Issues of concern with models for calculating GHG emissions from indirect land use change

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Summary

Several issues of concern have been identified with most existing models for calculating GHG emissions from indirect land use change (ILUC). Nearly all of the concerns with current models; in particular accounting for co-products, yield growth and use of idle land, will lead to overestimation of the GHG emissions from Indirect Land Use Change (ILUC), especially for crops grown within the EU. The magnitude of these concerns is:

Lack of accounting for the protein level in high protein co-products underestimates the ILUC credit of co-products by a factor of up to 30.
Lack of accounting for increased yield growth as a result of increased demand growth, overestimates the land use change for EU cereals by 4.5 times.
Lack of accounting for the use of idle land in the EU overestimates the GHG emissions from land use change for EU crops by a factor of between 2.5 and 4.

Due to these concerns, the results from current equilibrium models cannot be used to provide a reasonable estimate of the GHG emissions from indirect land use change for biofuels.

It is important to try to move to some level of agreement between modellers, as to which factors need to be modelled and how this is best done in the ILUC context: i.e. deterministic cost optimisation, price elasticities, direct elasticities, or other empirical historic relationships.

There is also a concern that much of the effort on modelling has been to enhance equilibrium models and has resulted in more complicated models that lack transparency. Less effort has been applied to provide justification of the methods and model parameters used to evaluate GHG emissions from ILUC. It may be of more value to develop simpler models, for example spreadsheet based differential models, which use agreed methods for modelling those factors and determine the parameters that are most important for determining GHG emissions from ILUC.

The major issues of concern with the equilibrium models that are likely to be relevant to EU biofuels production are summarised below.

1) Transparency

In order to check the validity of a modelling approach, or to understand why different models give different results, it is important to know the justification for the modelling approaches that are adopted, the data fitting processes and data that have been used to determine parameters, for example elasticities, in the model. In many cases this is lacking in current equilibrium models.

2) Accounting for biofuel co-products

Biofuel co-products used for animal feed, displace other crops and provide a substantial credit to the GHG emissions from ILUC. In the EU, high protein biofuel co-products such as DDGS and rape meal will economically displace a mixture of soy meal and cereal to give a similar metabolisable energy and digestible protein level in the resulting animal feed. Most models do not properly take account of biofuel co-products and the crops that they displace.

Some GTAP based models do not account for co-products at all, while models that do, fail to account of the co-product protein content in determining which crops are displaced.

The failure to take proper account of the protein content of biofuel co-products such as DDGS and rape meal, used as animal feed will underestimate the co-product credit by up to 30 times and cause a substantial overestimation of the GHG emissions from ILUC for biofuels from cereals and oilseed rape in the EU.

3) Modelling of the oilseeds market

Most oilseeds are grown primarily for the oil, with a lower value meal by-product, while soybean is primarily grown for the meal. Soybean is the marginal source of high protein meal, while palm is the marginal source of vegetable oil. In some models oilseed crops are aggregated together or are represented by aggregate vegetable oil and oilseed meals, so cannot model marginal meal and marginal oil supply. Other models where oilseed crops are disaggregated, still do not model soy bean as the marginal source of high protein meal. It is then not possible for these models model the land change effects of biofuel co-products that partially substitute for soy meal.

The aggregation of oilseeds, or the assumption that soy is grown for its oil, rather than primarily for its meal, will not allow for soy meal replacement by other high protein biofuel co-products. This will cause an overestimation of the GHG emissions from ILUC from biofuels with high protein co-products.

4) Modelling land area and yield changes

The crop demand growth due to increased use of biofuels will lead to an increase in crop yield growth via pricing effects, for example, a slower historic rate of real price decline. Most models do not account for the increased yield growth due to increased demand growth and the yield growth estimate is often an exogenous value based on historic data. The models therefore effectively assume that all the increase in demand above the estimated yield growth is met by land area change.

The lack of modelling of the proportion of demand growth from yield growth and area growth will cause an overestimation of the GHG emissions from ILUC for most crops and an overestimation of 4.5 times for the case of EU cereals.

The use of a factor to relate the yield on new land to existing yields is not justified and results in overestimation land area changes as a result of crop demand increases.

5) Changes to trade of biofuel crops

For crops, such as cereals, which are widely grown locally, the transport costs are high compared to the value of the crop and therefore many regions maintain a self sufficiency of these crops and the regional crop output is adjusted to meet demand. Any increased demand for these crops will therefore primarily be made up by increased production in that region. Most models use arbitrary elasticity factors to determine the amount of increased biofuel crop demand, which will be provided by increased imports or reduced exports. These factors do not take account of logistics cost and their applicability to agricultural crops such as cereals has not been justified.

The models overestimate the proportion of EU demand for cereals that will be met by EU imports or reduced EU exports. This results in the replacement cereals being modelled as being grown at lower yields than in the EU and gives an overestimation of the land use change and GHG emissions from ILUC.

6) Type of land changes

The methods for determining land use changes determine the amount of pasture and forest that will be displaced by extra cropland, but rarely include the re-use of idle land in the EU and FSU. When models do include the re-use of idle land, the factor used for foregone carbon sequestration is primarily based on carbon accumulation by afforestation, instead of by natural succession and is far too high.

The lack of inclusion of idle land will cause an overestimate of the GHG emissions from land conversion by a factor of between 2.5 and 4, for biofuel crops grown in the EU.

7) Validation of models

For predictions to be trusted, the equilibrium models need to be validated, by demonstrating that their predictions of past perturbations in crop land areas, trade flows etc satisfactorily match those observed. It is not clear whether any equilibrium models have been validated in this way.

Introduction

Increased global production of crop-derived biofuels creates a significant risk of indirect land use change, with potential impacts upon local environmental quality and biofuel lifecycle greenhouse balances. If the EU is to realise its climate change goals to 2020 and beyond, biofuel policy must visibly and scientifically account for the indirect impacts on land use. If this is achieved, it will create the necessary confidence for sustainable investment to meet these goals

It is inevitable that GHG emissions from ILUC will need to be quantified for different biofuels and feed-stocks and this is reflected in both US and EU legislation. However, there is currently no consensus on the modeling methods and model parameters that should be used to determine the GHG emissions from ILUC.

Several models and methods have been developed to calculate GHG emissions from indirect land use change (ILUC) due to biofuel production. The models are required to:

- Identify biofuel crops/regions where production is liable to lead to adverse land use changes, so that additional sustainability requirements can be applied to the production of such biofuels.
- Provide an estimate of the GHG emissions impact from indirect land use change for alternative biofuel pathways. The ILUC impact would depend on type of biofuel, where the biofuel crop is grown and the use of the biofuel co-products.

While a lot of modeling work has also been done to determine the ILUC effects of the EU 2020 renewable transport fuels policy, this is of limited value, until it can take into account measures that are used to limit biofuel pathways that could lead to adverse land use change.

Steps in ILUC Modelling

All ILUC models will need to include the following steps (DGTREN 2009).

- What crops are displaced by biofuel crop co-products?
- How much of the increased production of each crop in each region is met by land area change and how much by yield growth?
- How much of the increased demand in a region is met by increased production in the region land how much by changes in trade?
- Where extra cropland is required, what type of land is converted to cropland?
- What are the carbon stock changes from land conversion?

Models that are aiming to determine the ILUCs effects of the biofuels for transport fuels policy also need to determine the extra quantity of different crops will need to be produced.

It is generally accepted that the effects of biofuels on land use change should be determined on a consequential (substitution or system expansion) basis, rather than an allocation (attributional) basis (DGENVI 2009, EPA 2009).

Some methods for estimating GHG emissions from ILUC use an allocation method and do not include the steps above. These methods are answering the question of GHG emissions from ILUC due to cultivation in general, rather than the ILUC effects of a biofuels policy. They do not attempt to adequately differentiate between the ILUC effects of different biofuel crops and regions and are not considered further.

