A decomposition approach to assess ILUC results from global modeling efforts

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Contributed Paper at the IATRC Public Trade Policy Research and Analysis Symposium

"Climate Change in World Agriculture: Mitigation, Adaptation, Trade and Food Security"

June 27 - 29, 2010

Universität Hohenheim, Stuttgart, Germany

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Version: 21st of June, 2010

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1. Introduction

For several years biofuel production has been supported by policy in many countries. A key motivation for such support has been the argument that the carbon sequestration in the feedstock grown to produce the biofuel would offset the release of CO2 when the biofuel is used. This argument has been criticised in Searchinger et al. 2008 (Science, Vol 319, pp 1238-40) for its neglect of indirect land use changes (ILUC). Relying on the FAPRI modelling system Searchinger et al. showed at the example of additional ethanol production from maize in the US that the ILUC effects triggered in third countries would involve a considerable release of carbon into the atmosphere such that the payback period for such ethanol production would be 167 years.

This result stimulated critics of its underlying assumptions, most importantly that the net yield effect would be approximately zero, and various studies of ILUC from biofuel scenarios using other modelling systems, including IMPACT (IFPRI), AGLINK (OECD), GLOBIOM (IIASA), DART (IfW), LEITAP (LEI), and GTAP (Purdue), that yield different results. Differences in modelling results may arise from differences in

- Scenario definition, including the amount, type and region of additional feedstock demand
- Yield responsiveness, including increased yields from additional input use on given areas and yield changes from crops expanding into other areas
- Demand responsiveness, incorporated in functional forms and parameters of demand systems
- Trade responsiveness that differs between Armington style, Takayama-Judge or pooled net trade models
- Treatment of by-products
- Simulation year
- Regional and commodity disaggregation
- Presence of global economy feed back loops (GE vs. PE modelling)

One approach to shed light on these key drivers is to undertake sensitivity analyses relying on a single model like in Keeney and Hertel (2009, AJAE, Vol. 91, pp. 895-909). While this permits to focus on some determinants it also neglects other potentially important causes of different results, including the model structure. This paper applies a decomposition approach to detailed modelling results from several systems to identify the contributions of yield, demand and trade contributions to the overall ILUC effects. For this purpose we will express the simulated quantity changes in terms of their area contributions to ILUC in different regions and for common crop aggregates. Normalising by the size of the shock in terms of additional energy from biofuels leads to a comparative assessment. It shows, for example that lower ILUC effects from GTAP compared to FAPRI can be traced to higher yield and demand responsiveness in selected examples. Thus we may supplement the findings from sensitivity analyses with in a given modelling system with a comparison across systems.

This model comparison goes back to an initiative originating in a common OECD-JRC-EEA workshop in Paris, January 2009[1]. A synthesis from the studies commissioned by the JRC is currently under preparation (EU Commission 2010b), with a particular emphasis on policy relevant results and key underlying model characteristics. In contrast to the pending JRC report this paper directly uses the detailed modelling results to form comparable aggregates in terms of regions and

1 http://re.jrc.ec.europa.eu/biof/html/luc_bioenergy_policies_paris.htm

products. This required to focus on a smaller set of models and scenarios that is promising for a more selective comparison.

2. Overview on the systems and scenarios compared

An overview on the 3 scenarios and 5 modelling systems is given in Table 1.

Table 1: Scenarios and modelling systems used in the comparison

	USmaize
GTAP	+ 1 mtoe of ethanol based on US maize
FAPRI	+ 15.8 mtoe of ethanol based on US maize
IMPACT	+ 0.21 mtoe of ethanol based on US maize
GLOBIOM	+ 2.6 mtoe of ethanol based on US maize
	EUwheat
AGLINK	+ 11.8 mtoe of ethanol, + 12.9 mtoe of biodiesel
GTAP	+ 1 mtoe of ethanol based on EU wheat
FAPRI	+ 0.13 mtoe of ethanol based on EU wheat
IMPACT	+ 0.19 mtoe of ethanol based on EU wheat
GLOBIOM	+ 2.6 mtoe of ethanol based on EU wheat
	EUrape
AGLINK	+ 7.3 mtoe of ethanol, + 18.6 mtoe of biodiesel
GTAP	+ 1 mtoe of biodiesel based on EU oilseeds
FAPRI	+ 0.22 mtoe of biodiesel based on EU rape
GLOBIOM	+ 3.9 mtoe of biodiesel based on EU rape

The modelling systems are widely known but should be briefly characterised here nonetheless.

The Global Trade Analysis Project (GTAP) model is a static CGE model with the Armington approach reflecting imperfect substitutability of products across regions. A modified version of the GTAP-BIO model (Birur, Hertel, Tyner 2008) is used in the analysis. It permits substitution among various fuels and explicitly considers DDGS and oil meals as by-products that may substitute for coarse grains and oil seeds according to an elasticity of substitution. In terms of land use it considers 19 regions each of which possibly divided into several Agro-Ecological Zones (AEZ) in order to better reflect the rigidities imposed by natural conditions. Crops were aggregated to 6 products (wheat, rice, coarse grains, oil fruits, sugar plants, others) that also provided the common denominator for this analysis. The simulations were for year 2001, using the version 6 GTAP database.

The FAPRI modelling system (version operated at CARD, Iowa) is a set of recursive dynamic partial equilibrium models covering the (15) major crops (from an US perspective) and some 50 regions, depending on the product. The system is well known for its econometric underpinnings, but calibration approaches are also used where needed. Bio-ethanol and bio-diesel are explicitly represented together with related policy instruments. DDG may displace other feed according to displacement rates, adoption rates and inclusion rates specific for animal types. Oils meals are a standard feed input linked to the oilseeds sector and animal markets. The trade representation (explicit policy instruments or price transmission elasticities) varies according to the importance of regions. Whereas the EU scenarios are based on the 2009 model version and run to year 2023 the US ethanol scenario is from 2008 (Hayes et al. 2009), running to year 2022. In this context the most important updates of the 2009 model version refer to the yield specification and a more complete DDGS acknowledgement in non-US regions (see Annex 2).

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) from IFPRI has a stronger focus on developing country issues and water scarcity. There are 20 crops and about 115 market regions (mostly countries[2]), each of which possibly divided into several water catchment areas on the supply side. Irrigated and rainfed production is distinguished. The model has a strong focus on long run projections and technology improvements whereas trade policies are represented in simplified form (net trade model with uniform world market price). The "other" demand component was exogenously shifted in these scenarios to mimick the shock of additional feedstock demand for bio-fuel production, but by-products are not represented. Simulations were for the years 2010-2015.

The AGLINK-COSIMO[3] model is a joint OECD-FAO dynamic, partial equilibrium modelling tool with a strong tradition of projections and scenario analysis. About 10 crops have been used (knowing that separate coarse grains or oilseeds would require aggregation anyway) and a medium level regional breakdown (20 regions). Similar to the FAPRI model many equations are econometrically estimated and there is a detailed coverage of bioethanol including displacement rates for ruminants and non-ruminants (OECD 2008). This paper could not rely on the detailed model results from the marginal simulations for the above mentioned JRC report. Instead it benefitted from selective access to scenario results prepared at the IPTS, Seville for other purposes. As a consequence the AGLINK scenarios represent two versions of EU biofuel policies that involve both additional ethanol and bio-diesel demand. The scenario with a higher share of ethanol is attributed to the "EUwheat" group, but this is clearly not a marginal shock of one feedstock only. Results are presented for the year 2020.

The Global Biomass Optimization Model (GLOBIOM) is a global recursive dynamic partial equilibrium model covering agricultural and forestry sectors as well as dedicated biomass plants (Havlik et al. 2010). It is a huge linear programming model maximizing the sum of producer and consumer surplus to find the market equilibrium subject to resource constraints in the Takayama-Judge tradition. This analysis used 28 market region and 18 crops. Supply side modelling is based on up to 200 000 'simulation units', but for the simulations presented here, an aggregation to about 6000 supply regions was used, defined from an overlay of country borders, soil, slope, and altitude information. For each of these there are 4 management options permitting an endogenous choice of yields. Bio-diesel and ethanol from oilseeds and cereals are included, with displacement ratios for DDGS non-specific to animal types, as the version used here only included the animal sector in aggregate form. Simulations results are given for 2020. The size of the shock has been chosen somewhat larger than in the marginal calculations commissioned for the JRC to trigger some changes in management options.

This brief summary already reveals marked differences in model structure which renders the comparison difficult but potentially also very illuminating. Different model structures also imply that a direct comparison on the level of model parameters is difficult if not hopeless, given that functional forms, determinants and even the type of equations strongly differ. As a consequence the

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2 The regional breakdown did not permit to identify EU27 exactly. Instead the region shown in the tables also includes the Western Balkan, Belarus, Norway, and Switzerland.

3 The results of any analysis based on the use of the AGLINK model by parties outside the OECD are not endorsed by the Secretariat, and the Secretariat cannot be held responsible for them. It is therefore inappropriate for outside users to suggest or to infer that these results or interpretations based on them can in any way be attributed to the OECD Secretariat or to the Member countries of the Organisation.

comparison is made on the level of model outputs, using the knowledge on model structure just to guide the interpretation.

3. Decomposition of total land use changes

The focus of this model comparison is on the indirect land use changes triggered in particular scenarios. To consistently decompose and understand the ILUC contributions on the supply and demand side we start from the basic condition that changes in net trade of product i in a region r (Δnet_{ri}) follow from changes in supply (sup_{ri}) and demand (dem_{ri}):

Dnet_

$$\Delta net_{ri} = \Delta sup_{ri} - \Delta dem_{ri} \tag{1}$$

The change in demand will be further decomposed into the change in demand for processing to biofuels and for other uses. Supply changes are decomposed into an area ($\Delta land_{ri}$) and a crop yield component ($\Delta cyld_{ri}$) that could be done in various ways:

Dsup_

$$\begin{aligned} \Delta sup_{ri} &= sup^1_{ri} - sup^0_{ri} = cyld^1_{ri} land^1_{ri} - cyld^0_{ri} land^0_{ri} \\ &= cyld^1_{ri}\left(land^1_{ri} - land^0_{ri}\right) + land^0_{ri}\left(cyld^1_{ri} - cyld^0_{ri}\right) \\ &= cyld^1_{ri} \Delta land_{ri} + land^0_{ri} \Delta cyld_{ri} \\ &= cyld^0_{ri}\left(land^1_{ri} - land^0_{ri}\right) + land^1_{ri}\left(cyld^1_{ri} - cyld^0_{ri}\right) \\ &= cyld^0_{ri} \Delta land_{ri} + land^1_{ri} \Delta cyld_{ri} \end{aligned} \tag{2}$$

We arbitrarily assume that areas changes first and then yields change, thus picking the last decomposition, to be substituted into eq. (1).

