,000	338,174	
Mala_Indo	71,571,068	35,999,000	35,572,068	
R_SE_Asia	53,207,433	60,163,000		-6,955,567
R_S_Asia	46,956,517	43,712,000	3,244,517	
Russia	124,542,334	81,229,000	43,313,334	
Oth_CEE_CIS	111,522,274	94,998,000	16,524,274	
Oth_Europe	933,565	1,160,000		-226,435
MEAS_NAfr	53,633,308	49,933,000	3,700,308	
S_S_AFR	211,016,073	175,792,000	35,224,073	
Oceania	33957545	42,181,000		-8,223,455
Total	1,544,484,789	1,427,818,000	193,828,945	-77,164,156

There are large quantities of cropland in many parts of the world that were not in full production (either in fallow or in cropland pasture) in the base year of 2004.

While it was not feasible to include the fallow land (or the cropland pasture outside of the U.S. and Brazil) as a separate land category for this work, it was possible to adjust some of the GTAP parameters to simulate the increased production of a crop without an increase in cropland. In this analysis, we have increased the price-yield elasticity from a default value of 0.25 to 1.0. This is one simple way to model the utilization of some of the cropland that is currently fallow or in cropland pasture. For a further explanation of why this is an appropriate adjustment, and why we chose 1.0 for the price-yield adjustment, please see Appendix 1. In this analysis, we are not concluding that the true price-yield elasticity is really 1.0, we believe there are reasons why 0.25 as a default value is appropriate. However, we are merely using the increase from a value of 0.25 to a value of 1.0 to increase production without increasing the quantity of cropland (which is what happens when fallow land is brought into production).

In addition to utilizing idled land, there are also indications that little or no forest has been converted in the US, EU or Canada in the last decade. Therefore, we estimate emissions with and without forest converted in these three regions (we still allow forest conversions in regions other than these three). The results are shown in Table 17.

Table 17. Impact of Utilizing Fallow Land on Land Use Emissions (gCO_2e/MJ)

Feedstock/biofuel	With Fallow, Forest	With Fallow, no Forest
Rapeseed biodiesel	4.66	2.33
Soybean biodiesel	16.22	15.63
Palm biodiesel	24.13	15.19
Other Biodiesel	3.32	2.95
Wheat Ethanol	3.25	1.44
Sugar Beet Ethanol	6.84	4.74

Land use emissions for rapeseed biodiesel are 4.66 gCO_2e/MJ with forest conversions in the 3 regions, and are 2.33 gCO_2e/MJ without forest conversions in the 3 regions. Emissions for soybean and palm biodiesel are higher. Other biodiesel (sunflowers), wheat ethanol and sugar beet ethanol are all below 10 gCO_2e/MJ.

Additional detail on the rapeseed and wheat cases are presented below.

5.3.3.1 Rapeseed

Most of the world's rapeseed is grown in the EU, Canada, China, and India. When GTAP is shocked for a rapeseed biodiesel scenario, the price of rapeseed increases the most in the EU and in Canada (more than 4%) and very little in China and India (<1%) according to the GTAP model. Canada and the EU are known to have significant fallow area and the historical data shows that this has been reduced in recent years as rapeseed production has increased in both regions and there has been no increase in agricultural land in either region. Increasing this parameter will increase rapeseed production in the EU and Canada more than it increases production in the rest of the world. The results for no fallow use versus fallow use are shown in Table 18.

Table 18: Impact of Reduced Fallow Land - Rapeseed		
Parameter	No fallow	Fallow
Increase in rapeseed production, tonnes	7,756,794	8,071,055
Rapeseed area, ha	2,569,053	2,335,473
Change in total cropland, ha	611,383	172,959
Percent of increased production from yield	36	43
Reduction in OtherAgri land, ha	222,923	469,291

Figure 2 shows the impact of increasing the amount of fallow land through the price-yield parameter. Increasing this parameter from 0.25 to 1.0 has the effect of increasing fallow land use by 450,000 Ha in the EU27. This 450,000 ha is only 5% of the 9.1 million ha not cropped in the EU27 (see Table 16).