Consequential modelling of demand and supply relationships must be done by establishing empirical economic driven relationships between variables by fitting historic data. Since biofuel targets are quantity driven, the effects can modelled directly, using direct elasticities related to demand growth, for example by establishing the proportion of demand changes that will be supplied by yield changes and area changes. Alternatively the effects can be modelled indirectly using price elasticity factors, for example by determining the effects of increased demand on prices and then fitting land area changes to these prices. Both approaches should give similar overall results, although there is more ‘noise’ in price relationships due to price volatility and variations in regional price and input costs.

Consequential modelling of the effects of biofuels can either be done using integral models to compare a biofuel scenario to a baseline scenario, or if response functions are linear, a differential (marginal) model can be used to determine ILUC impacts directly. With the use of integral models, there is much debate about what baseline and biofuel scenarios should be used, but with differential models, this unnecessary for calculating the GHG emissions per MJ of biofuel.

Types of ILUC model

Most of the work on ILUC modelling has been done using complex “equilibrium” models which are used to determine the extra quantity of different crops that will be produced to meet a biofuel policy target and with additional modules can be used to determine the ILUC impact of the policy and/or of the different biofuel pathways.

An alternative approach is to use “cause and effect” models to determine the ILUC impact of different biofuel pathways.

Equilibrium models

Equilibrium models are integral models, which model economic relationships via prices and can be divided into two types:

- Computable general equilibrium models.
- Partial equilibrium models

Computable general equilibrium (CGE) models.

These models are all based on the Global Trade Analysis Project GTAP (O’Hare 2009), which was written to determine the effects of tariff changes on international trade flows. Various versions of the GTAP model are available and different versions have been or are being used for ILUC modelling by different groups. GTAP based models allow inter-sectoral and international trade interactions, but the model architecture poses restrictions in modelling some specific aspects of ILUC, such as co-product substitution. GTAP based models have been developed by CARB (CARB 2009), IFPRI-MIRAGE(Valin 2009), IFPRI–IMPACT, and LEITAP(Prins 2009).

Partial equilibrium models

These models are more varied and flexible than the GTAP based models. Some models have been developed specifically to model ILUC and are able to take a more sophisticated approach to the agricultural sector. Partial equilibrium models have been or are being developed by Aglink (OECD 2008), ESIM, IIASA, CAPRI, FAPRI and FASOM.
The US Environmental Protection Agency (EPA 2009) has used a combination of FAPRI and FASOM to determine ILUC factors for US biofuels.

“Cause and effect” models

“Cause and effect” models are differential, spreadsheet based models, which uses cause and effect logic to describe and derive ILUC impacts. The model are intended to determine the ILUC impact of different biofuel pathways, but not the extra quantity of different crops will be produced to meet a biofuel policy target. Such models can be made completely transparent and are more flexible than equilibrium models. They can be used for detailed modelling of ILUC to evaluate ways of mitigating the risk ILUC impacts. A “cause and effect” model has recently been developed by E4tech for the UK Dept for Transport.

Details of issues with ILUC models

The issues with equilibrium models below are based mainly on the CARB work (CARB 2009) and EPA work (EPA 2009), since detailed data on the calculation and the results of these models are readily available. Some issues are also based on IFPRI work (Valin 2009a), (IFPRI 2010), LEITAP (Prins 2009), work by JRC (JRC 2010a), (JRC 2010b) and the DGEnergy literature review (DGEnergy 2010). Many of these issues raised also apply to similar modelling approaches that are used in other equilibrium models.

The issues of concern with the equilibrium models that are likely to be relevant to EU biofuels production are explained in detail below. For each step in the ILUC calculation, the underlying science is discussed and then alternative modelling approaches are compared relative to the science.

1) Transparency

In order to check the validity of a modelling approach, or to understand why different models give different results, it is important to know the justification for the modelling approaches that are adopted, the data fitting processes and data that have been used to determine parameters, for example elasticities, in the model. In many cases this is lacking in equilibrium models.

Although a database of elasticity factors and the source code for the GTAP model is available on the internet, this does not provide the data needed to validate the models.

Some examples of the transparency issue are listed below and explained more fully under relevant sections.

- Lack of clarity of modelling approach: modelling of oil seed markets and changes in trade patterns
- Lack of justification of modelling approaches: assumption of constant yield growth rate and use of Armington elasticities for changes in trade patterns.
- Lack of references: sources for the model elasticities factors are not provided.
- Lack of a firm basis for assumptions: the elasticity used to account for lower yield on new land used to grow biofuel crops is justified by “best judgement”.

2) Accounting for biofuel co-products

The production of biofuels from crops such as cereals and oilseeds gives high protein co-products that are normally used for animal feed. They will replace the variable animal feed components in the production regions, which for the EU, are wheat exports and soy meal imports.

In the US substantial quantities of corn DDGS is used as liquid feeds or other direct feeds in local feedlots, or is dried and exported to China as a high protein animal feed. However, the animal feed industry in the EU operates differently from in the US. In the EU, most of the DDGS from bioethanol plants is dried and used in formulated animal feed. The costs of high protein animal feed i.e. imported soy meal in the EU are substantially higher then energy feeds such as wheat. Therefore animal feed compounders will maximize the use of DDGS and rape meal to displace soy meal (CE Delft 2008, Lywood 2009a), to minimize the overall cost of the feed (FEFAC 2009). The levels of essential amino acids (EAAs) in DDGS are supplemented by addition of synthetic EAAs such as lysine, threonine and methionine to boost protein quality. The price of DDGS and rape meal (as with other co-products) used in EU animal feed adjust so that they will be fully utilised for animal feed. Therefore in the EU, biofuel co-products will economically displace a mixture of soy meal and cereal. The substitution ratios of co-product for soy meal and cereal are such as to give the same digestible energy and digestible protein level of the resulting animal feed (Marshall 2006, Lywood 2009a). The digestible protein level of DDGS is greater than that of all oilseed meals except soy meal, so will displace soy meal on the same basis as for rape meal and sunflower meal.

Studies on crop displacement by biofuel co-products in the EU have been made by CE Delft 2008, Lywood 2009a and ADAS 2010. The results from are shown in table 1.

Substitution Ratios for EU Biofuel co-products			
	Co-product	Substution for soy meal	Substution for cereal
		t / t of co-product	
CE Delft 2008			
	Wheat DDGS	0.50	0.66
	Maize DDGS	0.45	0.69
Lywood et al 2009			
	Wheat DDGS	0.59	0.39
	Maize DDGS	0.40	0.49
	Rape meal	0.61	0.15
ADAS 2010			
Current scenario	Wheat DDGS	0.33	
Future high usage scenario	Wheat DDGS	0.60	

Table 1

Typically 1 t of wheat grown in Europe will produce about 0.33 t of DDGS co-product which taking an average of the future data above (1 t DDGS replaces 0.55 t soy meal and 0.45 t wheat) will displace about 0.18 t of soy meal and 0.16 t of wheat.

2.1 Accounting for co-products in models

Many studies and equilibrium models do not account properly for biofuel co-products. Some models such as LEITAP and IMPACT, do not account for co-products at all, while others such as CARB and IFPRI-MIRAGE do not account for the high protein value of oil meals and/or DDGS co-products and simply substitute them for cereal on a weight basis (CARB) or energy basis (IFPRI). Some models e.g. IFPRI-MIRAGE allow for rape meal to substitute for soy meal, but do not allow DDGS to substitute for soy meal, even though DDGS has a higher digestible protein content than rape meal (Premier 2008).

One reason why the displacement of soy meal by DDGS is not modelled in many equilibrium models is that the architecture of the equilibrium models does not allow it. Most equilibrium models are segmented into different sectors, for example oilseeds (or oilseed meals) and cereals and this segmentation does not allow for the co-product from one sector i.e. cereals to substitute for part of a different sectors i.e. oilseeds (or oilseed meals).