ALUC_

$$\begin{aligned} &\Delta net_{ri} = \left(cyld^0_{ri} \Delta land_{ri} + land^1_{ri} \Delta cyld_{ri}\right) - \Delta dem_{ri} \\ &\Leftrightarrow \Delta land_{ri} = \frac{\Delta net_{ri}}{cyld^0_{ri}} + \frac{\Delta dem_{ri}}{cyld^0_{ri}} - land^1_{ri} \frac{\Delta cyld_{ri}}{cyld^0_{ri}} \end{aligned} \tag{3}$$

Basically we have decomposed the (absolute) land use change into three components

1. Land use change for additional net exports
2. Land use change for additional domestic demand (for domestically produced or imported quantities)
3. Avoided land use change through yield increases

Dividing by the final[4] land use gives the following decomposition of *relative* land use change that may be compared across regions or products:

RLUC_
$$\frac{\Delta land_{ri}}{land_{ri}^{1}} = \frac{\Delta net_{ri}}{land_{ri}^{1} cyld_{ri}^{0}} + \frac{\Delta dem_{ri}}{land_{ri}^{1} cyld_{ri}^{0}} - \frac{\Delta cyld_{ri}}{cyld_{ri}^{0}} \quad (4)$$

Weighting these relative land use changes with the final area shares of each product i and summing up gives the total relative land use change in region r. Similarly we may weight the regional land use changes with the final area shares in a larger region to get the total relative land use change in that larger region, for example in the world. To give an overview we will only present results for the commodity where the shock originates and for total cropland use and regions EU, US, and the whole world.

4. Ethanol from US maize

Comparing results of different modelling systems is not only hampered by multiple differences in model structure. In addition the database and reference situation has not been harmonised:

Table 2: Baseline data on coarse grains production in the US

	2000			Last year		
	yield [t/ha]	area [1000ha]	production [1000t]	yield [t/ha]	area [1000ha]	production [1000t]
FAPRI	7.7	35488	272890	10.8	42059	452942
IMPACT	8.1	31757	255690	10.8	36380	393013
GTAP (year 2001)	7.5	36343	272408			
GLOBIOM	6.5	39987	260394	8.7	46521	404042

The ‘year 2000’ columns illustrate the well known fact that data from different databases almost never match exactly. Possible explanations are the raw data (for FAPRI P&S USDA database, for others[5] mainly FAO), and in this (typical) case the definition of the product ‘coarse grains’.

The last column introduces the baseline changes to the final simulation year as an additional source for differences. This is 2022 for FAPRI, 2015 for IMPACT, 2020 for GLOBIOM, and again 2001 for GTAP (hence no new entry for GTAP). Evidently the baseline may cause significant additional differences. FAPRI and IMPACT give similar growth rates but the levels differ. The GTAP base year (and simulation year) area data for 2001 happen to be quite close to IMPACT whereas GLOBIOM gives the highest areas.

Areas and yields are important components for absolute and relative LUC results (see equations (3) and (4) above). Evidently, higher yields result in lower LUC for a given shock to feedstock demand in terms of tons. As this has a systematic impact we have ‘normalised’ some results below such that they reflect yield levels of year 2020 (using the average of FAPRI and IMPACT yields growth for GTAP). Other baseline differences have not been corrected, assuming that their effect is less

[4] Dividing by the initial land gives an alternative but less intuitive expression.

[5] IMPACT also uses an average of 1999, 2000, 2001 of FAOSTAT data to generate a base year of 2000

systematic. Furthermore it is clear that a proper correction would require to rerun the models from a common database which is infeasible.

The decomposition of LUC according to (3) shall be introduced at the example of the GTAP results[6] on the US maize scenario. LUC results for the 19 GTAP regions of this analysis have been aggregated using the land shares, except for the US and the EU27.

Production of an additional 1 mtoe of ethanol requires 4.6 million tons of coarse grains. Dividing by the yield of 7.5 tons per ha (Table 2) gives a corresponding land demand of 609900 ha (Table 3, first line). However, a large part of that land demand is saved by a decline in coarse grain demand for non-biofuel uses, in particular due to the replacement of coarse grains in feed with DDGS. Other, smaller parts of the additional land demand from coarse grains are compensated through a reduction of net exports and via an increase in crop yields. The remaining net effect (left hand side of (3)) would be an expansion of US coarse grains area by 252300 ha. The following rows of Table 3 show that this area expansion is mainly at the expense of wheat, oil crops and 'other' crops area such that total cropland area in the US only increases by 68000 ha in this scenario.

Reduced net exports from the US of all commodities require additional net exports from other regions, mostly outside of the EU27 that is only mildly affected. The increasing net exports from the rest-of-the-world aggregate correspond to 67700 ha giving a world aggregate increase in land demand for coarse grains of 49100 ha. This is nonzero, in spite of a zero change in global net trade, because the savings in high yielding US land require a greater area in the rest-of-the-world aggregate to match the same quantity. Only in the case of oil crops there is a negative net trade effect on global land demand because replacing US net exports with net exports from elsewhere saves some land as US yields of aggregate oil crops are below the global average[7]. The final cropland expansion in other world regions (+83600 ha) is not simply equal to the change in net exports divided by yields because a part of this immediate land demand (+228000 ha) is compensated by declining consumption (-85100 ha) and increasing yields (-59300 ha), as crop prices are usually increasing. The global total effect is an increase of cropland of 164600 ha.

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[6] Production and areas were directly given from GTAP in physical units. As production for the base year 2001 was based on FAO, we supplemented the demand quantities and net trade also from FAO. The percentage changes from GTAP for total absorption have been applied to these base year demand data to obtain demand changes and then net trade changes in physical units.

[7] Compare the discussion of the impacts of the Armington assumption on global LUC effects in Golub 2009.

Table 3 Global land use change [1000 ha] from the GTAP US maize scenario decomposed into components

		Additional land demand (>0) or land savings (<0) due to changes in…				
		biofuel feedstocks	other domestic use	net exports	crop yields	sum total
USA	Coarse grains	609.9	-304.0	-23.2	-30.4	252.3
	Wheat	0.0	-2.0	-49.7	-5.0	-56.8
	Oil crops	0.0	2.9	-58.6	-6.2	-61.9
	Rice	0.0	-0.2	-2.3	0.0	-2.5
	Sugar crops	0.0	-0.1	0.0	-0.6	-0.8
	Other crops	0.0	-17.6	-32.6	-12.2	-62.4
	Total	**609.9**	**-321.0**	**-166.4**	**-54.5**	**68.0**
EU27	**Total**	**0.0**	**-6.1**	**20.9**	**-1.9**	**13.0**
Rest of the world	Coarse grains	0.0	-34.5	67.7	-9.4	23.7
	Wheat	0.0	-21.6	47.4	-10.5	15.3
	Oil crops	0.0	5.8	42.2	-10.9	37.1
	Rice	0.0	-3.7	3.6	-8.3	-8.4
	Sugar crops	0.0	-1.7	0.0	-1.0	-2.7
	Other crops	0.0	-29.4	67.1	-19.0	18.7
	Total	**0.0**	**-85.1**	**228.0**	**-59.3**	**83.6**
World	Coarse grains	609.9	-345.7	49.1	-40.1	273.2
	Wheat	0.0	-24.5	3.0	-16.2	-37.6
	Oil crops	0.0	10.8	-11.6	-17.6	-18.4
	Rice	0.0	-3.9	1.5	-8.3	-10.7
	Sugar crops	0.0	-1.8	0.0	-1.7	-3.4
	Other crops	0.0	-47.2	40.5	-31.8	-38.5
	Total	**609.9**	**-412.2**	**82.5**	**-115.7**	**164.6**

In the comparison of different modelling systems we have to adjust for the size of the additional feedstock demand in each model's version of this scenario. A common standardisation is to a shock of 1 million tons of oil equivalents (mtoe) which happened to be just the shock applied in the GTAP scenario, such that there is no visible effect for the GTAP results whereas the other results in the middle section are divided by the additional ethanol production as given in Table 1.

Furthermore the simulation results are given for different years such that the yields levels differ systematically for this reason (see the discussion of Table 2 above). To normalise all results to the yields in year 2020 they have been multiplied with the ratio of yields in the simulation year and in year 2020. In this case this has no effect on the GLOBIOM results, because there are already given for year 2020. Nonetheless the shock in terms of ha is highest for GLOBIOM, because it assumes the lowest coarse grain yields in 2020 (see Table 2)[8]. For GTAP the acknowledgement of yield growth results in an estimated 'GTAP yield' of 10.3 t/ha for 2020 that compares better to the other models than the original 7.5 t/ha for 2001.

[8] Some additional homogeneity could have been achieved by normalising with a common set of yields. However this would be inconsistent with the model's own results and has been avoided therefore. In the GTAP case we applied the average of FAPRI and IMPACT yield growth as GTAP only offered results for a single base year.

Table 4: Land use change [1000 ha] in the US under the US maize scenario decomposed into components according to several modelling systems

	Additional land demand (>0) or land savings (<0) due to changes in…				
	biofuel feedstocks	other domestic use	net exports	crop yields	sum total
	without scaling or normalisation				
GTAP	609.9	-304.0	-23.2	-30.4	252.3
FAPRI	6257.7	-54.3	-2017.1	-44.6	4141.8
IMPACT	88.5	-5.1	-60.0	-9.3	14.0
GLOBIOM	1389.4	-331.8	-14.4	-10.1	1033.1
	scaled to a shock of 1 mtoe				
GTAP	609.9	-304.0	-23.2	-30.4	252.3
FAPRI	395.8	-3.4	-127.6	-2.8	261.9
IMPACT	412.7	-24.0	-280.0	-43.6	65.1
GLOBIOM	544.9	-130.1	-5.6	-4.0	405.1
	scaled to a shock of 1 mtoe and normalised to year 2020 yields				
GTAP	445.8	-222.2	-16.9	-22.3	184.4
FAPRI	404.5	-3.6	-130.2	-2.9	267.8
IMPACT	392.2	-22.9	-266.1	-41.4	61.9
GLOBIOM	544.9	-130.1	-5.6	-4.0	405.1

Focussing now on the scaled and normalised results in the bottom part of Table 4 we may note that the response of other demand strongly differs among the modelling systems, most strikingly between GTAP and FAPRI. Whereas declining demand makes up for about 50% of the initial shock according to GTAP this is barely 1% according to FAPRI. This is surprising as the FAPRI analysis also explicitly incorporates additional production of DGS that may be expected to displace some coarse grains in feed. Instead the largest part of the additional DGS is exported (Hayes et al. 2009, WP 09-WP 487, p. 28), possibly because the FAPRI baseline already involves DGS quantities (43000 t) that hit upon the maximum inclusion rates assumed in the analysis. Another explanation is that the energy price shock triggering the additional ethanol production in the FAPRI scenario also hits the livestock sector and therefore dampens feed demand. The IMPACT results also feature quite low demand effects in the US but this is to be expected here as DGS is not accounted for in IMPACT.