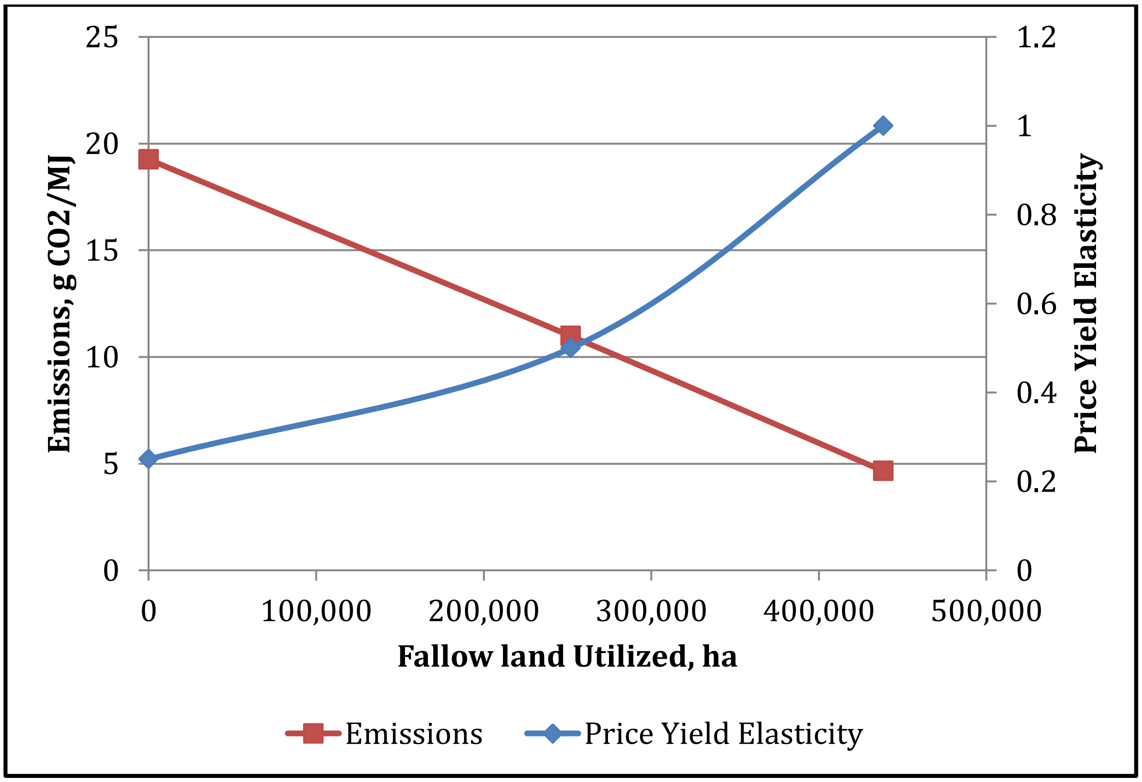

Figure 2. Relationship Between Fallow Land Utilized, and LUC Emissions, Rapeseed

Utilizing fallow land has a dramatic impact on the land use emissions for a rapeseed biodiesel shock. The land use emissions drop by 75% compared to the default case. The change in total cropland between the two cases is 438,000 hectares which is less than 10% of the fallow land that is available in Europe and is less than half of the reduction in fallow land between 2005 and 2010.

The land use modeling is obviously very sensitive to this parameter. The ability of land use change models to access fallow land (and probably the less than fully utilized cropland-pasture) is thus extremely important for any accurate assessment of indirect land use emissions.

5.3.3.2 Wheat

A similar trial was undertaken for wheat ethanol, the price yield elasticity factor was increased from 0.25 to 1.0. The results for the two cases are shown in the following table.

Table 19: Impact of Reduced Fallow Land – Wheat

Parameter	No fallow	Fallow
Increase in wheat production, tonnes	2,845,065	2,868,131
Wheat area, ha	217,338,585	217,292,766
Change in total cropland, ha	45,081	15.736
Percent of increased production from yield	49%	54%

The wheat ethanol results are very sensitive to the price yield elasticity as well. The increase in total cropland in both the default case and the higher price yield elasticity case is very small in comparison to the quantity of fallow cropland available in Europe (8 to 10 million hectares).

6.0 Discussion

There are several aspects of land use change that could not be modeled with the current version of GTAP. As it is important from a policy perspective to understand the limitations of the modeling, these aspects are briefly described below. GTAP and MIRAGE both assume that the existing cropland is fully utilized and that any additional demand must come from intensification (more crops from the same land), extensification (new land) or reduced demand in other sectors, or in practice a combination of all three factors.

6.1 Cropland-Pasture

The addition of cropland-pasture to GTAP for the United States and Brazil significantly reduces the amount of natural pasture and forests that are converted to cropland. This in turn reduces the GHG emissions associated with land change. We have assumed that the conversion of cropland-pasture back to annual crops will release some soil carbon and we have modeled a relatively high emission rate of 50% of the emissions associated with pasture conversion.

Feedstock-specific soil carbon models (similar to the Argonne Carbon Calculator for Land Use Change from Biofuels Production, or CCLUB model) need to be developed for the EU and applied since these models reflect most accurately soil carbon stock changes resulting from biofuels production. As evidenced by several US biofuels studies, these models tend to produce lower emissions for many biofuels scenarios. [22]

Since cropland-pasture is land that has been in annual crop production in the past and has been converted to a pastureland, the amount of soil carbon that could be built up will be a function of the number of years that it is perennial crop production before it is converted back to annual crops. It is unlikely that in this short time 50% of the previously lost soil carbon could be regained, so the 50% assumption is quite aggressive and may overestimate ILUC emissions.

Cropland-pasture is present in many regions of the world. In other countries it can be called seeded pasture or temporary grasslands. Data was collected for cropland pasture for Canada and the EU but there was insufficient time to include it in the GTAP model.
The cropland pasture data for the EU [23] and Canada [24] is compared to the information from the United States and Brazil in Table 20.

Table 20: Comparison of Cropland Pasture Areas

	Total Harvested Area (1000 ha)	Cropland Pasture (1000 ha)	% Cropland Pasture
United States	167,059	25,024	15.0
Brazil	86,403	23,573	27.3
EU (avg 2003/2005)	115,729	9,842	8.5
Canada (2006)	33,513	5,694	17.0

The addition of cropland-pasture data for the EU and Canada to the GTAP model will reduce the ILUC emissions. The impact will be different for different crops with rapeseed biodiesel and wheat ethanol expected to show the largest decreases, and smaller decreases for soy, palm, and sugar beets.

6.2 Fallow Land

Another factor that is not directly included in GTAP is land that is temporarily fallow. This could be due to agronomic practices or due to a lack of markets. A decade ago the European Union had programs that provided economic incentives to leave land fallow (set aside programs). There was also fallow land that was not part of the incentive programs. The economic incentives for fallow land are no longer in place and some of this land has come back into production. There are no land use change emissions associated with this land. In fact, there could be positive emission benefits as more carbon is added to the soils when fields are continually cropped than when they include a fallow period in the rotation. [25]

The Eurostats information on fallow land in 2003 and 2005 is shown in the following table. In the 2004 period, the base case for GTAP modeling runs, six million hectares, received financial incentives to remain fallow.

Table 21. EU Fallow Land (ha)

Land Type	2003	2005	Average
Fallow with incentive	6,310,110	5,996,250	6,153,180
Fallow w/o incentive	4,259,650	4,149,020	4,204,335
Total	10,569,760	10,145,270	10,357,515

There is evidence that some of this land has come back into production for the production of biofuel feedstock. The following table shows the fallow land, rapeseed area, and wheat area between 2005 and 2010 (Eurostats). There are some inconsistencies when the Eurostats database is queried, for example the fallow area in the following table is less than the sum of the incentivized and non-incentivized fallow area in the previous table.