Instead of correcting the models to enable DDGS to displace soy meal, it has apparently been argued by some modelers that although DDGS is not properly accounted for in GTAP based models, the effect of this on GHG emissions from land use change is small. On a weight basis, the amount of soy meal displaced (0.18 t / t wheat) may be regarded as small. However, when translated into GHG emissions from ILUC, the effects are far greater. The reasons for this are:

- The yield of soy is substantially lower than the yield of EU wheat

- The increased demand for EU wheat is primarily met by yield increases, whereas the increased demand for soy is primarily met by land area increases
- New wheat land in the EU will be obtained from using unused land or reducing the rate of creating idle land, while new soy land in S America is obtained from a mixture of deforestation and conversion of grassland to cropland.

The effect of these factors is illustrated in table 2.

		Feed Wheat	Displaced soy meal	Ratio SBM / wheat	Data Source
Source of crop		**EU**	**S America**		
Mass ratio		1.0	0.18	**0.18**	Table 1
Crop yield (avg 2006-9)	t/ha	5.3	2.6	**2.0**	FAO
Proportion of output from land area change		22%	90%	**4.1**	Lywood 2009b
Type of land displaced		unused / idle land	grassland / forest		
Avg. carbon stock of displaced land	t CO2/ha/yr	1.8	12.0	**6.8**	Lywood 2010 ADAS 2010
GHG emissions from ILUC				**10**	

Table 2

Although the quantity of soy meal displaced by the DDGS is only 18% of the quantity of wheat used to produce the bioethanol, the reduction in GHG emissions from ILUC associated with displacing the soy meal will be (0.18 x 2.0 x 4.1 x 6.8) = 10 times greater than those associated with growing the wheat. For models that simply substitute DDGS for cereal on a mass basis, the credit for the DDGS will only be 0.33 times the impact of growing the wheat. Thus including yield effects and the carbon stock changes of the land used to grow marginal crops, the DDGS credit when accounting for soy meal displacement is thirty times the figure when it is assumed in models that DDGS replaces wheat on a mass basis. It is calculated (ADAS 2010) that with high usage of DDGS for animal feed, the reduction in GHG emissions due to the displacement of soy meal by DDGS is equal to 150 gCO2 eq / MJ ethanol. This is equal to 1.7 times GHG emissions from gasoline of 85 gCO2 eq / MJ. These figures show that modelling of biofuel co-products used for animal feed, including their protein content, is essential and the results from models that do not include appropriate modelling should be discarded.

The failure to take proper account of the protein content of biofuel co-products such as DDGS and rape meal, used as animal feed in most ILUC models will underestimate the co-product credit by up to 30 times and cause a substantial overestimation of the GHG emissions from ILUC for biofuels from cereals and oilseed rape in the EU.

3) Modelling of the oilseeds market

Modelling of the oilseeds market is needed to understand the land use changes resulting both from making biodiesel from vegetable oil and to determine the credit for high protein biofuel co-products, such as DDGS and rape meal, that are used for animal feed.

The average prices (USDA 2009a) and relative values of vegetable oil and meal from different biofuel oilseed crops are shown in table 3.

		Soy	Rape	Sun flower	Palm
Typical oil yield	t/ha	**0.4**	**1.5**	**1.0**	**4.0**
Average prices 2001-08					
Oil price US	USD/ton	542	695	858	636
Meal price US	USD/ton	212	168	106	82
Oil yield	t/t crop	0.19	0.410	0.420	0.235
Meal yield	t/t crop	0.74	0.557	0.550	0.028
Oil value	USD/ton crop	102.9	285.1	360.2	149.6
Meal value	USD/ton crop	157.1	93.4	58.1	2.3
Oil value/total product value		**40%**	**75%**	**86%**	**98%**

Table 3, Source USDA 2009a

It may be seen that for rape, sunflower and palm, the vegetable oil is significantly more valuable than the meal and it is generally accepted that the crop is being grown primarily for the vegetable oil. However, in the case of soy bean, the meal has a significantly higher value than the oil and the typical oil yield from soy is substantially lower than for other oilseeds. It cannot therefore be economic to grow soy primarily for the oil.

Data for the global trade in meals (USDA 2009b) for animal feed vegetable oils are summarised in table 4.

Global Trade		Soybean	Rape seed	Sunflowe rseed	Palm	Fish Meal	Other
Meal Exports							
Exports Avg 2006-9	mt /yr	105.5	8.1	4.5		2.7	5.7
Export growth 1999-2009	mt /yr	51.4	2.6	1.7		-1.2	2.0
Vegetable oil exports							
Exports Avg 2006-8	mt /yr	9.9	2.2	4.2	32.4		5.3
Export growth 1999-2009	mt /yr	2.8	0.8	1.7	21.4		2.2

Table 4, Source USDA 2010

It can be seen that between 2006 and 2009 soy bean meal accounted for 83% of the trade of high protein meals and over the last 10 years has accounted for.91% of growth in trade in high protein meals It may therefore be concluded that soy meal is the variable global source of protein meals to meet the demand for high protein animal feed. This confirms earlier work by LMC 2007 and is consistent with FAO work on animal feed demand (FAO 2006). It follows that the increase in high protein meal biofuel co-products such as rape meal and DDGS will cause a reduction in the growth rate of soya bean output growth in order to balance the supply of high protein animal feed. This is also supported by FEFAC work (FEFAC 2009)

It may also be seen from table 4 that while there has been an increase in soy oil trade as a result of the increased production of soya bean, 80% of the increase in trade in vegetable oils over the last 10 years has been from palm oil. Since the soy oil increase is driven by the increased demand for soy meal, 89% of the increase in the marginal trade of vegetable oils has been met by increased palm oil production. It may therefore be concluded that palm oil is the primary variable global source to meet the growing global demands for vegetable oil. It follows that the use of soy oil to make biodiesel will not primarily affect the growth rate of soya bean and will be replaced in the vegetable oil market by increased production of palm oil.

The CARB GTAP model aggregates all the oilseed crops into a single sector. Therefore as well as not being able to model the soy meal substitution of co-products (see section 2), it also has to assume some sort of average yield of vegetable oil for the production of biodiesel. The oil yield of palm oil is about ten times that of soy oil, so the increase in land area for vegetable oil for biodiesel will be very sensitive to the split of vegetable oils that is used to calculate the average oil yield. Since soy oil used to make biodiesel will be replaced by increased production of palm oil, the soy oil yield is not relevant in calculating the average oil yield. Inclusion of the soy oil yield in the calculation of the average oil yield will overestimate the land area required for biofuels.

In the EPA study (EPA 2009), there is a large discrepancy in the trade response from the production of soybean biodiesel between the FASOM and FAPRI models. This appears to be due to different assumptions between the models as to whether soy is grown primarily for the oil or for the meal. The EPA FASOM model appears to assume (EPA 2009, fig 2.6-2) that the use of soy oil for biodiesel production will be met by growing more soybeans and that the soy meal co-product will substitute for cereals and hay. However, the EPA FAPRI model appears to assume (EPA 2009, fig 2.6-14) that soybean is grown primarily for the meal and the demand for vegetable oil will be met by imported soy oil.

The aggregation of oilseed crops or the assumption that soy is just grown primarily for its oil, rather than primarily for its meal will lead to an overestimation of the overall land used for the production of soy biodiesel and underestimate the land saved by soy meal replacement by other high protein biofuel co-products. These will both cause an overestimation of indirect land use change.

4) Modeling land area and yield changes

Economics of supply and demand dictate that higher demand for crops for biofuels will drive higher prices, which will in turn drive investment for increased output. Increased output will require additional investment and can either arise by land area increase, yield increases, or by increases in the frequency of cropping. Therefore in the medium term, the proportion of the increased supply of crops that will be met by land area change, or yield change, will differ by crop and region, depending on the relative economics of obtaining increased output from additional cultivated land area, additional yield and increased cropping frequency. Most of the available data on crops, e.g. FAO provides crop yield and crop harvested area, but there is much less data on cropping frequency. The effects of cropping frequency are therefore not often considered.