The largest net trade impacts are given from IMPACT which corresponds to a non-spatial trade specification with pooled net trade balanced globally via world prices that link to domestic prices with percentage wedges for policies and marketing margins (Rosegrant et al. 2008, p. 14). Interestingly the smallest net trade impacts, about 2% of the IMPACT projection, are given by GLOBIOM, relying on a spatial Takayama-Judge approach, and not from GTAP, that has some trade stickiness built into the Armington parameters. The (non-spatial) trade specification of FAPRI varies according to the region and may include an explicit policy representation or price transmission elasticities. In the case of coarse grains this gives a sizable net trade effect about midway between GTAP and IMPACT.

The land saving contributions from increasing coarse grain yields vary less among the models than the consumption and net trade effects but still the largest contribution (from IMPACT) exceeds the smallest (from FAPRI) by a factor of 14. The total coarse grains area expansion depends on the land saving contributions from lower consumption and net exports as well as yield increases. On these land saving contributions IMPACT and GLOBIOM have often obtained the largest or smallest values such that they also mark the outer ends of the observed range of results.

However, additional cropland for coarse grains partly substitutes for competing crops in the US according to all modelling systems (see the appendix). As a consequence the total crop land expansion in the US is only a quarter (FAPRI, GTAP) to about half (IMPACT, GLOBIOM) of the expansion of coarse grains area in the US (Table 5). If consumption ("other domestic use" in the table) and yield effects of other crops do not make strong contributions to saving land, this means that the ILUC impacts on other countries via less net exports from the US are reinforced by the conversion of some land to coarse grains.

With the EU27 (including some non EU regions for IMPACT, footnote 2) not strongly responding, a large part of the adjustment has to occur in the Rest-of-the-world region according to all models. These trade related ILUC components are largest according to FAPRI and IMPACT, in line with the relative large decline of net exports in the US. It may be observed in Table 5 (bottom part for the World) that this shift of production from the US to other regions on balance significantly increases cropland demand as yields are often higher in the US than elsewhere. According to both models there would be a significant 'saving' of LUC through a decline in consumption that may corresponds to 517100 ha of cropland (IMPACT). According to both GTAP and GLOBIOM a larger part of the shock would be absorbed by reduced consumption in the US.

Some particularities hold for the yield effects according to GLOBIOM and IMPACT. They are saving a lot of land according to IMPACT, in all regions. GLOBIOM on the contrary shows a significant land *using* yield effect in the Rest-of-the-world. This may be traced to a 7% drop in oilseed yields in the 'other Europe' region, triggered when the area of oilseeds is strongly expanding according to GLOBIOM. While the size and direction of these yield effects is thus a contentious issue, they may be seen to be critical for the overall results, as GLOBIOM also turns out to give the highest overall LUC effects in the US maize scenario.

Table 5: Global land use change [1000 ha] under the US maize scenario according to several modelling systems (per 1 mtoe and normalised to year 2020 yields)

	Additional land demand (>0) or land savings (<0) due to changes in…				
	biofuel feedstocks	other domestic use	net exports	crop yields	sum total
			USA, coarse grains		
GTAP	445.8	-222.2	-16.9	-22.3	184.4
FAPRI	404.5	-3.6	-130.2	-2.9	267.8
IMPACT	392.2	-22.9	-266.1	-41.4	61.9
GLOBIOM	544.9	-130.1	-5.6	-4.0	405.1
			USA, total		
GTAP	445.8	-235.8	-132.9	-41.6	35.5
FAPRI	404.5	-64.0	-273.1	11.4	78.7
IMPACT	392.2	-24.1	-287.3	-51.4	29.5
GLOBIOM	544.9	-356.1	-39.0	13.7	163.4
			EU27, total		
GTAP	0.0	-5.3	18.1	-1.6	11.2
FAPRI	-1.4	-15.7	33.0	-6.0	9.9
IMPACT	0.0	48.1	-0.2	-34.1	13.8
GLOBIOM	2.6	34.1	33.3	-23.9	46.1
			Rest-of-the-world, total		
GTAP	0.0	-63.6	176.1	-46.5	65.9
FAPRI	-4.4	-233.4	490.2	-17.5	234.9
IMPACT	0.0	-517.1	911.9	-339.5	55.4
GLOBIOM	-3.5	-23.2	-11.6	268.5	230.3
			World, total		
GTAP	457.0	-310.0	61.1	-89.9	118.3
FAPRI	398.4	-312.7	249.0	-12.1	322.5
IMPACT	387.4	-498.2	635.5	-425.8	98.8
GLOBIOM	543.9	-345.2	-17.3	258.3	439.8

Given the importance of yield effects different methodologies have been used to separate these into 'extensification effects' when crops are expanding into areas formerly covered with other crops or non-cropland on the one hand, and 'intensification effects' when more inputs are applied on the same area. The 'extensification effect' is usually reducing yields, if a crop is expanding into less suited areas. However it may also be positive if a crop is displacing other crops on high quality land because it has become more profitable. Furthermore we have yield increasing 'extensification effects' for those crops that are displaced. To acknowledge the uncertainty on the sign of these effects we prefer to call them 'aggregation yield effects' to distinguish them from 'pure yield effects', i.e. yield changes on the same areas. The distinction is given in Table 6 for GTAP, IMPACT and GLOBIOM.

Table 6: Yield changes for coarse grains in %, disaggregated into aggregation and pure yield effects according to GTAP, IMPACT, GLOBIOM and scaled to a shock of 1 mtoe

	Aggregation	Pure yield effect	Total
	USA		
GTAP	-0.013	0.096	0.083
IMPACT	-0.062	0.103	0.041
GLOBIOM	0.003	0.000	0.003
	Canada		
GTAP	-0.017	0.010	-0.007
IMPACT	-0.023	0.040	0.017
GLOBIOM	0.000	0.000	0.000
	EU27		
GTAP	-0.004	0.004	0.001
IMPACT	-0.033	0.055	0.022
GLOBIOM	-0.028	0.041	0.014
	Other Europe / former USSR		
GTAP	0.002	0.004	0.006
IMPACT	-0.019	0.033	0.014
GLOBIOM	-0.012	0.037	0.025
	Africa/Near East		
GTAP	-0.007	0.003	-0.003
IMPACT	-0.015	0.045	0.029
GLOBIOM	-0.006	0.003	-0.003
	Asia/Pacific		
GTAP	0.003	0.005	0.008
IMPACT	-0.016	0.030	0.014
GLOBIOM	-0.342	0.465	0.123
	Latin America		
GTAP	0.002	0.010	0.011
IMPACT	-0.037	0.072	0.035
GLOBIOM	0.017	0.003	0.020
	World		
GTAP	-0.003	0.017	0.014
IMPACT	-0.026	0.051	0.025
GLOBIOM	-0.093	0.131	0.037

The pure yield effects according to GTAP are those effects that may be calculated from the change in the ratio of output prices to land substituting inputs, as the own substitution elasticity of land has been initialised to give a particular intensification effect (Hertel, Keeney 2009, p. 897). In addition yields change in GTAP according to the transformation elasticity steering the land mobility across various crops and according to an assumed yield drop of 33% if cropland expands into non-cropland. The latter two effects together are the aggregation or 'extensification' effects in GTAP.

Identifying the pure yield effects from IMPACT relies on an entropy based procedure to estimate the yields on the (old) baseline crop area versus the yields on the change (positive or negative) in area under each (new) scenario[9]. Whereas this distinction is not a standard model output at the

[9] Basically the IFPRI/IMPACT results allowed to decompose the production under each scenario (prd(scen)) as follows: yld(scen,Area0)*Area0+yld(scen,dArea)*dArea=prd(scen), where yld(scen,Area0) is the new yield on the old area (Area0) and yld(scen,dArea) is the yield on the expanded area (dArea). See Tokgoz, Msangi 2010.

moment, it may be calculated in a supplementary, 'post-model' estimation. Furthermore the availability of 281 'food producing units' permits to isolate the effects on average yields in a country due to regional reallocation.

The separation of yield effects in GLOBIOM rests on the very fine regional disaggregation of market regions into 'simulation units' (s) on the supply side. The 'aggregation yield effect' from a change in the area allocation is

$$AggregationYldEffect_{ri} = \frac{\sum_{s\in S_r} cyld^0_{rsi} land^1_{rsi}}{\sum_{s\in S_r} land^1_{rsi}} - \frac{\sum_{s\in S_r} cyld^0_{rsi} land^0_{rsi}}{\sum_{s\in S_r} land^0_{rsi}},$$

whereas the 'pure yield effect' is the complement to the full change in yields:

$$PureYldEffect_{ri} = \frac{\sum_{s\in S_r} cyld^1_{rsi} land^1_{rsi}}{\sum_{s\in S_r} land^1_{rsi}} - \frac{\sum_{s\in S_r} cyld^0_{rsi} land^1_{rsi}}{\sum_{s\in S_r} land^1_{rsi}}$$

and $land_{rsi}$ ($cyld_{rsi}$) is the land use (crop yield) of product i in the supply region s that belongs to market region r (with index 0 for the baseline and index 1 for a scenario).

The results from the yield decomposition in Table 6 show some similarities and many differences. They agree that the pure yield effects are usually dominating such that there is some positive yield response in the US maize scenarios. Furthermore the yield effects are mostly very small which even applies to the highest yield growth in Asia/Pacific of 0.12% according to GLOBIOM.

IMPACT gives the most uniform effects across regions with the aggregation effects roundabout half as large as the pure yield effects. This is presumably both due to fairly uniform price effects and due to the entropy based estimation (with prior belief in mild negative aggregation effects in all regions). GTAP is more diverse in the strength and sign of the aggregation effects. While usually clearly dominated by the pure yield effects, the aggregation effects are expected to result in declining average yields of coarse grains in Africa, interestingly in line with GLOBIOM. In general the variation of yield effects is largest for GLOBIOM. Furthermore the pure yield effects and aggregation effects are often quite high but tend to cancel such that the net yield effects are in a similar order of magnitude as those from GTAP or IMPACT. Exceptions are the high yield effects in the Asia/Pacific region and very low yield effects in the US. This variability of GLOBIOM may be due to somewhat 'jumpy' behaviour of the underlying LP approach, even though the large number of supply regions should help to 'average out' such jumpiness.