Table 22. Land Use Trends (ha)

Land Type	2005	2007	2010
Fallow	8,534,220	8,574,880	7,413,020
Rapeseed	4,825,590	6,553,450	7,189,910
Wheat	26,334,720	25,376,330	26,322,020

The wheat area has remained relatively constant, whereas the rapeseed area and the fallow area have moved in opposite directions. It would appear that about 50% of the increase in rapeseed area has come from reduced fallow area. The wheat scenario only required a 915,000 ha increase in wheat production due to the modeled shock; this is only a 3.5% increase in production. Wheat yields can vary by much more than that due to weather conditions, so it is not surprising that no trends can be observed.

Europe is not the only area that has a significant amount of fallow land. Traditionally, summerfallow was a common practice in Canada as well, but the growth of canola (rapeseed) in western Canada has transformed agricultural practices and fallow land in crop rotations has been replaced by continuous cropping with canola now having a significant place in the rotations. The following figure shows the trends for canola and fallow area in western Canada (Statistics Canada).

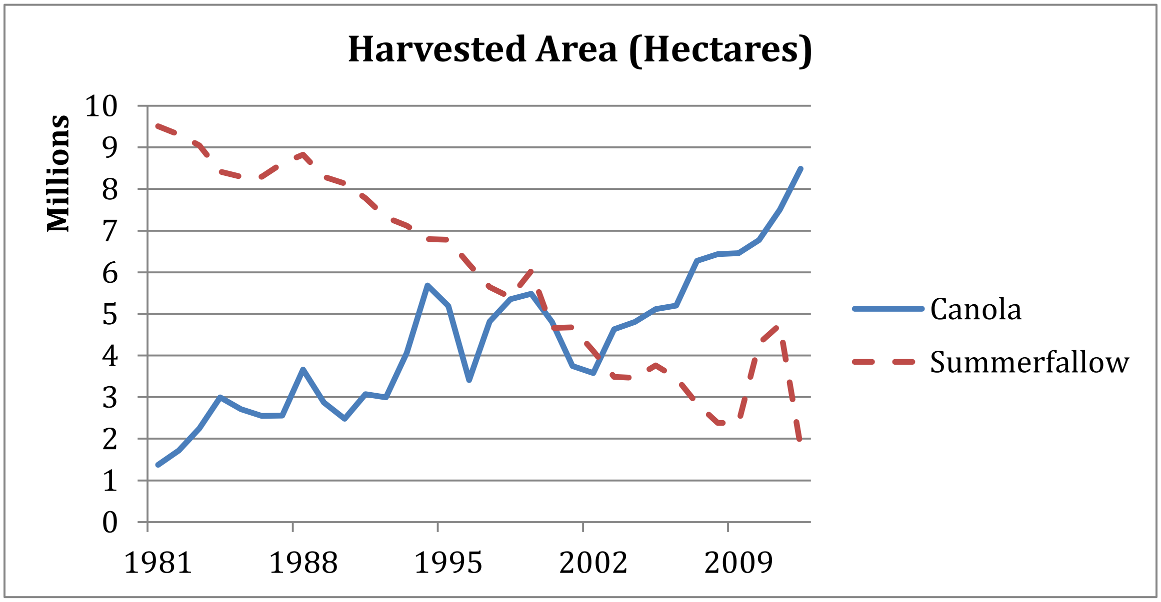

Figure 3. Canadian Trends in Canola and Summerfallow

Canola is the only major crop that shows a correlation with summerfallow area. The increase in summerfallow area in 2010 and 2011 was due to excessively wet fields at planting time. The shorter growing season for canola impacted this crop less than others. Between 2004 and 2011, almost 50% of the increase in canola area was related to the decrease in fallow area, very similar to the change seen in the EU.

6.3 Yield Increases

GTAP and MIRAGE forecast some increase in yield as the price for a commodity increases. There is much uncertainty about what the appropriate value for this is and as shown above it can have a large impact on the overall results. It is also likely that the yield response to price increases will vary by crop and by region.

Most of the rapeseed grown within the EU is in two AEZ's, yet there is very significant yield variation from country-to-country, as shown in the following figure. This could suggest that there is the potential for improvement in production practices within the EU.

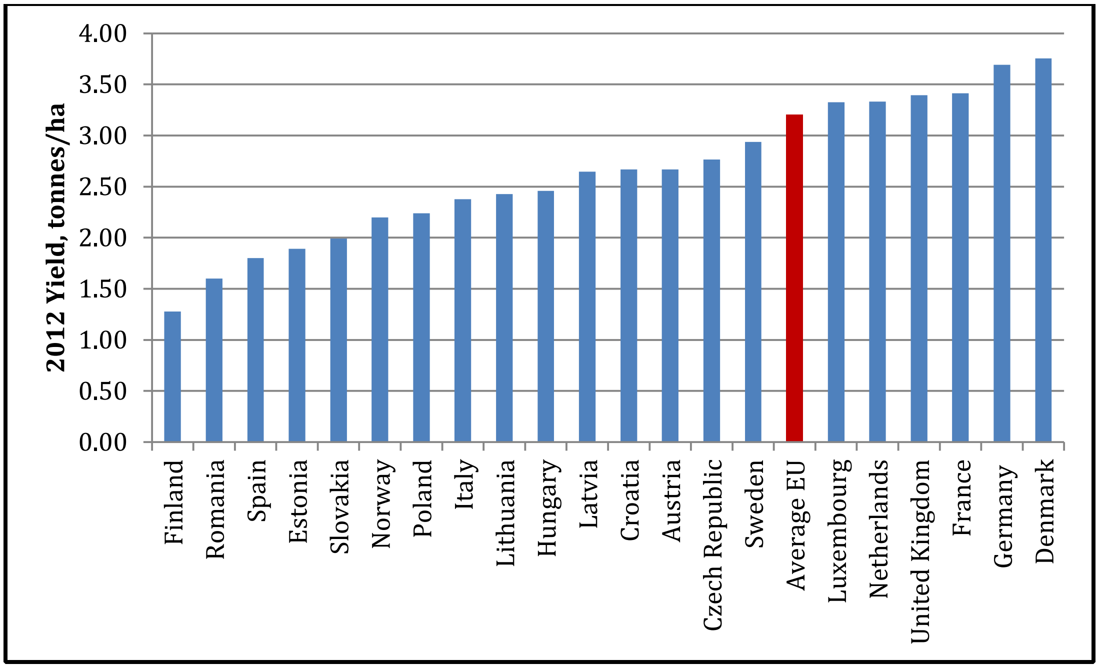

Figure 4. 2012 Rapeseed Yields in the EU

The EU yield of rapeseed in GTAP for 2004 (3.39 t/ha) is just about the same as the yield in 2012. In Canada, the yield has increased by 20% since 2004 and this higher yield is not included in the model except by the yield response to price.