There are many ways in which crop yields can be improved, for example: crop variety development, fungicide treated seeds, adoption of technology, improved drainage, increases in inputs such as fertilisers and pesticides, increased mechanisation allows a longer growing season, precision farming allows improved timing and selective spatial input addition, use of improved crop varieties and pesticides allows changes to the crop rotation to reduce the proportion of fallow land and maximise the use of higher yielding crops.

Some authors try to differentiate yield growth between increased inputs and improved technology. It is then argued (Searchinger 2008b) that improved technology happens anyway, so is constant and is not a function of price or demand growth. However, other authors show that underlying or ‘trend’ rate of yield growth for a crop is not constant and is itself dependent on prices or land availability: For example Guyomard *et al.* (1996) and Benjamin & Houee (2005) show that European yield growth was responsive to support prices under the EU CAP.

4.1) Relating land area and yield growth to prices

While many views have been expressed on the relationship between yield growth and price, little analytical work has resulted in statistically significant elasticity factors. Keeney (2008) summarised some of this work and concluded that taken as a group, the studies show that there is a relationship between price and yield growth. Searchinger (2008b) draws a different conclusion from these data that yield is unresponsive to price in countries that have adopted modern agriculture.

It cannot be assumed that just because a statistically significant relationship between yield changes and prices has not been found, that the effect of price on yield growth is negligible. To justify the assumption of “inelastic yield”, analysis must show that there is a relationship between land area growth and prices with no corresponding relationship between yield growth and prices. Little if any evidence has provided on this.

Clearly since increased crop output is driven by higher prices, there must be relationships between land area growth, yield growth and prices or margins. If it is not possible to find significant price elasticities from simplistic models, then more appropriate ways of relating yield growth and area growth to prices must be found. Three reasons why elasticity factors relating yield changes and area changes to price changes, have been difficult to determine are:

- the timescale for yield increases,
- large year to year yield changes due to weather.
- use of price changes rather than prices

Most of the analysis work has focused on short term relationships between price changes and yield changes to obtain a yield : price elasticity. However, the effect of prices takes between one and five years to be fully reflected in yield and land area changes due to the investment timescale of cultivating new land, infrastructure improvements, introduction of modern machinery, and adoption of higher yielding crop varieties in the years following high prices.

As pointed out by Searchinger (2008b), high yields in one year will tend to produce abundant crops that lower prices, while low yields result in high prices, confusing the causal relationship. These problems can be largely overcome by using a one year lag between prices and yield changes and by averaging yields changes and prices over a few years.

Technology improvements are not discarded in the case of falling prices (Kloverpris 2008). The increase in output growth is therefore related more closely to **prices**, or **margins** than to **price changes**

Reasonable fits to historic data can be found, by fitting to the prices relative to the long term trend price as long as it is done in an appropriate way (Lywood 2009b). For example, the relationship between land area growth, yield growth and prices is demonstrated in figure 1 for the case of global wheat supply.

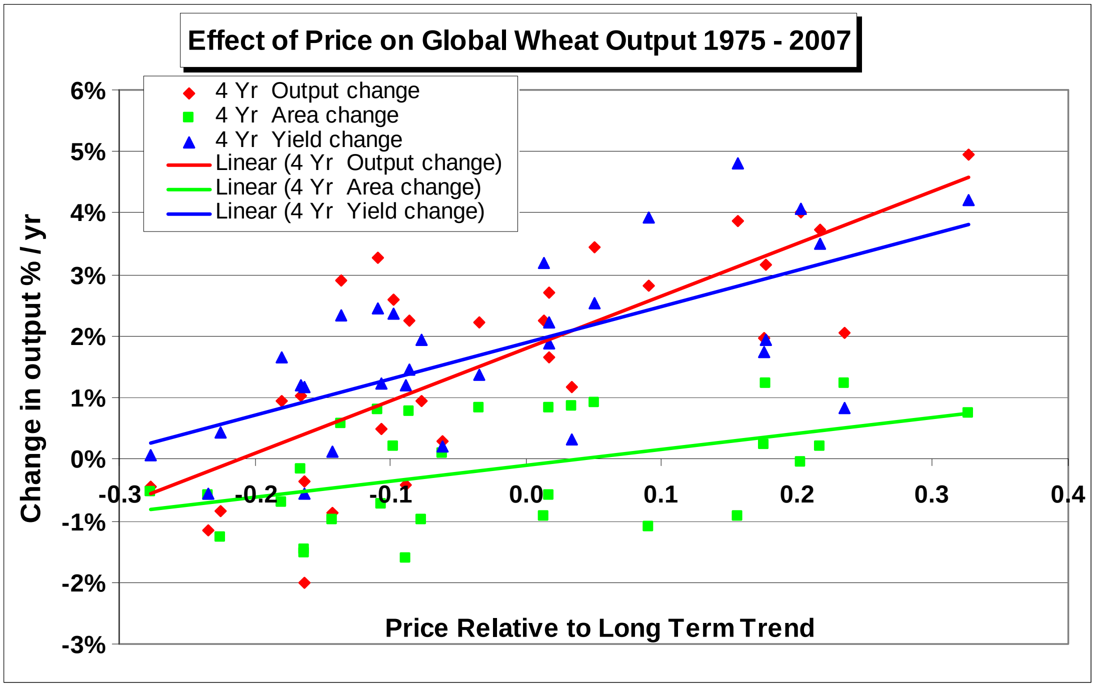

Figure 1, Source – FAOstat, Lywood 2009b

Each point represents one year using the compound annual growth rate (CAGR) over a four-year time span. The trend-lines show the historic relationship established by linear regression. There is a quite a lot of scatter on these models and the price relationships cannot be determined accurately. However, it may be shown that:

- There is a statistically high confidence that yield growth is not independent of price
- There is therefore no apparent 'normal' rate of yield growth independent of prices.
- Most of the increased output of wheat is from higher yield growth, not from higher land area growth.

It is therefore not valid as in many equilibrium models to assume that the rate of yield growth is unrelated to price or to the growth in demand.

IFPRI (Rosegrant *et al.* 2001) assume that yield growth and area growth both respond to increased prices, and derives elasticity factors for yield and area based on expert estimates.

For some crops in some regions, it is still difficult to find relationships between changes in output and prices, due to other factors such as changes in variable input costs and changes in agricultural subsidies. In these cases alternative approaches can be taken to determine the split between yield growth and area growth.

Some GTAP based models, for example the CARB model include an elasticity factor for yield changes with price changes. The source data for the elasticity factor of 0.25, used in the CARB GTAP model is not provided. Since neither an output : price or area : price elasticity is provided, the relative proportions of the demand growth that is met by yield growth and area growth is not known.

4.2) Relating land area growth and yield growth to demand growth

The effects of demand growth can alternatively be modeled by relating changes in yield growth to changes in area growth. The relationship between yield growth and land area growth is shown in figure 2 using FAO EU cereals (wheat, maize, barley, rye and triticale) data from 1961 to 2008.

Each point represents one year with changes averaged over a six year time span. The trend-line shows the historic relationship established by linear regression.