5. Ethanol from EU wheat

The EU wheat scenario comparison is partly influenced by certain differences in the baseline. Due to the importance of the yields in the calculation of LUC results, these have been normalised to reflect the year 2020 situation. As a consequence the GTAP yield for year 2001 (4.9 t/ha) has been adjusted for the likely yield growth up to 2020 such that the normalised yields are broadly in line for EU27. GLOBIOM gives the highest yields and also the smallest wheat area for the EU27 in 2020, whereas the area data for the 2000 were quite well in line across models.

For GLOBIOM we also show the results for the region EU north (Scandinavia, UK and Ireland) because this is the region where the additional wheat production for ethanol is likely to originate. In the IMPACT analysis, by contrast, all EU regions increase their wheat production very uniformly in relative terms (about +0.6%). This sub regional distribution will turn out important.

Table 7: Baseline data on wheat production in the EU

	2000			Last year		
	yield [t/ha]	area [1000ha]	production [1000t]	yield* [t/ha]	area [1000ha]	production [1000t]
AGLINK	4.9	26595	131454	6.3	23776	149258
FAPRI	5.0	26471	131697	5.8	26435	157744
IMPACT	4.7	27861	131934	5.6	26986	145538
GTAP (initial = final = 2001)	4.9	25269	122565	5.8	25269	122565
GLOBIOM	5.1	25269	129177	6.9	18624	128160
GLOBIOM EU north	*7.9*	*2894*	*22779*	*11.7*	*3106*	*36209*

Note: Yield* data are normalised to year 2020, even if last year differed from 2020

The main results for the EU wheat scenario are given in scaled and normalised form again (Table 8). The first particularity to be explained is the extremely small direct LUC impact of the additional feedstock use of wheat according to AGLINK. This is due to the fact that the AGLINK scenario shown involves a higher EU demand for bio-fuels than without supporting policies, but that this is not only met by additional production of wheat, but also production of coarse grains, sugar beet, oilseeds and imports of these feedstocks and the biofuels themselves. Thus it will be more interesting to look at the total results for AGLINK than to the contributions of wheat alone.

Nonetheless there are marked differences in terms of the areas shown corresponding to the shocks with IMPACT and GLOBIOM marking the outer ends of the range and GTAP and FAPRI fairly close together. These differences are not due to the conversion coefficients from wheat to ethanol as we applied the GLOBIOM coefficient (0.189 toe/t) also to the IMPACT results. Instead the low area requirement according to GLOBIOM (450000 ha/mtoe) is due to the fact that the additional feedstock production is expected to occur only in the ‘EU north’ region where yields are expected to attain high levels (compare Table 7), compared to IMPACT (6.9 t/ha) or recent CAPRI projections (8.1 t/ha) for the same sub-region. The same effect is working in the other direction in the IMPACT results. Here it has been assumed that the demand shock is evenly shared among the 14 EU sub-regions of the IMPACT model which implies that a large part of the shock in terms of tons is converted into hectares using rather low yields.

The reduction of other wheat demand appears to be quite uniform apart from AGLINK and FAPRI, but it may be assessed better relative to the total shock. According to GTAP, FAPRI, IMPACT, and GLOBIOM the drop in consumption would save 11%, 49%, 9%, and 33% respectively of the area required by the initial shock. These shares were 50%, 1%, 6%, and 24% for the same models under the US maize scenario. While FAPRI had thus the lowest relative demand response in the US maize scenario and GTAP the highest, these positions have been exactly reversed in the EU wheat scenario. For GTAP we see that a large part of the demand reduction has been attributed to coarse grains, presumably because the GTAP ‘tree’ of substitution relationships treats DDGS from wheat and maize alike and causes strong substitution with coarse grains. Furthermore a larger share of coarse grains compared to wheat will be fed such that the responsiveness of wheat demand will be higher. The high demand responsiveness of wheat according to the FAPRI results is somewhat surprising against the US maize results, even though it may be seen that wheat is partly replaced by coarse grains. It may be due to the model update from 2008 to 2009 but it may also result from the high baseline consumption of DDGS in the US maize scenario in connection with maximum inclusion limits for DDGS, as argued above.

Table 8: Global land use change [1000 ha] under the EU wheat scenario according to several modelling systems (per 1 mtoe and normalised to year 2020 yields)

	Additional land demand (>0) or land savings (<0) due to changes in…				
	biofuel feedstocks	other domestic use	net exports	crop yields	sum total
			EU27, wheat		
AGLINK	81.4	-5.3	-30.4	-1.4	44.3
GTAP	901.2	-100.1	-151.8	15.4	664.7
FAPRI	997.3	-489.0	-89.9	-27.1	391.2
IMPACT	1226.3	-105.6	-1030.1	-30.2	60.3
GLOBIOM	449.6	-150.2	-11.1	6.1	294.4
			EU27, coarse grains		
AGLINK	75.0	-54.2	-10.3	-1.5	9.0
GTAP	0.0	-495.2	20.0	93.9	-381.3
FAPRI	0.0	182.6	-1.2	3.1	184.5
IMPACT	0.0	43.4	-20.2	-14.2	8.9
GLOBIOM	0.0	-94.1	-101.1	-17.2	-212.5
			EU27, total		
AGLINK	520.5	-78.0	-369.0	-3.4	70.2
GTAP	901.2	-617.6	-216.8	213.6	280.4
FAPRI	952.3	-290.3	-115.5	-24.0	522.5
IMPACT	1226.3	-69.4	-1054.6	-51.6	50.7
GLOBIOM	438.0	-274.5	-135.8	18.3	46.1
			USA, total		
AGLINK	0.0	107.9	-90.3	-1.7	15.9
GTAP	0.0	93.5	6.2	-58.3	41.4
FAPRI	0.0	0.9	8.9	-0.4	9.3
IMPACT	0.0	-17.8	92.8	-43.9	31.1
GLOBIOM	0.0	24.8	119.7	-7.0	137.6
			Rest-of-the-world, total		
AGLINK	0.0	-404.8	639.2	-45.6	188.8
GTAP	0.0	-54.4	510.9	-153.1	303.3
FAPRI	0.0	-168.5	213.8	-38.2	7.1
IMPACT	0.0	-829.5	1429.3	-456.3	143.4
GLOBIOM	-1.4	199.1	-205.7	145.6	137.6
			World, total		
AGLINK	520.5	-374.9	180.0	-50.7	275.0
GTAP	884.9	-505.0	316.1	-26.8	669.3
FAPRI	950.1	-454.9	106.9	-62.5	539.6
IMPACT	1189.2	-925.0	515.9	-554.0	226.1
GLOBIOM	436.6	-50.5	-221.8	156.9	321.2

Moving to the trade results some characteristics from the US maize scenario reappear. GTAP and FAPRI are in the centre of the projections shown whereas the outer bounds are marked by IMPACT and GLOBIOM. It has been argued above that the pooled trade representation with proportional price wedges of IMPACT may contribute to high trade effects. In this scenario the mechanical allocation of the demand shock in IMPACT has also caused some additional land 'savings' from intra EU gains from trade: High yield producers like France, Germany, UK and Ireland would see a stronger increase in production than most of the low yielding regions of EU27. Nonetheless these intra EU effects are unlikely to be responsible for more than 25% of the total net trade effect projected by IMPACT. GLOBIOM, on the contrary, gives only a small net trade response of wheat, mainly because strong substitution among crops redistributes the shock from wheat to the whole crop sector as shown for coarse grains.

The yield effects are small in general, as under the US maize scenarios, but with some surprising differences. In particular the projection of a non-negligible drop of wheat yields in the EU (additional land demand of +15400 ha, due to extensification effects) from GTAP (less markedly from GLOBIOM) is remarkable, but still possible in theory. The sum total effect on wheat area is smallest for IMPACT, because a large part of the shock is exported to other regions, whereas the other models are closer to each other.

Moving to the block of total area effects we see first of all a large increase in the total shock due to additional feedstock demand for AGLINK even though this is still smaller than for the other models except GLOBIOM. The particularity of the AGLINK scenario is that non-negligible parts of the demand shock are absorbed through additional imports of biofuels (4.7/11.8 = 39% for ethanol and 1.6/12.9 = 12% for bio-diesel). The ethanol is mainly from sugar cane in Brazil and the corresponding areas reduce the 'land savings' in the Rest-of-the-world results of AGLINK. In other words the land savings in this region would have been larger than 404800 ha if the EU had not increased its net imports of ethanol. Note that the increased feedstock demand for cane is *not* explicitly shown in the AGLINK results (in column 'biofuel feedstocks'). For FAPRI and GLOBIOM there are some reductions in the use of other feedstocks such that the 'total' area demand from additional feedstocks is smaller than the 'wheat only' results.

The total 'other demand' effects are close to the sum of wheat and coarse grains for all models whereas the land savings from net trade include important contributions from other products for AGLINK and GTAP. In the case of AGLINK this is mainly from additional imports of oilseeds and oils for biodiesel consumption that also increases in this AGLINK scenario.

Moving to the yield effects in the EU27, GTAP stands out with quite significant aggregation or extensification effects (see Table 9) that apply to all crops. In spite of a strong reduction in domestic demand GTAP predicts an additional cropland expansion of 280000 ha that is only exceeded by FAPRI. Still the FAPRI result need not be considered 'extreme'. Basically it results from all compensating effects being projected weak. GLOBIOM gives a low cropland expansion in the EU because the producing region is expected to have very high yields. Finally both AGLINK and IMPACT show only small additional cropland demand in the EU because a large part of the adjustment need is exported to other countries.

This adjustment is usually projected to occur in the rest-of-the-world region with consumption declining and yields and area use increasing. The drop in consumption is highest for IMPACT (in line with high net trade impacts) and smallest for GTAP. From GLOBIOM however, we have an *increase* in consumption that is due to regional shifts in animal production and due to the rigid definition of feed ratios in the GLOBIOM version used. Land savings from increased yields in the rest-of-the-world region are predicted to be small according to AGLINK and FAPRI. By contrast they are larger according to GTAP and IMPACT, also compared to their projections from the US maize scenario. GLOBIOM shows a strong land *using* yield effect that may be traced to negative aggregation effects for wheat is Australia, where wheat area is expanding considerably (8%).

The total effects in the rest-of-the-world region and for the whole world follow from horizontal or vertical aggregation in Table 8. 1 mtoe from biofuels triggers a cropland expansion in the range of of 0.2-0.7 million ha according to the models compared.