6.4 Livestock Feed Demand

GTAP is a static model and yet the increased biofuel shock that is being applied will not happen instantaneously but will take a number of years to accomplish. Any underlying trends in the demand for agricultural commodities will not be reflected in the results since there is no time period considered in the model.

In Europe, the United States, and Canada there have been significant changes in the consumer demand for meat in the past 3 decades. In all three regions there has been a shift away from beef and towards poultry in the diets. This has significant demand for livestock feed and thus the demand for land to supply that feed. The rates of change have been different in each region. In the following figure the per capita supply of the three major types of meat is shown.

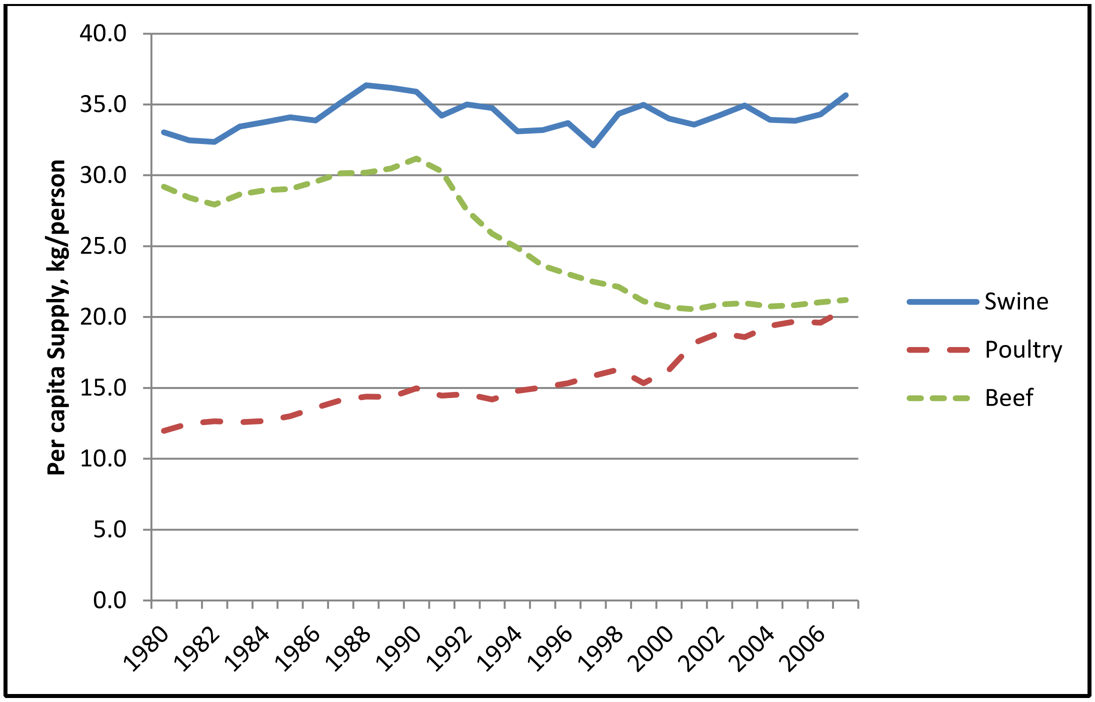

Figure 5. Trends in European Meat Production

The implication of a decline in beef (which requires about 18 kg of feed to produce one kg of boneless meat) and a rise in poultry (which requires about 3 kg for a kg of boneless meat) is a reduction in feed demand. The trend in the US is even more pronounced as shown in the following figure.