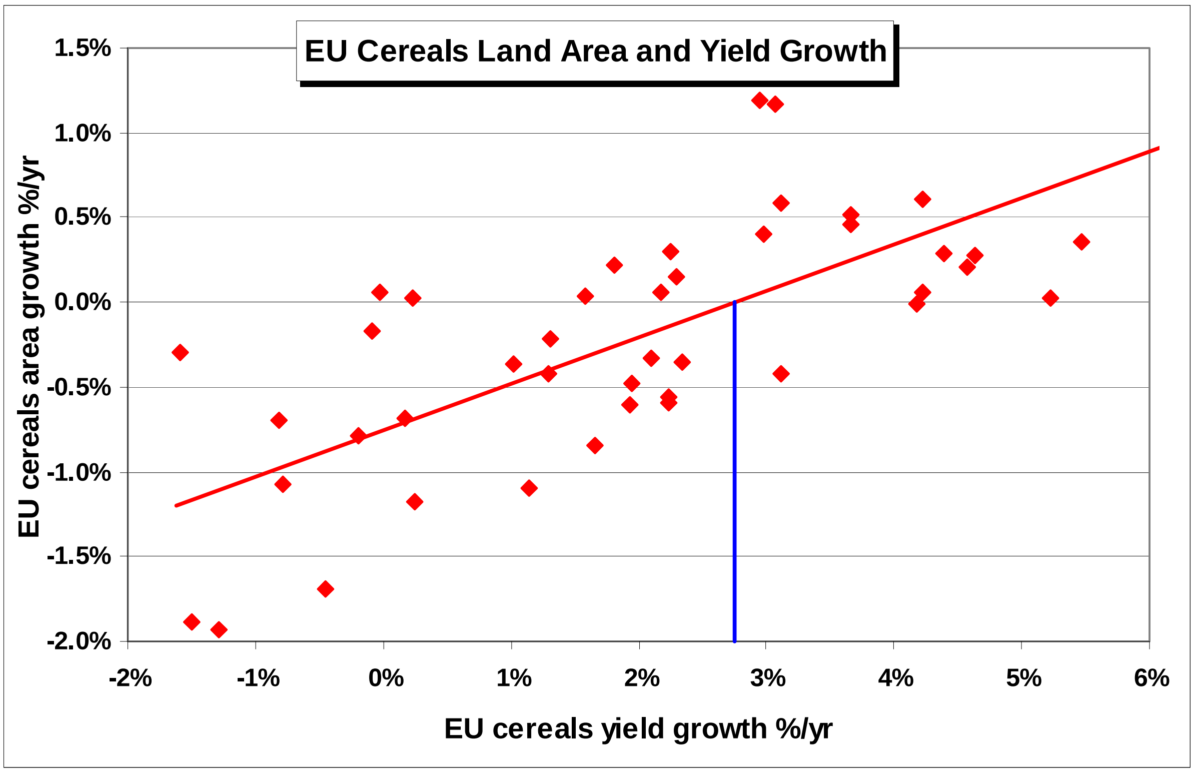

Figure 2, Source – FAOstat, Lywood 2009b

This graph confirms that there is no apparent 'normal' rate of yield growth and most of the increase in output of cereals comes from increased yield, not from increased land area. There is significant scatter of data, but the best regression fit shows that 78% of incremental EU cereals output growth is from yield growth and 22% from land area growth. No extra land would be needed to meet an increased output growth of cereals in the EU up to a growth rate of 2.7%/yr. This compares to the output growth rate since 1990 of 0.3%/yr.

Similar analyses have been done for other crops both globally and regionally (Lywood 2009b). For all the crop region combinations that were modeled there was always a positive correlation between area growth and yield growth. The results for different crops and regions from this analysis are shown in table 5.

Region	Cereals EU	Rapeseed EU	Maize US	Soy S Am	Sugar cane Brazil	Oil Palm S E Asia
Yield growth change / output growth change	78%	37%	58%	10%	23%	23%
Area growth change / output growth change	22%	63%	42%	90%	77%	77%

Table 5 Source Lywood 2009b

The proportion of incremental output growth from land area growth varies between 22% for EU cereals and 90% for S American soy. This compares to the value of 100% used in many equilibrium models.

This analysis of crop yield growth was not included in the DGEnergy peer review (DGEnergy 2010).

Figures 1 and 2 demonstrate two different ways to show how appropriate modeling can be used to determine the proportion of output growth that is met by yield growth and land area growth. Modelers should use these or other methods to determine the proportion of incremental output growth from land area growth and yield growth.

4.3) Modelling of yield growth in current models

It might be expected that since equilibrium models are classed as economic models they would determine the proportion of the increased demand of crops from land area change and yield change, by relating these changes to prices in the same way as they determine output/price elasticities. However none of the equilibrium models determine crop land area changes in this way. Even though the determination of land area changes is a primary step in the calculation of ILUC, few equilibrium models determine or use factors to relate land area changes to prices.

IFPRI and E4tech models take account of the effect the effect of demand growth on yield growth, to determine the proportion of marginal demand growth that is met by yield growth and land area growth. However, the basis of the IFPRI figures is not given.

Most equilibrium models attribute increases in yield to technological gains that are independent of market signals, while attributing year to year variations in yield to the weather. (Keeney 2008). Other models split yield growth into increased inputs and improved technology. The models determine the land area growth indirectly by subtracting a yield growth estimate from the demand growth. Most equilibrium models e,g, FAPRI, FASOM assume an exogenous yield growth rate based on average historic yield growth rates. Thus in these models, yield growth is not related to price or to output growth at all. The effect of this assumption is that if the forecast output growth is greater than the exogenous yield growth rate, the incremental land area growth will be assumed to be met entirely by land area growth. For EU cereals, this approach leads to a modelled land use change which is 1/0.22 = 4.5 times higher than when the effect of demand growth on yield growth is properly accounted for.

It is not clear that any equilibrium models have validated their approach by demonstrating that their predictions of past perturbations in crop land areas satisfactorily match those observed.

The lack of proper modelling of land area change in equilibrium models, by assuming that yield growth rate is unrelated to output growth rate causes an overestimation of the GHG emissions from ILUC for most crops, with an overestimation of 4.5 times for the case of EU cereals.

4.4) Factor for lower yield on new land area

It is possible that when new land is needed to grow extra crop, the new land will be more marginal than the existing cropland, so the yield on the new land will be lower than on existing land. In GTAP based models this effect is termed "slippage" and the models use an elasticity factor to relate the yield on new land to the yield on existing cropland. The effect of slippage is subtracted from the yield growth. It is accepted by CARB that "little empirical evidence exists to guide modellers in selecting the most appropriate value". The CARB GTAP model work uses "best available professional judgement" to choose a central case elasticity factor of 0.5, meaning that the average yield on new land will be half of that on existing cropland. The GTAP model for EU biofuels JRC (2010b) uses a factor of 0.66, while the IFPRI MIRAGE model uses a factor of 0.5 for everywhere except Brazil, where a factor of 0.75 is used. These factors appear to be entirely arbitrary.

When there is a lower yield on new land area, then:

Net yield growth =
yield growth on existing crop land - land area growth x (1- slippage factor)

Historic yield change data for example from FAO is collected on an average regional or country basis and is the net yield growth. Therefore these yield changes already take into account any effect of lower yield on new land. As long as a relationship derived from historic yield data is used to relate yield growth to prices or to demand growth, as in figures 1 and 2, then these relationships already includes the effects of slippage and there is no justification for a separate elasticity factor for a fractional yield on new land area.

It may be seen from the equation above that if the yield growth on existing land is constant and the slippage factor is less than unity, the yield growth and area growth will be negatively correlated. However, as seen in Figure 2 for EU cereals and is also for the other crop region combinations in table 5, this was not the case. For all crop region combinations, yield growth increases with area growth. If modellers believe that changes in demand effects net yield growth, they must derive a relationship between demand growth and yield growth. If modellers believe that changes in demand growth do not effect net yield growth, they cannot justify the use of a slippage factor. Modellers can't have it both ways, by using a yield growth that on existing land that is independent of demand growth and then adding a slippage factor.

The use of an elasticity factor to relate the yield on new land to existing yields is not justified. When yield growth estimates are based on historic regional yield data. The effect of introducing such a factor results in overestimating land area changes as a result of crop demand increases.

4.5) Increased yield with increased price

Some models e.g. CAPRI, include a yield v price elasticity such that the yield in any year may be higher due to a higher price in that year. However, this effect of price only applies to the specific year, so has a minor effect on the yield increase over a period of years. It does not model the increased yield growth with increased demand over a multi-year period, which has a major effect on the proportion of demand growth that is met by yield growth and area growth.