Table 9: Yield changes for wheat in % of the final yield, disaggregated into aggregation and pure yield effects according to GTAP, FAPRI, IMPACT, GLOBIOM and scaled to a shock of 1 mtoe

	Aggregation	Pure yield effect	Total
	USA		
GTAP	0.010	0.077	0.088
FAPRI	-0.002	0.008	0.006
IMPACT	-0.214	0.333	0.119
GLOBIOM	-0.002	0.000	-0.002
	Canada		
GTAP	-0.117	0.072	-0.045
FAPRI	-0.001	0.005	0.005
IMPACT	-0.250	0.389	0.139
GLOBIOM	-0.044	0.000	-0.044
	EU27		
GTAP	-0.296	0.225	-0.071
FAPRI	-0.037	0.137	0.100
IMPACT	-0.232	0.348	0.116
GLOBIOM	-0.103	0.072	-0.031
	Other Europe / former USSR		
GTAP	0.021	0.035	0.056
FAPRI	0.000	0.009	0.009
IMPACT	-0.142	0.269	0.127
GLOBIOM	-0.089	0.073	-0.016
	Africa/Near East		
GTAP	0.042	0.029	0.071
FAPRI	0.000	0.008	0.008
IMPACT	-0.159	0.296	0.137
GLOBIOM	0.005	0.048	0.054
	Asia/Pacific		
GTAP	0.005	0.022	0.027
FAPRI	-0.002	0.047	0.045
IMPACT	-0.155	0.313	0.158
GLOBIOM	-1.007	0.829	-0.178
	Latin America		
GTAP	-0.007	0.046	0.039
FAPRI	-0.001	0.009	0.008
IMPACT	-0.249	0.367	0.118
GLOBIOM	-0.077	0.002	-0.075
	World		
GTAP	-0.032	0.060	0.029
FAPRI	-0.006	0.039	0.034
IMPACT	-0.176	0.312	0.136
GLOBIOM	-0.416	0.343	-0.073

The results from the yield decomposition in Table 9 are even more heterogeneous than from the US maize scenario but some characteristics reappear. GTAP and IMPACT agree that any yield effect on the level of world regions are probably small and not exceeding 0.16%. As before we see that GTAP is more variable in the decomposition, for example with strong negative aggregation effects in those regions where wheat area is also expanding sizeably (EU27 and Canada). As a consequence GTAP gives negative total yield effects for those regions. By contrast the IMPACT results are more uniform with negative aggregation effects around 60% of the pure yield effect.

For this scenario we may also show the aggregation and pure yield effects from FAPRI. The FAPRI yield specification has been updated in 2009 to explicitly include negative extensification effects according to a set of elasticities with respect to the relative area changes. These have been estimated for the US and applied to other countries after scaling for differences in land availability (Carriquiry et al. 2009). The resulting (negative) aggregation effects are the weakest among the models compared here and total yield responsiveness is also low. However, in the EU27 we observe that the net effects on wheat yields from IMPACT and FAPRI in the EU are very close to each other. GLOBIOM tends to give strong aggregation effects that often result in negative overall yield effects. This may not be unrealistic, as GLOBIOM has the finest regional disaggregation among the three. However it appears that some peculiarity is affecting the Asia/Pacific region (that may be further traced to Australia) such that sizeable yield effects are projected for this region.

6. Bio-diesel from EU rape

The key product for the EU rape scenario is the aggregate of all 'oil crops'. To permit comparisons across regions and models this aggregate product has been converted into 'oil equivalents' using the oil yields of underlying oil crops in leading producer regions from FAOSTAT (year 2001). For GTAP we replaced the year 2001 production data in tons of oil fruits (with region specific composition) with production in terms of oil based on FAO data for 2001. In this way market balances of temperate zone oilseeds and tropical palm oil could be combined making sure that the aggregate balance hold on the global level if the balances for all components hold. In AGLINK we had to consolidate the given vegetable oil balance with the aggregate balance for oilseeds to obtain market balances measured in oil and area yields measured in tons of oil per ha. With yields normalised to year 2020 the baseline data were broadly comparable in terms of yields but with some differences in the areas (Table 10).

Table 10: Baseline data on oil crops production in the EU

	2000			Last year		
	yield	area	production	yield*	area	production
AGLINK	0.64	8278	5296	1.01	9406	9482
FAPRI	0.81	8148	6587	1.08	11326	12567
GTAP (initial = final = 2001)	0.78	12863	10062	0.95	12863	10062
GLOBIOM	0.88	6586	5778	1.15	11580	13272

Note: Yield* data are normalised to year 2020, even if last year differed from 2020

A particularity of GTAP is that olives are part of the oil crops whereas they are neglected in the other systems. This explains why GTAP gives rather high areas for 2001 (= last year for GTAP).

Table 11 shows that the initial shock corresponds to an area of about 0.8 – 0.9 million ha per 1 mtoe, except for AGLINK, because this involves a package with additional ethanol production as well (but less so than under the AGLINK version of the 'EU wheat' scenario). This is a fairly homogeneous picture, as it should be, because all differences can be only due to different crop yields and conversion coefficients.

FAPRI and GTAP show a large part of the additional demand for processing to bio-diesel being matched by less processing (consumption) for food purposes. This diversion effect is far weaker according to AGLINK and GLOBIOM, for different reasons. In AGLINK a large part of the adjustment occurs via additional imports of vegetable oil that is visible in strong land savings (0.5 million ha) for the EU from reduced net exports. Note that such imports of vegetable oils are booked as an increase in the total demand for oil crops in the consolidated oils – oil crops balance of AGLINK whereas they are not directly affecting the oil crops balance of the other systems. In GLOBIOM, finally, the scenario definition included not only that the additional bio-diesel should be produced from EU rape oil but also that this rape oil is produced in the EU, such that the additional demand for rape oil is fully translated into an additional production of EU rape seed. The additional oil meal is assumed to displace coarse grains and soya in EU feed rations, but soya production is declining to negligible quantities in the EU according to GLOBIOM. As a consequence the land savings from less soya demand of the EU will only affect non EU regions.

The greatest part of the area expansion of EU oil crops is compensated by reduced areas under cereals according to FAPRI and GLOBIOM whereas GTAP would yield an expansion of total EU cropland of 0.1 million hectares.

Table 11: Global land use change [1000 ha] under the EU rape scenario according to several modelling systems (per 1 mtoe and normalised to year 2020 yields)

	Additional land demand (>0) or land savings (<0) due to changes in…				
	biofuel feedstocks	other domestic use	net exports	crop yields	sum total
			EU27, oil crops		
AGLINK	560.8	-27.6	-513.7	0.7	20.1
GTAP	803.0	-504.6	-88.4	-14.7	195.3
FAPRI	937.4	-651.3	-45.6	0.0	240.5
GLOBIOM	920.5	-39.1	-193.7	42.3	730.0
			EU27, wheat		
AGLINK	59.3	-0.2	-29.7	-2.1	27.3
GTAP	0.0	-22.8	-13.9	-8.2	-44.8
FAPRI	-5.9	-61.4	-23.6	-10.7	-101.5
GLOBIOM	0.0	-99.2	-140.5	-89.4	-329.0
			EU27, coarse grains		
AGLINK	53.0	-40.1	-8.2	-1.2	3.6
GTAP	0.0	25.3	-9.4	-14.7	1.3
FAPRI	0.8	-78.3	-20.6	-5.7	-103.8
GLOBIOM	0.0	-210.9	-111.9	-75.3	-398.2
			EU27, total		
AGLINK	678.6	-68.0	-551.5	-2.8	56.4
GTAP	803.0	-510.4	-136.1	-50.7	105.8
FAPRI	932.3	-787.2	-89.5	-16.4	39.2
GLOBIOM	920.4	-361.9	-452.1	-76.3	30.1
			USA, total		
AGLINK	0.0	105.5	-94.0	-1.1	10.4
GTAP	0.0	-6.7	56.4	-38.7	11.0
FAPRI	0.0	-109.9	166.5	-9.8	46.8
GLOBIOM	0.0	36.8	102.0	-2.6	136.2
			Rest-of-the-world, total		
AGLINK	0.0	-676.0	907.7	-55.3	176.4
GTAP	0.0	92.4	173.8	-109.7	156.5
FAPRI	0.8	428.8	16.9	-99.4	347.2
GLOBIOM	-1.7	62.6	414.3	-108.6	366.9
			World, total		
AGLINK	678.6	-638.5	262.1	-59.2	243.1
GTAP	803.3	-431.0	99.3	-194.1	277.6
FAPRI	944.5	-476.7	93.0	-125.4	435.4
GLOBIOM	918.7	-262.5	64.2	-187.4	533.3

Impacts on LUC in the US would be moderate according to all models. According to AGLINK there would be reduced net exports and additional domestic use. It has to be explained that this additional domestic use is partly vegetable oil used to produce bio-diesel for the EU. In this way the US reinforces the adjustment need in the rest-of-the-world-region. By contrast the US would reduce domestic consumption according to FAPRI, most importantly in terms of coarse grains, because additional availability of oil meals on global markets triggers some displacement of maize (and additional EU imports of bio-diesel precluded in the scenario definition). Both GTAP and GLOBIOM would see some additional net exports from the US, but GLOBIOM also gives more domestic demand (mainly in terms of coarse grains).

LUC impacts would be significant for the rest-of the-world. AGLINK shows the largest net trade effects but most of the immediate land demand would be compensated by reduced consumption.

According to the other models additional domestic demand would reinforce the expansion of cropland. In FAPRI and GTAP this is because additional processing of oilseeds to replace EU demand of vegetable oils is increasing the domestic demand contribution to land expansion (whereas the traded vegetable oil reduces domestic demand for oilseeds in the EU). In GLOBIOM the additional domestic demand is both for oil crops and for coarse grains, as in the US and somewhat surprisingly. Increasing yields help to reduce the area requirements according to all models.

On the global level the differences are moderate with GLOBIOM giving the largest LUC impacts. This is mainly because of a small part of the land demand for additional feed stocks being compensated by the drop in domestic demand in GLOBIOM whereas the yield effects are fairly uniform. The fact that there is a lot of agreement on global LUC effects while models disagree in the regional and product specific results also reflects the complexity and multiple adjustment possibilities in the bio-diesel sector. Trade in the fuel itself was constrained by the scenario design except for AGLINK. But there is trade in the crops and in the vegetable oil (of different types) such that the detailed solutions may differ while still agreeing on the bottom line in terms of less domestic consumption, some yield effects, and global cropland expansion.