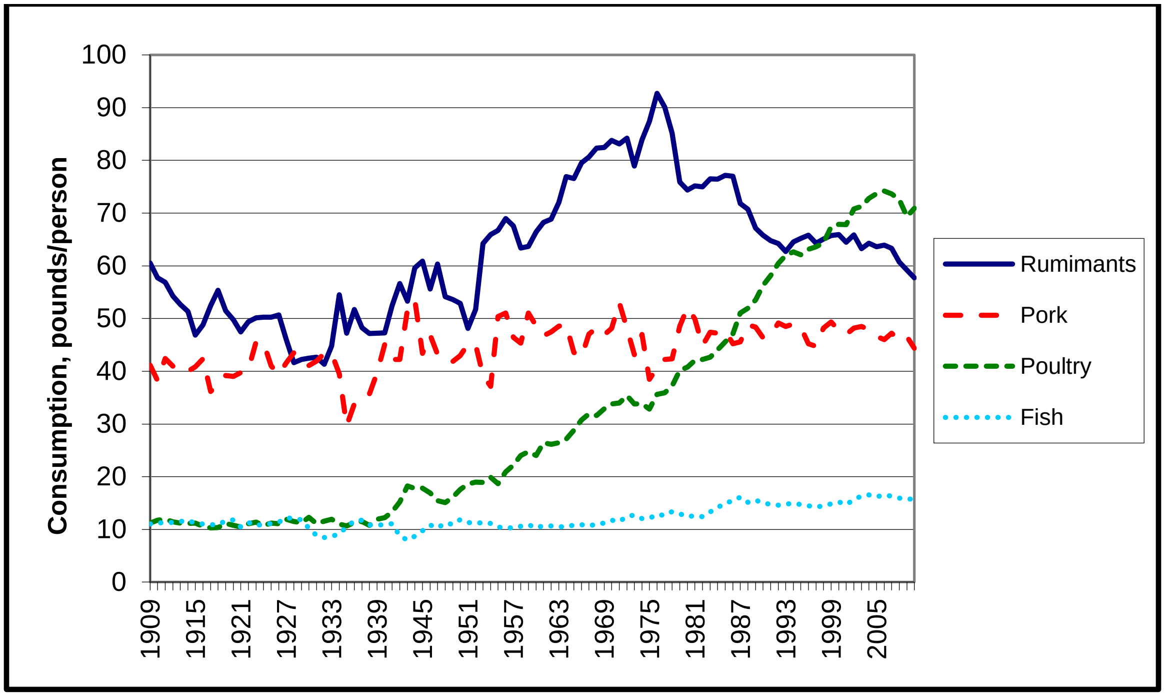

Figure 6. U.S. Trends in Meat Consumption

There are other factors that will influence the conversion of this meat consumption into land demand including population, crop yields, and animal conversion rates. The data on animal conversion rates is difficult to obtain, but ignoring that factor will understate the demand for land since it has been improving over time. The following figure shows the demand for land for livestock feed in the US over almost the past century. Land demand for feed was fairly constant up until about 1975, at which time US beef consumption per capita started to decline, land demand has dropped since then.

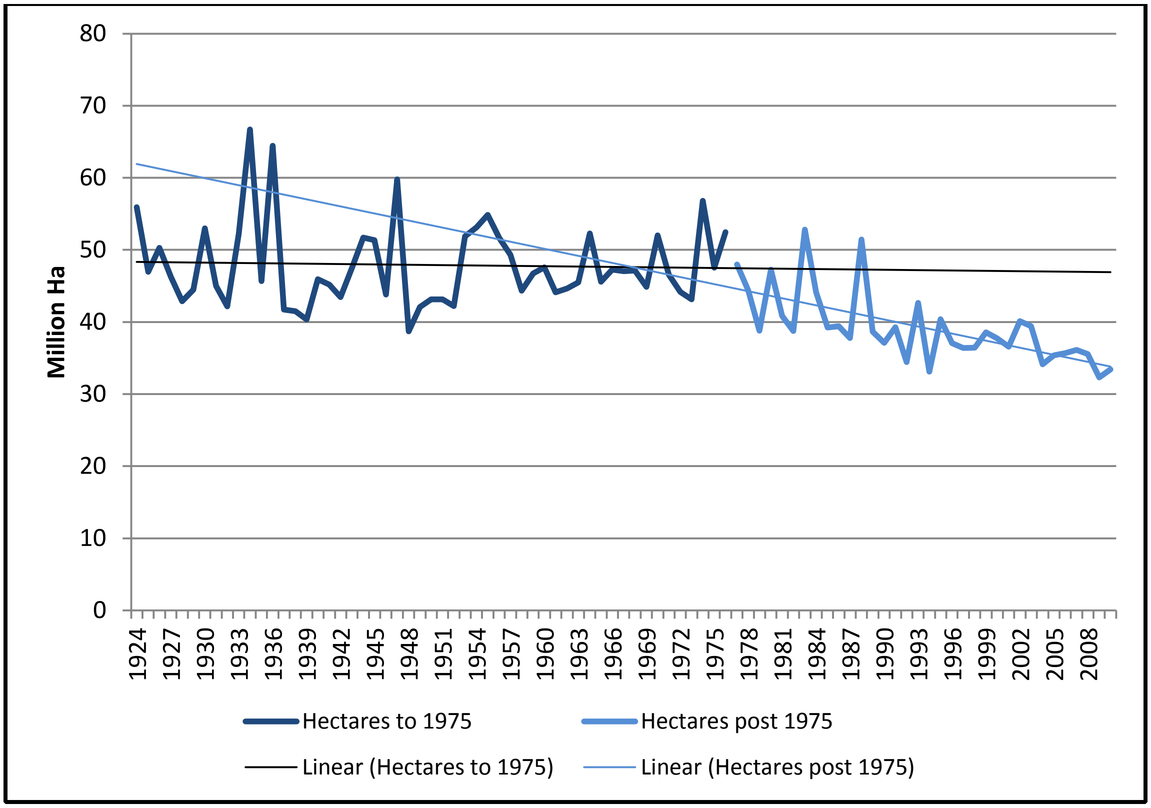

Figure 7. U.S. Demand for Livestock Feed

This drop in demand from the livestock sector due to changing consumption patterns is one of the reasons that there is a difference between what the models predict will happen for land demand and what is observed.

6.5 Summary

This work has found that indirect land use emissions calculated using the latest version of GTAP are much less than those calculated by IFPRI in 2011. There are two primary reasons for this, the first is that less land is required in the new GTAP, probably the result of higher yields on new cropland than was assumed by IFPRI, and the second is that less forest land is converted. As with any complex modeling system there are a number of other reasons that also contribute to the final results, including a better representation of the oilseed and biodiesel industries.

There is reason to believe that the indirect emissions could be even lower if GTAP was further enhanced to be able to more accurately reflect the availability of fallow land in the world and cropland pasture in more regions than just the United States and Brazil. The reduction in ILUC emissions could be significant with this enhancement.

The regionalization and crop specificity of yield response to price could also make a difference to the results, although it is more difficult to estimate the impact from these enhancements.

Finally, there are major shifts in diets and demand for meat in the developing world that is reducing the demand for land to produce animal feed. The ILUC models do not incorporate this factor but there are significant reductions in land demand in places like the United States that helps to explain the differences in projected land use from expanded biofuel production and the actual changes. These factors could only be properly included if the ILUC models were dynamic.

Other GTAP model enhancements that need to be considered include further tuning of the factor that selects the quantity of land converted from forest vs. pasture. This would also consider the regional restrictions that have effectively stopped forest land conversion in the EU, the United States and Canada.

Since GTAP only provides the quantity and types of land that are converted, information on the carbon contents of the converted land could be also be improved. Consideration should be given of the actual carbon loss (or gain) from putting cropland pasture and fallow land back into crop production. The importance of this factor increases as the GTAP model has better access to this land. Not all of the carbon stored in forests is lost when forests are harvested, some of the carbon is stored in the harvested wood products.

There has also been research that shows that the simple accounting for the impact of time on the emissions may not be the most appropriate approach that could be used. Alternative approaches could lead to lower emission estimates.