5) Changes to trade in biofuel crops

When crops are used for biofuel production, it is important to determine in which country or region the additional crop will be grown, in order to determine the land use changes. If there is an increased demand for a crop, for example in the EU, due to increased biofuel demand, then some of this demand is met within the EU, while some of the demand is met by changes in trade: reduced exports or increased imports. For biofuel crops that are primarily imported into the EU or where a crop product, for example vegetable oil, or the biofuel itself is imported into the EU, it may be assumed that increased EU demand will be met primarily or entirely by increases in imports. For example it is shown (JRC 2010b) that for vegetable oils, the world market behaves like an integrated world market.

However, for crops, such as cereals, which are widely grown locally, the transport costs are high, compared to the value of the crop and therefore many regions maintain a self sufficiency of these crops and the crop output is adjusted to meet demand. It is shown that increased demand for crops for which the region is self sufficient, will primarily be made up by increased production in that region.

The cumulative world trade balance for wheat is represented in Figure 3. Each point represents a country with the countries sorted by the ratio of imports/consumption.

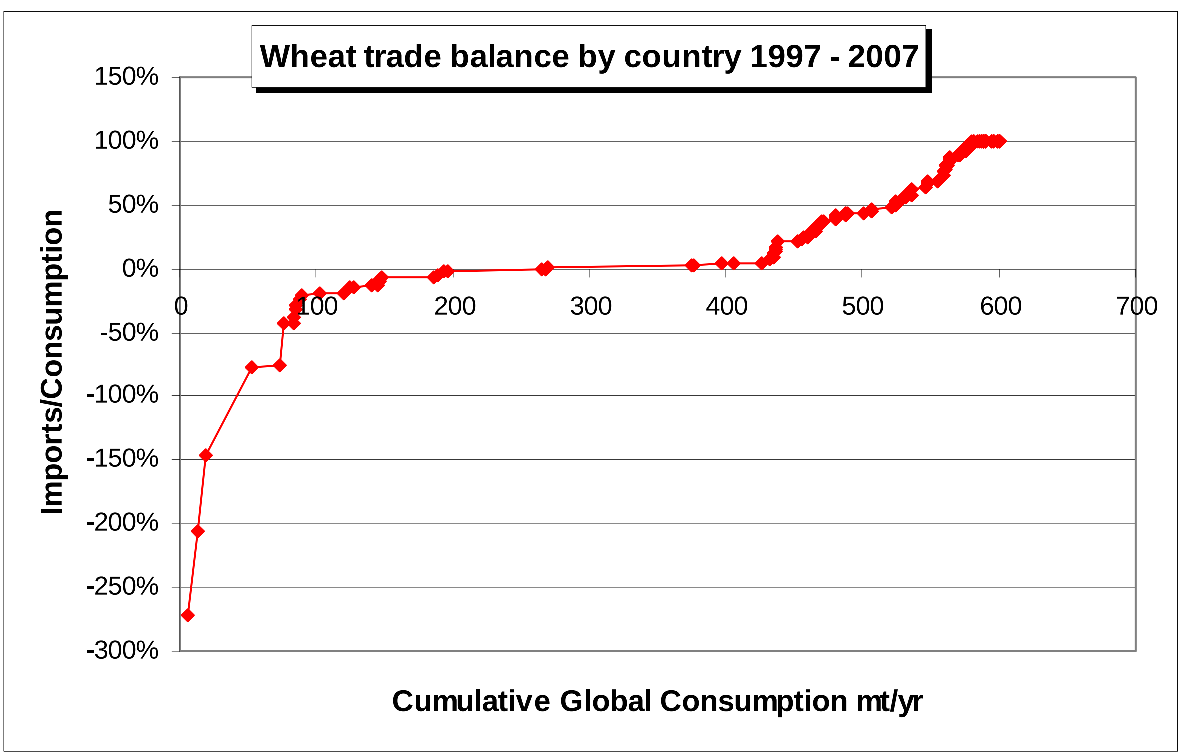

Figure 3 Source USDA 2010, Ensus analysis

It can be seen that a large proportion of wheat consumption is in countries that are in a trade balance for wheat. 41% of total global wheat consumption is by countries that have a ratio of imports/consumption between -10% and 10%. The cumulative world trade balance for maize is similar, with 42% of total global consumption being by countries that have a ratio of imports/consumption between -10% and 10%.

When regional groups of countries are taken together the traditional intra regional trading can maintain a close trade balance. In the EU, France exports cereals to countries such as Italy, Spain, Algeria and Morocco which don't grow all their own cereals. The production, consumption and trade balance of cereals in the EU27 + Algeria + Morocco is shown in figure 4, by plotting four year moving averages, of USDA data from 1960 to 2009.

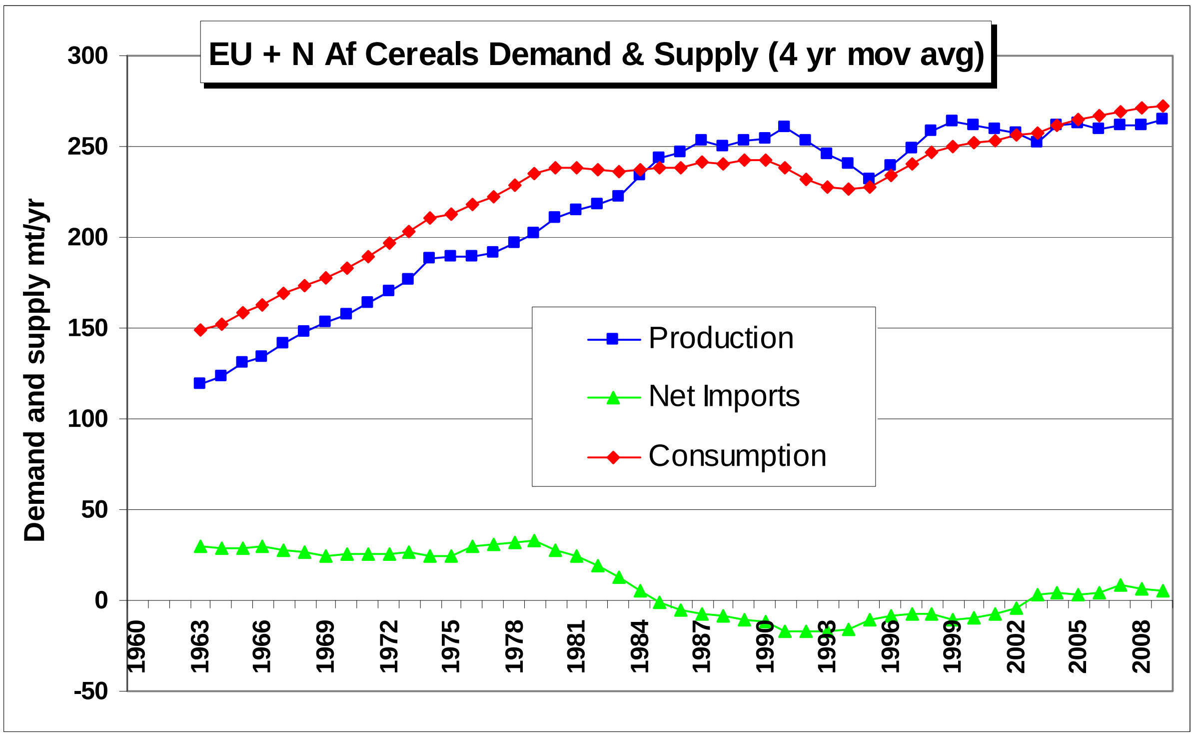

Figure 4, Source – USDA 2010, Ensus analysis

It may be seen that in the period from 1960 to 1980, the consumption of cereals was increasing rapidly, but since 1980, the demand has levelled out. The increasing demand up to 1980 was met by increased production within the EU, but with a lag. The rate of production continued to increase till about 1985 and then levelled out to keep cereal production close to a trade balance. It can be shown (Lywood 2010) that although cereal yields continued to increase in the EU, increased production was avoided by idling of excess land. The EU maintains a rough trade balance on cereals because of the significant differences in logistics costs associated with being a net importer and net exporter. It is more economic to increase cereal yield, or reduce the rate of abandonment of cropland, rather incur the logistics costs associated with importing cereals.