As before we may show the decomposition of the yield effects from GTAP and GLOBIOM (Table 12)

Table 12: Yield changes for oil crops in % of the final yield, disaggregated into aggregation and pure yield effects according to GTAP and GLOBIOM and scaled to a shock of 1 mtoe

	Aggregation	Pure yield effect	Total
	USA		
GTAP	0.026	0.028	0.054
GLOBIOM	0.005	0.000	0.004
	Canada		
GTAP	-0.028	0.020	-0.008
GLOBIOM	-0.039	0.000	-0.039
	EU27		
GTAP	0.015	0.121	0.136
GLOBIOM	-0.362	0.296	-0.066
	Other Europe / former USSR		
GTAP	0.006	0.027	0.033
GLOBIOM	-0.153	0.002	-0.151
	Africa/Near East		
GTAP	-0.004	0.020	0.016
GLOBIOM	-0.003	0.000	-0.003
	Asia/Pacific		
GTAP	0.009	0.019	0.028
GLOBIOM	0.000	0.005	0.005
	Latin America		
GTAP	0.020	0.037	0.057
GLOBIOM	-0.019	0.002	-0.017
	World		
GTAP	0.011	0.031	0.043
GLOBIOM	-0.047	0.028	-0.019

Negative aggregation effects may be seen to dominate frequently according to GLOBIOM whereas GTAP gives this result only for Canada.

7. Summary and conclusions

Various types of biofuel scenarios have often been investigated using different modelling systems. This paper applies an approach to decompose and organise the total LUC impacts from selected scenarios following from AGLINK, GTAP, FAPRI, IMPACT and GLOBIOM. These models strongly differ in their methodology, region and product breakdown and in the detailed scenario implementation. The global results for total cropland are repeated for convenience in Table 13.

Table 13: Global land use change under three biofuel scenarios according to several modelling systems (per 1 mtoe and normalised to year 2020 yields)

	Additional land demand (>0) or land savings (<0) due to changes in…						
	biofuel feedstocks	other domestic use	net exports	crop yields	sum total		
			US maize				
GTAP	457 =100%	-68%	13%	-20%	26%	=	118
FAPRI	398 =100%	-79%	63%	-3%	81%	=	323
IMPACT	387 =100%	-129%	164%	-110%	26%	=	99
GLOBIOM	544 =100%	-63%	-3%	47%	81%	=	440
			EU wheat				
AGLINK	521 =100%	-72%	35%	-10%	53%	=	275
GTAP	885 =100%	-57%	36%	-3%	76%	=	669
FAPRI	950 =100%	-48%	11%	-7%	57%	=	540
IMPACT	1189 =100%	-78%	43%	-47%	19%	=	226
GLOBIOM	437 =100%	-12%	-51%	36%	74%	=	321
			EU Rape				
AGLINK	679 =100%	-94%	39%	-9%	36%	=	243
GTAP	803 =100%	-54%	12%	-24%	35%	=	278
FAPRI	944 =100%	-50%	10%	-13%	46%	=	435
GLOBIOM	919 =100%	-29%	7%	-20%	58%	=	533

Discarding the smallest and largest value from each group it appears that ethanol from US maize has the smallest global area impacts (0.1-0.3 million ha), followed by bio-diesel from EU rape (0.3-0.4 million ha) and finally EU wheat (0.3-0.5 million ha). Depending on where these LUC occur and what other land uses are replaced this may easily offset any gains from the sequestration of carbon while growing the feedstocks. However, a full analysis also requires inclusion of fertiliser use and the animal sector as well as some consideration of the timing for the release of the carbon.

However, this further analysis of the full emission impacts is not the topic of this paper. This comparison tried to infer some characteristics of the model behaviour from a detailed analysis of model results. These characteristics are easier to note when they stand out and reappear.

IMPACT apparently gives quite marked global reallocation effects as well as a strong yield and demand effects. The high trade responsiveness has been attributed to the pooled trade representation with proportional price wedges, the latter presumably the more important point. If net exports of relatively high yielding regions are reduced and compensated via additional net exports other regions, the net effect will be an increase in global land demand. In this case there are thus negative gains from trade in terms of hectares. Nonetheless in the two scenarios included here high yield and demand responsiveness prevailed and resulted in fairly low cropland expansion at the global level. It should be noted that the strong demand response is *not* due to overly optimistic assumptions on by-product displacement effects, because these were entirely ignored by IMPACT. Correcting for these would therefore tend to increase the demand reductions even further.

GLOBIOM had usually quite large LUC effects, at least when expressed relative to the initial area requirements. This could be traced to two aspects. First there were often large negative yield effects attributable to crops expanding into less suitable regions. Second domestic demand showed a rather low responsiveness, in particular in the EU scenarios. The strength and regional prevalence of the aggregation effects on yields might be considered surprising but these results are difficult to compare with the other systems as GLOBIOM is the only one to derive these in a bottom-up approach from detailed variation in biophysical parameters. Despite its methodological particularities (LP) and extensive coverage of forestry, GLOBIOM was usually not far away from the other models.

AGLINK was only covered here with two scenarios which are just differing in their mix of the additional bio-ethanol and bio-diesel production. Hence any characteristics identified here may be more typical for this basic scenario than for the modelling system. However, it may be noted that both the response of global demand and of net exports was relatively high compared to the initial shock in terms of additional land demand to produce the required feedstocks. In terms of the climate effects this may appear reassuring but the domestic demand reduction may be worrisome.

FAPRI and GTAP have often been in the centre of the range of model results obtained, and not very far apart in the overall results. In the US maize scenarios the differences were largest, with GTAP and IMPACT agreeing that the global cropland expansion would amount to about 0.1 million hectares.

This coincidence may be surprising given that the methodology of a fairly standardised GTAP approach applied to all regions and products is in strong contrast with the flexible partial equilibrium approach of the FAPRI models with many particularities in terms of product and regions. It is even impossible to identify systematic differences in the model results when looking a the key components, domestic demand, trade, and yields where sometimes GTAP and sometimes FAPRI had higher impacts, at least at the global level and aggregated over all products.

This is not to say that the decomposition approach cannot identify key model characteristics. It has not been possible so far, for example, to assess the components of total yield effects (aggregation or pure yield effects) from FAPRI. Also, the available information on the DDGS contribution to demand changes in the cereal scenarios has been too diverse to be compared even though this would be a highly interesting plausibility check. Furthermore there are many regional and product specific aspects that could be identified but do not lend themselves to a generalising synthesis.

The detailed comparison on the basis of single contributions helps to assess which of these may be considered ‘high’ or ‘low’. However, it has to be acknowledged that many relevant models have been excluded from this comparison. Both DART and CAPRI are currently improved to better prepare them for similar analyses of LUC on the global level. LEITAP and MIRAGE have been discarded for lack of time, just to mention a few other well known modelling systems that have already addressed bio-fuel scenarios. It would be interesting, for example, to see whether other CGE models using the GTAP database arrive at similar results as those from the GTAP-BIO version included already in the comparison.

8. Acknowledgements

This research was made possible through financial support of the German Marshall Fund (GMF) of the United States and from the Clean Air Task Force, Boston, USA. Organisational support from the Joint Research Centre, Institute for Energy (JRC-IE), Renewable Energy in Ispra, Italy has been extremely helpful. The corresponding author thanks Thomas Heckelei and Arnim Kuhn for their contributions in the setting off phase of this research.

9. References

Carriquiry M., Dong F., Du X., El-Obeid A., Fabiosa J., Chavez E., and S. Pan (2009): World Market Impacts of High Biofuel Use in the EU, Technical report to the German Marshall Fund of the United States (GMF) and the European Commission - Joint Research Centre (EU-JRC), December 2009.

EU Commission (2010a): Biofuel Modelling (AGLINK, ESIM, CAPRI). Internal report of the IPTS Agro-Economic Modelling Platform.

EU Commission (2010b): Indirect Land Use Change from increased biofuels demand, Comparison of models and results for marginal biofuels production from different feedstocks. Authors: Robert Edwards, Declan Mulligan and Luisa Marelli, Draft report edited by Luisa Marelli. EU Commission, JRC, IES, Ispra.

Golub A. (2009): Calculation of the Effects of Increased Demand for Biofuel Feedstock on the World Agricultural Markets: Intermediate Results and Characteristics of the GTAP model, Final Report to the JRC, December 10, 2009.

Havlík P., Schneider U.A., Schmid E., Böttcher H., Fritz S., Skalský R., Aoki K., de Cara S., Kindermann G., Kraxner F., Leduc S., McCallum I., Mosnier A., Sauer T., and M. Obersteiner (2010): Global land-use implications of first and second generation biofuel targets, Energy Policy, Special Issue: Sustainablity of Biofuels [doi:10.1016/j.enpol.2010.03.030]

Hayes D., Babcock B.A., Fabiosa J.F., Tokgoz S., Elobeid A., Tun-Hsiang Y., Dong F., Hart C.E., Chavez E., Pan S., Carriquiry M.A, and J. Dumortier (2009): Biofuels: Potential Production Capacity, Effects on Grain and Livestock Sectors, and Implications for Food Prices and Consumers. Journal of Agricultural and Applied Economics, August 2009, vol. 41 no. 2, pp. 465-491.

Hertel T. W., Tyner W.E., and D. K. Birur (2010). "Global Impacts of Biofuels." Energy Journal 31(1): 75-100.

Hertel, T., Golub A., Jones A., O'Hare M., Plevin R., Kammen D. (2010): Global Land Use and Greenhouse Gas Emissions Impacts of U.S. Maize Ethanol: The Role of Market-Mediated Responses. BioScience. Supporting online material is available at https://www.gtap.agecon.purdue.edu/resources/download/4606.pdf .

Keeney R, Hertel TW. (2009): Indirect land use impacts of US biofuels policies: The Importance of acreage, yield and bilateral trade responses. American Journal of Agricultural Economics 91: 895–909.

Msangi S., Tokgoz S. (2010): The effects of increased biofuel feedstock demand on world agricultural markets: Analysis with the IMPACT model, Presentation on the Workshop on "Effects of increased demand for biofuel feedstocks on world agricultural markets and areas", 10-11 February 2010, JRC, Ispra, Italy.

OECD (2008). Biofuel Support Policies: An Economic Assessment, Paris 2008

Rosegrant M.W, Ringler C., Msangi S., Sulser T.B., Zhu T., Cline S.A. (2008) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description, International Food Policy Research Institute, Washington, D.C., June 2008

Searchinger T., Heimlich R., Hougthon R., Dong F., Elobeid A., Fabiosa J., et al. (2008): Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land-Use Change. Science 29 February 2008: Vol. 319. no. 5867, pp. 1238 - 1240. [DOI: 10.1126/science.1151861].

10. Annex 1 Complete results

The following tables give a complete set of results for all scenarios. Note that the 'Total' includes 'Rice', 'Sugar crops', and 'Other crops', even though these are not shown separately.