References

1. Laborde, D. *Assessing the Land Use Change Consequences of Eurpoean Biofuel Policies, Final Report*, International Food Policy Institue, ATLASS Consortium, Specific Contract No. S12.590403.
2. O'Connor, D., $(S\&T)^2$ Consultants, *Review of IFPRI Reports on Land Use Change From European Biofuel Policies*, prepared for European Biodiesel Board, July 31, 2011.
3. Wicke B, Verweij P, van Meijl H, van Vuuren DP, Faaij APC, *Indirect Land use Change: Review of Existing Models and Strategies for Mitigation*, Future Science, Biofuels, 3/1/2012, ppg 87-100.
4. Hertel, T., W. Tyner, and D. Birur, *The Global Impacts of Multinational Biofuels Mandates.* Energy Journal, 2010. 31(1): p. 75-100.
5. Hertel, T.W., S. Rose, and R. Tol, *Land Use in Computable General Equilibrium Models: An Overview*, in *Economic Analysis of Land Use in Global Climate Change Policy*, T.W. Hertel, S. Rose, and R. Tol, Editors. 2009, Routledge Press: UK.
6. Taheripour, F., et al., *Biofuels and Their By-Products: Global Economic and Environmental Implications.* Biomass and Bioenergy, 2010. **34**(3): p. 278-89.
7. Taheripour, F., T.W. Hertel, and W.E. Tyner, *Implications of biofuels mandates for the global livestock industry: a computable general equilibrium analysis.* Agricultural Economics, 2011. 42: p. 325–342.
8. Taheripour, F. and W.E. Tyner, *Incorporating Recent Land Use Change Data into Simulations of Biofuels Land Use Change.* Applied Sciences 2013. **3**: p. 14-38.
9. Taheripour, F. and W.E. Tyner, *Induced Land Use Emissions due to First and Second Generation Biofuels and Uncertainty in Land Use Emission Factors.* Economics Research International, 2013(Article ID 315787): p. 12.
10. Taheripour, F., et al., *Biofuels, cropland expansion, and the extensive margin.* Energy, Sustainability and Society, 2012. **2**(25).
11. Tyner, W.E., *Biofuels and Land Use Change.* Biofuels, 2012. **3**(3): p. 251-253.
12. Avetisyan, M., U. Baldos, and T. Hertel, *Development of the GTAP Version 7 land Use Data Base*, in *GTAP Research Memorandum No. 19*, 2010, Purdue University: West Lafayette, IN.
13. Horridge, M., *SplitCom - Programs to Disaggregate a GTAP Sector*, 2005, Centre of Policy Studies, Monash University, Melbourne, Australia.
14. Horridge, M., *GTAPAdjust - A Program to Balance or Adjust a GTAP Database*, 2011, Centre of Policy Studies, Monash University, Melbourne, Australia.
15. Laborde, D. and H. Valin, *Modeling Land-Use Changes in a Global CGE: Assessing the EU Biofuel Mandates with the MIRAGE-BioF Model.* Climate Change Economics, 2012. 3(3): p. 39.
16. Taheripour, F., et al., *Introducing Liquid Biofuels into the GTAP Database*, in *GTAP Research Memorandum No 11*, GTAP, Editor 2007, Purdue University: West Lafayette, IN.

17. Taheripour, F. and W.E. Tyner, *Introducing First and Second Generation Biofuels into GTAP Data Base version 7*, in *GTAP Research Memorandum No 21* 2011, Purdue University.
18. Brown, E., S. Kennedy, and K. Miranda, *Ethanol from Sugar Beets: A Process and Economic Analysis*, in *Worcester Polytechnic Institute*2010: Worcester, MA.
19. U.S. Department of Agriculture, *The Economic Feasibility of Ethanol Production from Sugar in the United States*, 2006: Washington, D.C.
20. Maung, T. and C. Gustafson, *The Economic Feasibility of Sugar Beet Biofuel Production in North Dakota*, 2009, Department of Agribusiness and Applied Economics, North Dakota State University, ND, USA.
21. Tyner, W.E., F. Taheripour, and A. Golub, *Calculation of Indirect Land Use Change (ILUC) Values for Low Carbon Fuel Standard (LCFS) Fuel Pathways, Interim Report to the California Air Resources Board*, 2011.
22. Dunn, J., Mueller, S., Kwon, H., and Wang, M., *Land use change and greenhouse gas emissions from corn and cellulosic ethanol*, Biotechnology for Biofuels, 2013, 6:51, htpp://www.biotechnologyforbiofuels.com/content/6/1/51.
23. Eurostat. Farmland: number of farms and areas by economic size of farm (ESU) and NUTS 2 regions. (ef_lu_ovcropesu) http://epp.eurostat.ec.europa.eu/portal/page/portal/agriculture/data/database# (accessed May 5, 2013).
24. Personal Communication. Devon Worth, Agriculture and AgriFood Canada. April 2013.
25. National Inventory Report 1990–2010: Greenhouse Gas Sources and Sinks in Canada. Environment Canada.

Appendix 1

The Use of Price Yield Elasticity to Model the Use of Idle Cropland

There is a large difference between the quantity of cropland in the GTAP model and the sum of all of the harvested areas. This idle cropland could be cropland pasture, fallow land, land in reserve programs, land that was planted but not harvested, etc. At the present time GTAP cannot access this land except for the cropland pasture land in the United States and Brazil. Unfortunately, adding these other land categories to the model is a time consuming process and was beyond the scope of this work.

Alternative approaches were considered to simulate the use of idle land. The use of idle land essentially increases the production of crops without increasing the cropland area since this land is already included in the cropland area. Thus there is no conversion of pasture or forest lands required to support this increased production. Conceptually this is the same as increasing the yield of crops from the cropland.

Modeling an increase in yield can be accomplished by changing the price yield elasticity factor in the GTAP model. This parameter already exists in the model and is set to a value of 0.25. There is evidence that this value is reasonable, at least for some crops. However, if we adjust this parameter higher we will increase the yield for those crops that have a higher price as a result of the biofuel shock and for those crops that have a lower price as a result of the biofuel shock the yield will decrease more with higher values of the elasticity with respect to price. Currently in GTAP the same value is applied to all crops and regions. Thus changing this parameter would appear not to be a very targeted approach to the use of idle land.