The proportions of increased crop demand that will be met by increased production and by changes in trade can be determined directly using factors to relate the change in trade flows and change in production to changes in demand.

The results for the case of changes in EU + Alg + Mor cereals trade and production as a result of changes in demand within the EU are shown in figure 5. This uses a one year time lag between demand changes and trade and production changes and four year averages to reduce annual noise.

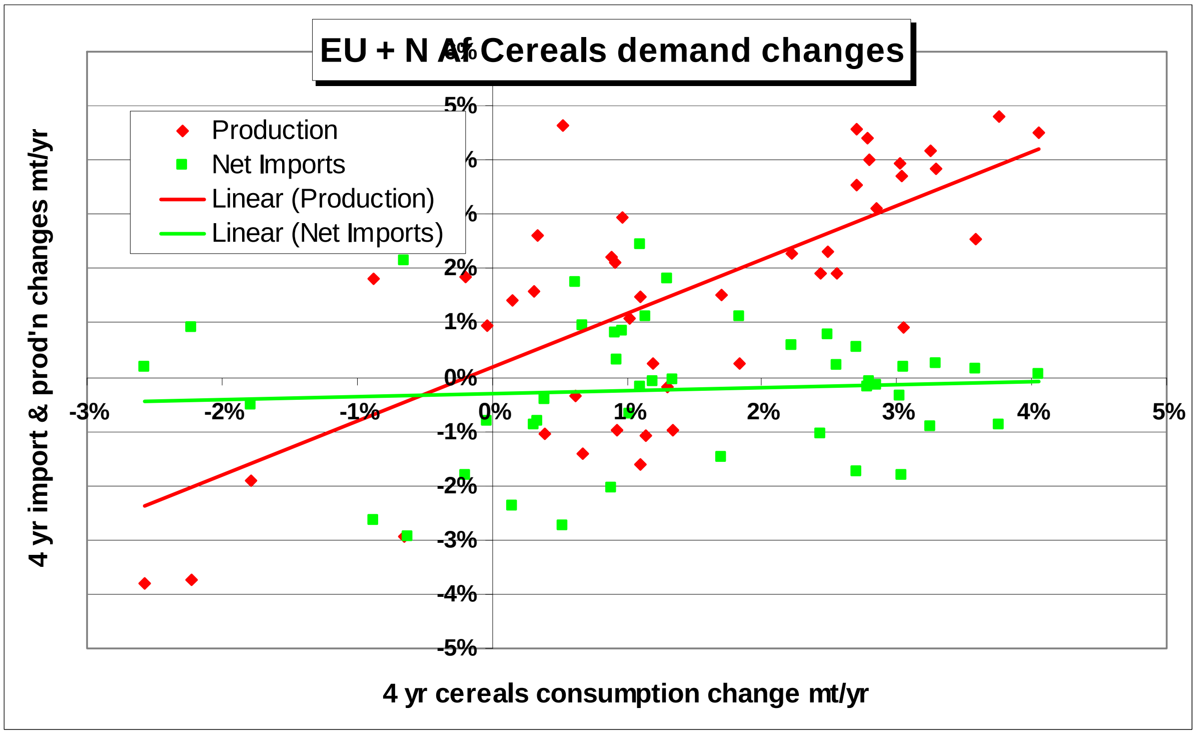

Figure 5, Source – USDA 2010, Ensus analysis

The best fit to these data is that 99% of the changes in demand are met by changes in EU production. There is a substantial scatter in these data and so there is some uncertainty in the fitting. However, there is no statistically significant relationship between EU demand changes and changes in net imports. These data shows that nearly all the change in EU demand for cereals is provided by changes in EU production and very little will be met by changes in trade.

The issue of modelling changes in trade was not addressed in the DGEnergy literature review (DGEnergy 2010).

5.1) Modelling Changes in trade

Many equilibrium models use an “elasticity of substitution” to determine how much of the change in crop demand due to biofuels crops is met by increased imports or reduced exports. The elasticity (often referred to as an Armington elasticity) factor relates the change in marginal imports to changes in prices in trading countries or regions. These values appear somewhat arbitrary since none of the models details the value or the source of the elasticity of substitution being used, let alone provide any justification of the factor.

For some equilibrium models, for example FAPRI and FASOM it is not stated how changes in trade are modelled.

There are some concerns about the use of the Armington model for modelling cereals in the EU:

- The Armington elasticity model assumes that each country produces its own set of products which are somewhat differentiated from products from elsewhere and therefore products from different countries are imperfect substitutes of each other. However, cereals, for example wheat used in animal feed rations from different sources are interchangeable and not differentiated between countries.
- The Armington elasticity model does not take account of changes in logistics costs associated with switching from net import to net export or vice versa, when a country or region is close to a trade balance. Due to the high transport cost, relative to the production cost of cereals, it would be expected that local production changes would be used to meet changes in local demand.
- There has been much debate on what is the correct value of Armington elasticity factors to be used for changes in trade as a result of duty changes. (McDaniel 2002). Different values are used for Armington elasticity factors, with the IFPRI-MIRAGE model using an Armington elasticity factor of 10 for single crops (IFPRI 2010), compared to a value of 2.6 used in the CARB version of the GTAP model.

If equilibrium modellers use elasticity factors, for based on theoretical price changes and hypothetical demand elasticities, they should validate their factors, by showing that they give similar results as those obtained by the data analysis in Fig 5.

The results from different models for the proportion of increased EU cereals demand, that is met by changes in trade or changes in land area is shown in table 6.

EU ethanol production from cereals								
Model		**FAPRI**	**Aglink-Cosimo**	**CAPRI**	**GTAP**	**LEITAP**	**E4tech**
Share of increased cereals from cereal imports	t/t	6%	53%	70%			0%
Share of increased LUC from non EU regions	ha/ha	-4%	65%		54%	34%	0%

Table 6 Sources JRC 2010a, JRC 2010b, E4tech 2010

The results for many of the equilibrium models give a much lower share of cereals from EU production and a much higher share from changes in trade than is justified by historic responses to demand changes. The models will therefore use lower cereal yields and higher GHG emissions per ha of land than would apply within the EU. This will have the effect of overestimating the GHG emissions from ILUC for EU cereals ethanol production.

The models overestimate the proportion of EU demand for cereals that will be met by EU imports or reduced EU exports. This results in the replacement cereals being modelled as being grown at lower yields and on higher carbon stock land than in the EU and gives an overestimation of the land use change and GHG emissions from ILUC.

6) Type of Land Changes

Various approaches have been taken by different models to determine what types of land are converted to cropland in different countries. These include:

- Extrapolation of historic data
- Use of cross elasticity factors
- Economic analysis using cost curves and agro-economic zones.

Different models use different categories of land which is converted to cropland. These can include various types of grassland and forest and idle land.

6.1) Extrapolation of historic data

Historic land use data is available from FAO, MODIS satellite data and studies made for specific countries. FAO data provides the most comprehensive set of historic data covering all countries, with crop area data since 1961 and forest area data since 1990. The FAO cropland area data is similar to USDA data (USDA 2009) and compiled from official country annual statistics and is expected to be generally accurate. However, the forest area data is based on data every 5 years and is less accurate. There is an issue with large countries such as Brazil, that the land use change to provide extra cropland will be different for different crops e.g. sugar cane and soy bean depending on where the crop is grown within the country. FAO data is may therefore not be representative for any particular crop, but several land use change studies have been done for Brazil, which will provide appropriate historic data.