Table A1: Complete LUC results [1000 ha] under the US maize scenario according to several modelling systems (per 1 mtoe and normalised to year 2020 yields)

			Additional land demand (>0) or land savings (<0) due to changes in…				
			biofuel feedstocks	other domestic use	net exports	crop yields	sum total
EU27	Wheat	FAPRI	0.0	0.5	5.1	-2.4	3.1
		IMPACT	0.0	30.8	-30.5	-6.3	-6.0
		GTAP	0.0	-0.7	4.5	-0.5	3.2
		GLOBIOM	0.0	11.3	4.5	-16.2	-0.4
	Coarse grains	FAPRI	0.0	2.4	5.4	-3.5	4.3
		IMPACT	0.0	16.9	37.6	-21.9	32.6
		GTAP	0.0	-6.2	3.9	-0.2	-2.5
		GLOBIOM	0.0	18.1	31.2	-9.2	40.2
	Oil crops	FAPRI	-1.4	-17.9	22.4	0.0	3.0
		IMPACT	0.0	-4.5	4.4	-0.1	-0.1
		GTAP	0.0	1.8	4.0	-0.4	5.4
		GLOBIOM	2.8	4.0	-2.2	-0.1	4.4
	Total	FAPRI	-1.4	-15.7	33.0	-6.0	9.9
		IMPACT	0.0	48.1	-0.2	-34.1	13.8
		GTAP	0.0	-5.3	18.1	-1.6	11.2
		GLOBIOM	2.6	34.1	33.3	-23.9	46.1
USA	Wheat	FAPRI	0.0	6.7	-38.5	0.5	-31.3
		IMPACT	0.0	1.2	-0.9	-4.8	-4.5
		GTAP	0.0	-1.6	-41.3	-4.2	-47.2
		GLOBIOM	0.0	-1.3	0.0	0.2	-1.1
	Coarse grains	FAPRI	404.5	-3.6	-130.2	-2.9	267.8
		IMPACT	392.2	-22.9	-266.1	-41.4	61.9
		GTAP	445.8	-222.2	-16.9	-22.3	184.4
		GLOBIOM	544.9	-130.1	-5.6	-4.0	405.1
	Oil crops	FAPRI	0.0	-64.2	-97.6	13.6	-148.1
		IMPACT	0.0	-8.7	-8.5	-2.5	-19.7
		GTAP	0.0	2.3	-46.9	-5.0	-49.6
		GLOBIOM	0.0	-224.5	-17.7	19.7	-222.5
	Total	FAPRI	404.5	-64.0	-273.1	11.4	78.7
		IMPACT	392.2	-24.1	-287.3	-51.4	29.5
		GTAP	445.8	-235.8	-132.9	-41.6	35.5
		GLOBIOM	544.9	-356.1	-39.0	13.7	163.4
Rest-of-the-world	Wheat	FAPRI	-0.1	-7.5	29.6	0.0	22.1
		IMPACT	0.0	-4.0	40.6	-46.3	-9.7
		GTAP	0.0	-17.4	38.2	-8.5	12.3
		GLOBIOM	0.0	-3.8	-9.0	535.9	523.1
	Coarse grains	FAPRI	-1.2	-74.4	313.6	0.0	237.9
		IMPACT	0.0	-412.7	759.6	-174.3	172.7
		GTAP	0.0	-25.5	49.9	-6.9	17.5
		GLOBIOM	-3.5	-18.8	-73.2	-452.0	-547.5
	Oil crops	FAPRI	0.0	-72.5	93.7	-0.1	21.2
		IMPACT	0.0	-33.3	18.3	-12.6	-27.5
		GTAP	0.0	5.0	36.4	-9.4	31.9
		GLOBIOM	0.0	-8.5	22.6	309.1	323.2
	Total	FAPRI	-4.4	-233.4	490.2	-17.5	234.9
		IMPACT	0.0	-517.1	911.9	-339.5	55.4
		GTAP	0.0	-63.6	176.1	-46.5	65.9
		GLOBIOM	-3.5	-23.2	-11.6	268.5	230.3
World	Wheat	FAPRI	-0.1	-0.4	-3.7	-1.9	-6.0
		IMPACT	0.0	27.0	10.7	-57.7	-20.0
		GTAP	0.0	-20.0	2.5	-13.2	-30.8
		GLOBIOM	0.0	6.2	-4.5	519.8	521.5
	Coarse grains	FAPRI	403.0	-75.2	187.6	-6.4	509.0
		IMPACT	387.4	-422.2	539.8	-238.2	266.8
		GTAP	457.0	-259.1	36.8	-30.0	204.7
		GLOBIOM	541.4	-130.8	-47.6	-465.1	-102.2
	Oil crops	FAPRI	-1.5	-154.6	18.5	13.5	-124.0
		IMPACT	0.0	-46.2	13.8	-15.0	-47.4
		GTAP	0.0	8.9	-9.5	-14.5	-15.1
		GLOBIOM	2.8	-229.0	2.7	328.6	105.1
	Total	FAPRI	398.4	-312.7	249.0	-12.1	322.5
		IMPACT	387.4	-498.2	635.5	-425.8	98.8
		GTAP	457.0	-310.0	61.1	-89.9	118.3
		GLOBIOM	543.9	-345.2	-17.3	258.3	439.8

Table A2: Complete LUC results under the EU wheat scenario according to several modelling systems (per 1 mtoe and normalised to year 2020 yields)

			Additional land demand (>0) or land savings (<0) due to changes in…				
			biofuel feedstocks	other domestic use	net exports	crop yields	sum total
EU27	Wheat	AGLINK	81.4	-5.3	-30.4	-1.4	44.3
		FAPRI	997.3	-489.0	-89.9	-27.1	391.2
		IMPACT	1226.3	-105.6	-1030.1	-30.2	60.3
		GTAP	901.2	-100.1	-151.8	15.4	664.7
		GLOBIOM	449.6	-150.2	-11.1	6.1	294.4
	Coarse grains	AGLINK	75.0	-54.2	-10.3	-1.5	9.0
		FAPRI	0.0	182.6	-1.2	3.1	184.5
		IMPACT	0.0	43.4	-20.2	-14.2	8.9
		GTAP	0.0	-495.2	20.0	93.9	-381.3
		GLOBIOM	0.0	-94.1	-101.1	-17.2	-212.5
	Oil crops	AGLINK	356.3	-18.4	-328.4	-0.2	9.3
		FAPRI	-45.0	25.1	-24.8	0.0	-44.7
		IMPACT	0.0	-3.6	3.4	0.0	-0.3
		GTAP	0.0	5.1	-30.2	23.5	-1.5
		GLOBIOM	-11.7	-26.3	-23.0	28.4	-32.6
	Total	AGLINK	520.5	-78.0	-369.0	-3.4	70.2
		FAPRI	952.3	-290.3	-115.5	-24.0	522.5
		IMPACT	1226.3	-69.4	-1054.6	-51.6	50.7
		GTAP	901.2	-617.6	-216.8	213.6	280.4
		GLOBIOM	438.0	-274.5	-135.8	18.3	46.1
USA	Wheat	AGLINK	0.0	57.6	-40.5	-0.5	16.6
		FAPRI	0.0	-11.1	29.6	-1.2	17.2
		IMPACT	0.0	-50.9	115.6	-23.1	41.6
		GTAP	0.0	-3.5	51.9	-16.4	32.0
		GLOBIOM	0.0	1.9	9.6	0.2	11.7
	Coarse grains	AGLINK	0.0	-3.7	12.0	-1.6	6.6
		FAPRI	0.0	10.0	-14.1	0.3	-3.9
		IMPACT	0.0	30.8	-7.0	-15.6	8.2
		GTAP	0.0	103.7	-22.6	-16.7	64.4
		GLOBIOM	0.0	16.0	20.1	-0.1	36.0
	Oil crops	AGLINK	0.0	54.0	-61.9	0.4	-7.5
		FAPRI	0.0	-9.7	-2.0	0.7	-11.0
		IMPACT	0.0	-7.0	-2.9	-1.8	-11.8
		GTAP	0.0	0.8	-14.4	-10.1	-23.7
		GLOBIOM	0.0	6.8	104.4	-5.0	106.1
	Total	AGLINK	0.0	107.9	-90.3	-1.7	15.9
		FAPRI	0.0	0.9	8.9	-0.4	9.3
		IMPACT	0.0	-17.8	92.8	-43.9	31.1
		GTAP	0.0	93.5	6.2	-58.3	41.4
		GLOBIOM	0.0	24.8	119.7	-7.0	137.6
Rest-of-the-world	Wheat	AGLINK	0.0	-37.6	130.3	-6.7	86.0
		FAPRI	0.0	-32.6	130.8	-43.7	54.5
		IMPACT	0.0	-710.4	1187.0	-222.1	254.5
		GTAP	0.0	-4.6	270.4	-47.1	218.8
		GLOBIOM	0.0	-12.7	26.9	120.5	134.7
	Coarse grains	AGLINK	0.0	27.1	-34.6	-6.9	-14.3
		FAPRI	0.1	-76.9	64.4	-7.3	-19.7
		IMPACT	0.0	-16.6	105.0	-90.9	-2.5
		GTAP	0.0	-0.8	33.4	-17.3	15.3
		GLOBIOM	-1.4	127.6	286.6	-516.3	-103.5
	Oil crops	AGLINK	0.0	-451.5	546.9	-15.8	79.6
		FAPRI	0.0	-57.2	50.9	2.9	-3.4
		IMPACT	0.0	-26.9	12.5	-12.1	-26.5
		GTAP	0.0	-1.0	53.6	-14.7	37.9
		GLOBIOM	0.0	62.8	-581.4	381.8	-136.7
	Total	AGLINK	0.0	-404.8	639.2	-45.6	188.8
		FAPRI	0.0	-168.5	213.8	-38.2	7.1
		IMPACT	0.0	-829.5	1429.3	-456.3	143.4
		GTAP	0.0	-54.4	510.9	-153.1	303.3
		GLOBIOM	-1.4	199.1	-205.7	145.6	137.6
World	Wheat	AGLINK	81.4	14.7	59.4	-8.7	146.8
		FAPRI	995.6	-531.9	70.5	-72.0	462.2
		IMPACT	1189.2	-871.6	316.4	-276.9	357.0
		GTAP	884.9	-106.3	176.4	-48.8	906.2
		GLOBIOM	449.6	-161.0	25.4	126.8	440.8
World	Coarse grains	AGLINK	75.0	-30.9	-32.9	-10.0	1.3
		FAPRI	0.1	117.4	48.8	-3.8	162.6
		IMPACT	0.0	54.8	81.0	-121.3	14.4
		GTAP	0.0	-325.3	28.2	47.0	-250.1
		GLOBIOM	-1.4	49.4	205.7	-533.7	-279.9
World	Oil crops	AGLINK	356.3	-415.9	156.7	-15.6	81.5
		FAPRI	-45.5	-41.4	23.9	3.7	-59.4
		IMPACT	0.0	-37.4	12.7	-13.9	-38.5
		GTAP	0.0	4.9	6.3	-0.9	10.3
		GLOBIOM	-11.7	43.4	-500.0	405.2	-63.1
World	Total	AGLINK	520.5	-374.9	180.0	-50.7	275.0
		FAPRI	950.1	-454.9	106.9	-62.5	539.6
		IMPACT	1189.2	-925.0	515.9	-554.0	226.1
		GTAP	884.9	-505.0	316.1	-26.8	669.3
		GLOBIOM	436.6	-50.5	-221.8	156.9	321.2