In practice, since the yield is a function of the elasticity factor and the change in price, the yield change will be different for each region and for each crop. For the rapeseed biodiesel shock using the base price yield elasticity factor of 0.25 produces yield changes for each crop and region as shown in the following table.

Region	Rapeseed	Soybeans	Palm	Other oilseeds	Coarse Grains	Wheat	Sorghum	Sugar	Other Agr	Rice	Cropland Pasture
	% Yield Change										
USA	2.331	0.013	0.084	0.044	0.041	0.084	0.044	0.068	0.063	0.048	0.110
EU27	2.681	0.248	0.025	0.170	0.320	0.235	0.320	0.259	0.279	0.172	0.031
BRAZIL	2.438	0.021	0.100	0.018	0.033	0.058	0.030	0.017	0.040	0.025	0.152
CAN	2.617	0.093	0.004	0.145	0.188	0.178	0.010	0.407	0.160	0.073	0.039
JAPAN	0.998	-0.026	0.010	0.016	0.022	0.040	-0.005	0.015	0.017	0.015	0.001
CHIHKG	0.422	0.231	0.256	0.108	0.031	0.029	0.031	0.022	0.033	0.023	0.005
INDIA	0.875	-0.138	0.009	-0.031	0.052	0.048	0.050	0.046	0.072	0.056	0.049
C_C_Amer	2.589	-0.002	0.064	0.028	0.061	0.089	0.060	0.064	0.090	0.053	-0.004
S_o_Amer	3.478	0.015	0.309	0.034	0.072	0.080	0.066	0.051	0.111	0.057	0.001
E_Asia	0.214	-0.212	0.071	-0.047	0.024	0.033	0.020	0.013	0.035	0.024	-0.011
Mala_Indo	0.693	0.040	0.264	0.102	0.046	0.061	-0.002	0.066	0.080	0.058	0.016
R_SE_Asia	0.782	-0.064	0.133	-0.023	0.056	0.022	0.056	0.039	0.072	0.044	0.000
R_S_Asia	0.680	0.129	0.016	0.045	0.038	0.030	0.038	0.031	0.045	0.024	0.011
Russia	1.263	-0.182	0.099	-0.056	0.035	0.059	0.035	0.032	0.039	0.032	0.004
Oth_CEE_CIS	1.365	0.088	0.070	0.072	0.084	0.076	0.083	0.067	0.089	0.051	0.016
Oth_Europe	0.479	0.006	0.059	-0.030	0.102	0.121	-0.013	0.093	0.129	-0.006	0.006
MEAS_NAfr	0.874	0.033	0.050	0.012	0.052	0.076	0.052	0.047	0.082	0.065	0.005
S_S_AFR	1.329	0.003	0.091	0.012	0.044	0.069	0.044	0.031	0.082	0.044	0.000
Oceania	2.894	0.052	0.056	0.116	0.111	0.107	0.112	0.104	0.111	0.089	0.000

The impact of the price yield elasticity is higher for rapeseed than it is for the other crops, as it is increased rapeseed production that the model is shocked for and the price of rapeseed must rise to satisfy this additional demand. Rapeseed prices in the EU are forecast to increase by more than 10%.

When the price yield elasticity factor is increased to 1.0, the yields do increase, but due to the higher production the price increase required to meet the additional demand is lowered. The two factors partially offset each other and the yield changes for rapeseed increase by a factor of less than two, in spite of a fourfold increase in the parameter. For the rapeseed biodiesel shock using the price yield elasticity factor of 1.0 produces yield changes for each crop and region as shown in the following table.

Region	Rapeseed	Soybeans	Palm	Other oilseeds	Coarse Grains	Wheat	Sorghum	Sugar	Other Agr	Rice	Cropland Pasture
	% Yield Change										
USA	3.988	-0.171	0.182	-0.061	0.003	0.081	0.010	0.020	0.028	0.003	0.065
EU27	4.676	0.103	0.052	0.236	0.615	0.443	0.609	0.495	0.524	0.324	0.055
BRAZIL	4.323	-0.190	0.197	-0.131	-0.037	0.021	-0.044	-0.071	-0.038	-0.073	-0.215
CAN	3.907	-0.040	0.006	0.266	0.400	0.339	-0.001	0.797	0.276	0.135	0.066
JAPAN	1.346	-0.122	-0.042	-0.056	0.004	0.031	-0.024	-0.005	-0.006	-0.006	-0.025
CHIHKG	0.527	0.200	0.740	0.187	0.017	0.003	0.017	-0.001	0.010	-0.006	-0.009
INDIA	0.692	-0.299	0.036	-0.184	0.074	0.063	0.071	0.063	0.105	0.067	0.073
C_C_Amer	3.622	-0.163	0.053	-0.053	0.028	0.104	0.027	0.030	0.080	0.023	-0.034
S_o_Amer	5.291	-0.233	0.794	-0.072	0.057	0.067	0.045	0.008	0.106	0.016	-0.027
E_Asia	0.158	-0.460	0.119	-0.279	0.000	0.001	-0.007	-0.014	0.005	-0.009	-0.080
Mala_Indo	1.053	-0.126	0.653	0.179	0.045	0.078	0.012	0.072	0.095	0.070	0.041
R_SE_Asia	1.172	-0.268	0.226	-0.220	0.052	0.029	0.053	0.005	0.057	0.019	-0.027
R_S_Asia	0.767	0.097	-0.037	-0.031	0.028	-0.013	0.026	-0.008	0.013	-0.018	0.007
Russia	2.261	-0.563	0.219	-0.377	-0.018	0.026	-0.017	-0.027	-0.009	-0.017	-0.046
Oth_CEE_CIS	2.190	-0.115	0.131	-0.030	0.057	0.053	0.055	0.034	0.073	0.026	-0.005
Oth_Europe	0.409	-0.186	0.080	-0.318	0.100	0.138	-0.082	0.052	0.146	-0.021	-0.016
MEAS_NAfr	0.960	-0.153	0.094	-0.158	0.006	0.056	0.006	-0.003	0.046	0.018	-0.032
S_S_AFR	2.017	-0.158	0.154	-0.120	0.027	0.070	0.026	0.017	0.087	0.025	-0.024
Oceania	4.775	-0.084	-0.055	0.154	0.157	0.139	0.158	0.105	0.137	0.102	-0.007

It is the difference in the yields between the two cases that we are really interested in and this data is shown in the following table. This table also includes a weighted average yield increase for each crop.