An alternative source of data is from the MODIS satellite imaging, from 2001 to 2004, which was analysed by Winrock (2009). These data are used to determine the changes in cropland areas and the proportions by which new cropland displaces forest, grassland, savanna and shrub land between 2001 and 2004. However, the MODIS data is not consistent with FAO for cropland area change for some regions. The data are compared in table 7.

	Change in Cropland Area 2001-2004	
	MODIS	**FAO**
EU	17.9%	-1.1%
Brazil	-2.0%	20.7%
US	7.1%	1.1%

Table 7, Source FAO 2009b, Winrock 2009

The EU Member States crop data is required for the Common Agricultural Policy and should be accurate, so the differences between FAO and MODIS data must be attributed to errors in the MODIS data. A more detailed analysis and comparison of MODIS data has been submitted to the EPA (Lywood 2009c). This work shows that the accuracy of satellite data must be considerably improved before it can be used for monitoring land use changes.

While FAO data includes idle land, the MODIS data doesn’t.

FAO data is used by Searchinger (2008), MODIS data is used by EPA (2009) and historic data for Brazil from specific papers are used by ADAS(2010).

6.2) Other methods of modelling types of land use change

The CARB GTAP model uses land substitution elasticities to determine the proportion of land that any crop will displace, in terms of: substitutable crops, other crops, grassland and forest. The elasticities proposed for the EU are listed (Valin 2009a) based on OECD work. The substitution elasticity factors between agricultural v forest and cropland v pasture can be used to determine the proportions by which new cropland will displace forest and pasture, or by which forest and pasture will arise on idled cropland.

The IFPRI-MIRAGE (Valin 2009b) and LEITAP (Prins 2009) GTAP models are also evaluating an option to use land supply curves in a deterministic modelling approach to determine the lowest cost option for obtaining new cropland from different areas of natural vegetation.

JRC ISPRA have developed a new methodology (JRC 2010c) to determine where land use will occur, on the basis of existing cropped area, land availability and land suitability.

It is not clear that any of these methods for modelling types of land use change have been validated against historic data and more work is required to justify such approaches.

6.3) Inclusion of idle land

Within the EU and FSU, any additional land to meet the demand for EU biofuels crops will come from the uses of former arable land that is now idle and in the EU from the reduction in the rate of abandonment of arable land. About 4 million ha of former set-aside idle land were created within the EU, which were released for use as normal cropland in 2008, to meet the increased demands for biofuels.

A detailed analysis of agricultural land in the EU, using FAO data (Lywood 2010) shows that:

- The area of arable land in the EU has reduced continuously since 1961 with an average reduction of 0.4 million ha/year from 1985 to 2007 (FAO 2009a)
- The rate at which EU cropland is idled is related to the EU demand of arable crops.
- Therefore the increase in demand for EU biofuel crops will be met by use of former set-aside land and a reduction in the rate of creation of idle land in the EU.
- Most of the idled land in the EU is left for natural succession and only 12% of the the idled land is subsequently afforested.
- Using carbon accumulation rates of 0.34 t C/ha/yr for natural succession (Post and Kwon 2000) and 1.5 t C/ha/yr for managed afforestation (Greig 2007), the average level of foregone sequestration is 0.48 t C/ha/yr

This figureof 0.48 t C/ha/yr can be compared to values of carbon stock changes for conversion of other land to cropland in the EU, amortised over 20 years of 1.2 t C/ha/yr from JRC (2010c) and 1.9 t C/ha/yr from IFPRI (2010). Thus if models do not take account of idle land in the EU, they overestimate the GHG emissions land use changes by a factor of between 2.5 and 4.0.

Most models have been developed for global land use change modelling and do not take into account changes in fallow land, temporary grassland and unused land, which are relevant in the EU and FSU. Only the E4tech (2010) models take account of the re-use and reduction in the rate of abandonment of idle land in the EU.

The lack of inclusion in models of unused and idle land in the EU and abandoned land in FSU will cause an overestimate of the GHG emissions from land conversion to cropland.

This will be an overestimation of a factor of between 2.5 and 4, for biofuel crops grown in the EU.

7) Validation of models

It may be seen that several of the issues of concern with equilibrium models are common to several of the models. Also nearly all of the issues of concern appear to lead to an overestimation of the GHG emissions from ILUC, especially for crops grown within the EU. It is therefore not valid to draw any conclusions on the accuracy of equilibrium models, or the uncertainties in ILUC factors, or the potential range of ILUC factors by comparing the results of equilibrium models with each other.

For predictions to be trusted, the equilibrium models need to be validated, by demonstrating that ex-ante predictions of past perturbations in crop land and grassland areas, trade flows etc satisfactorily match those observed. It is not clear whether any equilibrium models have been validated in this way.

There are problems with validating equilibrium models against recent predicted outcomes (Babcock 2009), due to other random variables that might affect these outcomes. However, other ways must be found of validating these models. Price elasticities used within the models can be validated against historic data. For example land area : price and yield : price elasticities can be validated for crops as in figures 1, 2, and 7, while price elasticity factors for determining changes in trade can be validated as in figure 5.

8) Evaluation of policy

Some equilibrium models seek to evaluate the land use changes and GHG emissions from ILUC associated with a complete policy, for example the EU 2020 renewable energy for transport target. Since equilibrium models are derived from trade models and are to some extent based on prices, they attempt to determine the most economic mixture of biofuels production to meet the 2020 RED target. However, there are substantial difficulties with this approach:

- Some biofuel pathways will be restricted by the higher RED GHG savings thresholds that will be in place from 2014 and especially after 2017
- The choice of options for meeting the RED transport target will also depend on the GHG savings of different biofuel pathways and the need to meet the FQD target.
- There are limitations in the rate at which some biofuels, such as sugar cane bioethanol can be made available due to infrastructure bottlenecks
- The relative proportions of biodiesel, bioethanol and other renewable fuels will depend on vehicle limitations on the use of fuel blends in the EU
- The use of high blends such as E85 will depend on decisions by car manufacturers
- The uptake of high blends by motorists will depend on incentives provided in different Member States.

These difficulties may explain why different models have provided very different estimates of how the 2020 target will be met.

9) Modelling Approach

Although equilibrium models use price relationships for modelling crop and biofuel trade and the mixture of biofuels production to meet the 2020 RED target, the calculation of most of the factors in the equilibrium models associated with the calculation of ILUC are not based on economic drivers. Several factors for ILUC modelling have been modelled using assumptions or exogenous factors, rather than by economic analysis, or market understanding. These include:

- Displacement ratios of other crops by biofuel co-products
- Which oil seed crops provide marginal production of oil and meal
- Proportion of increased crop output supplied by land area changes
- Type of land that is converted to extra cropland

This may be because more work is needed to be able to include better economic modelling and market understanding, or because economic modelling is not appropriate for some of these relationships. The recent E4tech model (E4tech 2010), which has had the benefit of a wide range of experienced input, using a multi-functional expert advisory group has been able to include market understanding based on economic drivers, for the first three issues above.

Different models have chosen different ways of modelling these and other factors. It is important to try to move to some level of agreement between modellers, as to which factors are best modelled by different methods i.e. margin optimisation, price elasticities, direct elasticities and empirical models based on historic data. Use of assumptions, unvalidated factors and “expert judgement” is not appropriate, for the derivation of ILUC impacts that could determine the viability of some biofuel investments.

A substantial part of the reports and presentations on equilibrium models is associated with description and justification of model platforms, model structure and model linking. There are also descriptions of novel approaches or methods for modelling particular relationships. There is somewhat less justification for the method chosen for modelling different relationships. There is little or no justification of the parameters used in the models and the data sources.

There is a concern that much of the effort has been in developing more complicated models, rather than determining and justifying modelling methods and values of the parameters used in the models. It may be of more value to develop simpler models, for example spreadsheet based differential models, which use agreed methods for modelling those factors and determine the parameters that are most important for determining GHG emissions from ILUC.

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