Table A3: Complete LUC results under the EU rape scenario according to several modelling systems (per 1 mtoe and normalised to year 2020 yields)

			Additional land demand (>0) or land savings (<0) due to changes in…				
			biofuel feedstocks	other domestic use	net exports	crop yields	sum total
EU27	Wheat	FAPRI	-5.9	-61.4	-23.6	-10.7	-101.5
		AGLINK	59.3	-0.2	-29.7	-2.1	27.3
		GTAP	0.0	-22.8	-13.9	-8.2	-44.8
		GLOBIOM	0.0	-99.2	-140.5	-89.4	-329.0
	Coarse grains	FAPRI	0.8	-78.3	-20.6	-5.7	-103.8
		AGLINK	53.0	-40.1	-8.2	-1.2	3.6
		GTAP	0.0	25.3	-9.4	-14.7	1.3
		GLOBIOM	0.0	-210.9	-111.9	-75.3	-398.2
	Oil crops	FAPRI	937.4	-651.3	-45.6	0.0	240.5
		AGLINK	560.8	-27.6	-513.7	0.7	20.1
		GTAP	803.0	-504.6	-88.4	-14.7	195.3
		GLOBIOM	920.5	-39.1	-193.7	42.3	730.0
	Total	FAPRI	932.3	-787.2	-89.5	-16.4	39.2
		AGLINK	678.6	-68.0	-551.5	-2.8	56.4
		GTAP	803.0	-510.4	-136.1	-50.7	105.8
		GLOBIOM	920.4	-361.9	-452.1	-76.3	30.1
USA	Wheat	FAPRI	0.0	-38.2	92.9	-6.1	48.7
		AGLINK	0.0	10.1	-1.3	-0.3	8.5
		GTAP	0.0	-1.5	4.5	-4.8	-1.7
		GLOBIOM	0.0	2.2	46.4	1.4	50.0
	Coarse grains	FAPRI	0.0	-48.8	71.2	-3.9	18.6
		AGLINK	0.0	-1.6	7.2	-1.0	4.7
		GTAP	0.0	-2.3	2.1	-8.9	-9.1
		GLOBIOM	0.0	23.1	15.0	1.3	39.3
	Oil crops	FAPRI	0.0	-29.0	6.7	0.4	-21.8
		AGLINK	0.0	97.0	-100.0	0.3	-2.8
		GTAP	0.0	-1.5	46.9	-14.1	31.3
		GLOBIOM	0.0	11.4	37.5	-5.3	43.5
	Total	FAPRI	0.0	-109.9	166.5	-9.8	46.8
		AGLINK	0.0	105.5	-94.0	-1.1	10.4
		GTAP	0.0	-6.7	56.4	-38.7	11.0
		GLOBIOM	0.0	36.8	102.0	-2.6	136.2
Rest-of-the-world	Wheat	FAPRI	-0.1	-136.7	-9.7	-59.1	-205.7
		AGLINK	0.0	-35.7	79.2	-5.7	37.8
		GTAP	0.0	-4.7	24.9	-12.3	7.9
		GLOBIOM	0.0	-15.9	283.8	84.4	352.3
	Coarse grains	FAPRI	0.0	-13.4	-86.4	-43.1	-143.0
		AGLINK	0.0	26.4	-22.4	-9.1	-5.1
		GTAP	0.0	-0.3	7.1	-14.0	-7.2
		GLOBIOM	-1.7	8.7	386.6	-261.2	132.7
	Oil crops	FAPRI	0.2	594.8	127.8	-1.4	721.4
		AGLINK	0.0	-696.2	853.7	-24.3	133.2
		GTAP	0.0	110.0	90.7	-36.9	163.9
		GLOBIOM	0.0	40.5	-265.2	131.3	-93.5
	Total	FAPRI	0.8	428.8	16.9	-99.4	347.2
		AGLINK	0.0	-676.0	907.7	-55.3	176.4
		GTAP	0.0	92.4	173.8	-109.7	156.5
		GLOBIOM	-1.7	62.6	414.3	-108.6	366.9
World	Wheat	FAPRI	-6.1	-236.1	59.4	-75.8	-258.6
		AGLINK	59.3	-25.8	48.3	-8.2	73.6
		GTAP	0.0	-28.6	16.1	-25.3	-37.7
		GLOBIOM	0.0	-112.9	189.8	-3.6	73.2
	Coarse grains	FAPRI	0.7	-141.0	-35.4	-52.5	-228.2
		AGLINK	53.0	-15.2	-23.4	-11.3	3.1
		GTAP	0.0	19.4	1.2	-36.1	-15.5
		GLOBIOM	-1.7	-179.1	289.6	-335.3	-226.1
	Oil crops	FAPRI	949.0	-93.7	87.8	-1.0	942.2
		AGLINK	560.8	-626.9	240.0	-23.3	150.6
		GTAP	803.3	-401.1	46.6	-64.5	384.3
		GLOBIOM	920.5	12.7	-421.5	168.2	680.0
	Total	FAPRI	944.5	-476.7	93.0	-125.4	435.4
		AGLINK	678.6	-638.5	262.1	-59.2	243.1
		GTAP	803.3	-431.0	99.3	-194.1	277.6
		GLOBIOM	918.7	-262.5	64.2	-187.4	533.3

11. Annex 2 Technical details of the comparison

In general the comparison involved the establishment of mappings between the product and region sets of the models considered and a set of aggregate regions and products as a 'common denominator' that could be calculated from all models.

Any land use change components were first calculated on the model specific, detailed level of items and subsequently aggregated to the total hectares of the aggregates. This ensures, for example, that any demand change in a sub region of an aggregate region is converted into hectares using the yields of the sub region, rather than the average yield of the aggregate region.

In spite of this rather straightforward strategy several model specific adjustments were needed.

11.1. FAPRI

Particularities in the processing of the FAPRI results were the following:

- The product specific structure of the results required particular attention to detect mapping problems.
- Units were almost exclusively metric, but a few exceptions had to be dealt with (e.g. bio-fuels, cotton).
- Stock changes were integrated into total domestic use.
- Areas of palm in the 2008 scenarios have been calculated using the yields from the 2009 baseline, implying that all production changes in these scenarios have been attributed to area changes
- Bio-fuel use of oilseeds has been assigned from the use of the corresponding oils divided by processing yields.

Important differences between the 2008 version used for the US maize scenario and the 2009 version are

1. The more recent version has updated trend parameters in the yield equation based on data up to 2008.

2. It has intensification and extensification effects in the yield equation for most crops in all countries covered. These were absent in the former version.

3. It relies on a spatially disaggregated Brazil model with a more detailed land allocation specification.

4. It has an expanded DDG specification in selected countries outside the US whereas DDG coverage was confined to the US in the former versions.

11.2. AGLINK

It applies even more to AGLINK than to FAPRI that the equations and variables can be quite specific for regions and products such that specific actions were sometimes needed. Noteworthy particularities were

- The oil crops balance is a consolidated aggregate of the vegetables oils and oilseeds balances (converting the latter into oil).
- Stock changes have been integrated into domestic use.
- Double cropping of wheat and oilseeds in Argentina has been allocated to wheat and oilseeds on half of the area.

11.3. IMPACT

IMPACT results are in general organised in fairly homogeneous excel files for all commodities and regions such that processing was straightforward. Particularities were:

- Aggregation of supply side country level data from the underlying river basin data.
- Aggregation of total crops from rainfed and irrigated. The switch of these technologies were expected to contribute to (pure) yield changes, but apparently the shares were not responsive to the bio-fuel scenarios.
- Stock changes (the residual in market balances) have been integrated into domestic use.
- Sugar scenarios have been ignored as other models did not provide such scenarios.
- The estimation of yield changes on old and new land has been handled by IFPRI and was given among the model outputs.

11.4. GLOBIOM

A set of fresh biofuel scenarios has been simulated and results tailored to the needs of this comparison have been compiled by IIASA. Particularities were:

- Information on LUC between cropland, forestry types, grassland and natural land has been ignored as only GTAP offered similar information.
- Scenarios with fast growing wood plantations for second generation biofuels have been ignored as well given that no other model offered such information.
- The calculation of pure and aggregation yield effects has been incorporated in the GLOBIOM results routines as explained in the text.

11.5. GTAP

In terms of physical information GTAP offered base year crop production and land use in physical units and percentage or absolute changes on production, areas, yields (decomposed into intensification and extensification effects), total demand, food demand. The GTAP physical production data on crops were indicated to be derived from FAO. Even though GTAP uses the

Armington approach and treats wheat from different origin and qualitatively different, we have established conventional market balances for comparison purposes as follows.

The demand, production, and net trade data for 2001 have been downloaded from the FAO website (09.03.2010) and mapped to the GTAP crop items using detailed correspondence tables to recalculate the same aggregates as those in the GTAP database. The ratio of production according to GTAP to production according to FAO has been used as a correction factor for the fresh download of the demand data (with some exceptions) such that after applying this correction factor, production and demand should be given in comparable definitions, and hence could be used to calculate net trade. The percentage changes given from the GTAP results have been applied to this completed database for 2001. Finally it has been imposed that global net trade does not change in the scenarios.

The demand and net trade results were therefore derived from the percentage changes given from GTAP, but they were not exclusively based on GTAP output. Clearly, the necessary level of 'processing' of the GTAP data was higher than for any other model to permit comparisons with the partial equilibrium models that usually give all their results in physical units. Other particularities were:

- Information on LUC between cropland, forestry land, and grassland has been ignored as only GLOBIOM offered similar information.
- The scenario with biodiesel based on imported palm oil has been ignored as it was unique for GTAP.
- The distinction of extensification and intensification yield effects was adopted from GTAP, but a correction was applied to impose that they sum up to the total yield effect (occasionally violated in the original output).