Region	Rapeseed	Soybeans	Palm	Other oilseeds	Coarse Grains	Wheat	Sorghum	Sugar	Other Agr	Rice	Cropland Pasture
	% Yield Change										
USA	1.66	-0.18	0.10	-0.11	-0.04	0.00	-0.03	-0.05	-0.03	-0.05	-0.04
EU27	1.99	-0.15	0.03	0.07	0.29	0.21	0.29	0.24	0.24	0.15	0.02
BRAZIL	1.88	-0.21	0.10	-0.15	-0.07	-0.04	-0.07	-0.09	-0.08	-0.10	-0.37
CAN	1.29	-0.13	0.00	0.12	0.21	0.16	-0.01	0.39	0.12	0.06	0.03
JAPAN	0.35	-0.10	-0.05	-0.07	-0.02	-0.01	-0.02	-0.02	-0.02	-0.02	-0.03
CHIHKG	0.10	-0.03	0.48	0.08	-0.01	-0.03	-0.01	-0.02	-0.02	-0.03	-0.01
INDIA	-0.18	-0.16	0.03	-0.15	0.02	0.01	0.02	0.02	0.03	0.01	0.02
C_C_Amer	1.03	-0.16	-0.01	-0.08	-0.03	0.02	-0.03	-0.03	-0.01	-0.03	-0.03
S_o_Amer	1.81	-0.25	0.49	-0.11	-0.02	-0.01	-0.02	-0.04	-0.01	-0.04	-0.03
E_Asia	-0.06	-0.25	0.05	-0.23	-0.02	-0.03	-0.03	-0.03	-0.03	-0.03	-0.07
Mala_Indo	0.36	-0.17	0.39	0.08	0.00	0.02	0.01	0.01	0.02	0.01	0.03
R_SE_Asia	0.39	-0.20	0.09	-0.20	0.00	0.01	0.00	-0.03	-0.01	-0.02	-0.03
R_S_Asia	0.09	-0.03	-0.05	-0.08	-0.01	-0.04	-0.01	-0.04	-0.03	-0.04	0.00
Russia	1.00	-0.38	0.12	-0.32	-0.05	-0.03	-0.05	-0.06	-0.05	-0.05	-0.05
Oth_CEE_CIS	0.83	-0.20	0.06	-0.10	-0.03	-0.02	-0.03	-0.03	-0.02	-0.03	-0.02
Oth_Europe	-0.07	-0.19	0.02	-0.29	0.00	0.02	-0.07	-0.04	0.02	-0.02	-0.02
MEAS_NAfr	0.09	-0.19	0.04	-0.17	-0.05	-0.02	-0.05	-0.05	-0.04	-0.05	-0.04
S_S_AFR	0.69	-0.16	0.06	-0.13	-0.02	0.00	-0.02	-0.01	0.00	-0.02	-0.02
Oceania	1.88	-0.14	-0.11	0.04	0.05	0.03	0.05	0.00	0.03	0.01	-0.01
Wt Avg	0.84	-0.18	0.25	-0.10	0.02	0.02	-0.01	-0.01	0.01	-0.02	-0.20

The difference in yield that results from a change in the price yield elasticity is most apparent in the rapeseed production. There is a smaller impact on palm production and a negative impact on soybeans and other oilseeds. The impact on the cereals and sugar crop is very small. There is a reduction in cropland pasture that is converted back to cropland.

The average increase in rapeseed yield between the price yield elasticity factor of 0.25 and 1.0 is 0.84%. The change in cropland area for each region between the 0.25 and the 1.0 price yield elasticity factor is shown in the following table.

	0.25	1.0	Change in Area	Percentage Change in Area
	hectares			
Rapeseed	27,881,250	27,647,673	233,577	-0.84%
Soybeans	91,113,946	91,126,920	-12,974	0.01%
Palm	12,303,659	12,288,832	14,828	-0.12%
Other oilseeds	80,495,350	80,520,823	-25,473	0.03%
Coarse Grains	269,571,964	269,528,707	43,257	-0.02%
Wheat	216,550,324	216,453,840	96,483	-0.04%
Sorghum	40,515,661	40,506,302	9,359	-0.02%
Sugar	25,619,468	25,614,090	5,378	-0.02%
Other Agr	451,393,485	451,144,445	249,040	-0.06%
Rice	150,455,527	150,479,979	-24,452	0.02%
Cropland Pasture	48,483,515	48,634,127	-150,612	0.31%
Total	1,414,384,149	1,413,945,739	438,411	0.03%

The percentage change in areas for all of the other crops is much smaller than it is for the rapeseed crop. Thus the approach of using the price yield parameter is actually quite targeted to the crop that is being shocked.

Excluding the cropland pasture area change, the cropland increase resulting from the rapeseed biodiesel shock is reduced by almost 600,000 hectares when the price yield elasticity factor is increased from 0.25 to 1.0. Furthermore about 40% of the impact is found in the rapeseed crop.

This model result can be compared to what has actually happened to fallow land in the EU between 2004 (the GTAP base year) and 2010 (the last year for which data is available). During this period the fallow land decreased by 1.1 million hectares, while rapeseed area increased and wheat area stayed steady.

Increasing the price yield elasticity factor has reduced the land change requirements of the rapeseed biodiesel shock. The reduction in cropland requirement of almost 600,000 ha is about half of the reduction in fallow land that has been experienced in the 2004 to 2006 period and is less than 10% of the fallow land available in the EU.

Ideally GTAP would be expanded in the future so that some portion of the idle land could be accessed by the model to meet the demand for increased crop production but until that is done the price yield elasticity factor can be used to get an approximation of the impact of using idle land to meet the demand for increased production.