JRC Scientific and Technical Reports

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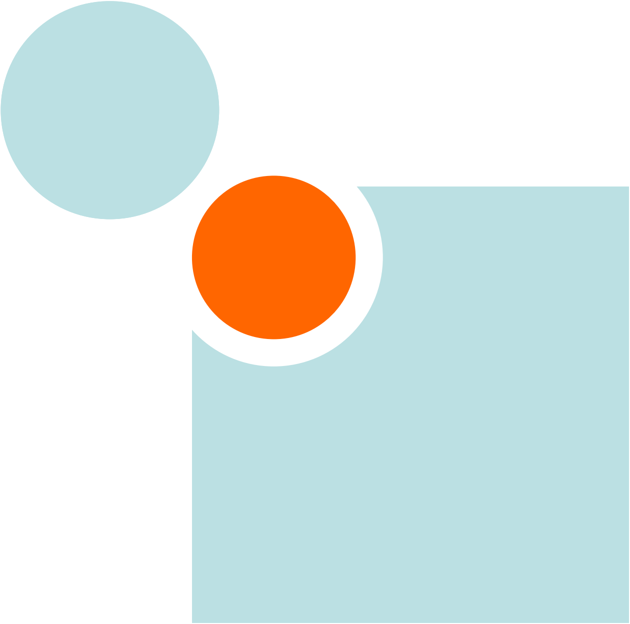
Comparison of models and results for marginal biofuels production from different feedstocks

Robert Edwards, Declan Mulligan and Luisa Marelli.



EUR 24485 EN - 2010

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JRC 59771

EUR 24485 EN
ISBN 978-92-79-16391-3
ISSN 1018-5593
doi:10.2788/54137

Luxembourg: Publications Office of the European Union

Printed in Italy

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Institute for Energy
Renewable Energy (Ispra)

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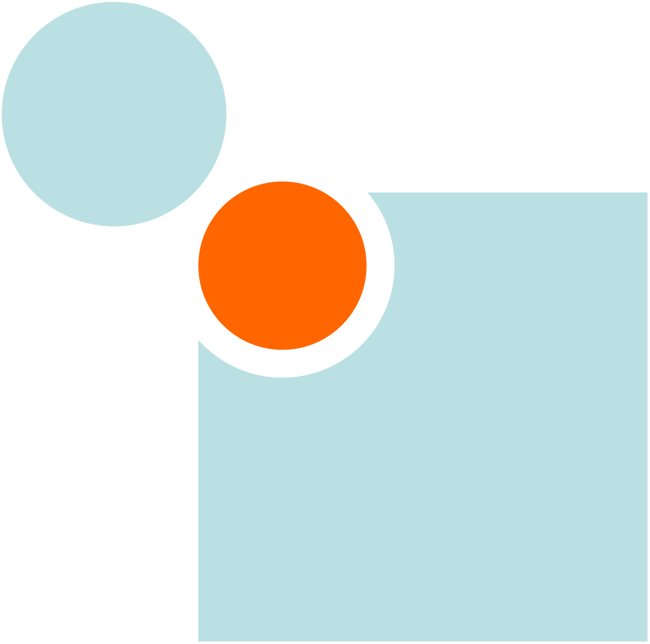

Final report of the contract n. 070307/2008/517067/C3

Acknowledgments:

This report is the result of the consultations with EU and US experts, and the inputs of all of them are acknowledged.

We thank in particular:

Martin Von Lampe (OECD),
Alla Golub (Purdue University)
Jacinto Fabiosa and Jerome Dumortier (FAPRI-CARD, Iowa State University)
Sonja Petersen and Bettina Kretschmer (Kiel Institute for the World Economy),
Ignacio Perez Dominguez and Geert Woltjer (Agricultural Economics Research Institute - LEI)
Elke Stefhest (PBL - Planbureau voor de Leefomgeving)
Simla Tokgoz and Siwa Msangi (International Food Policy Research Institute-IFPRI)
Stefan Unnasch (Life Cycle Associates)
Timothy Searchinger (Princeton University)
Michael O'Hare (University of California, Berkeley)
Peter Witzke (EuroCARE GmbH)
Steve Berry (Yale University)

for their prompt response in providing modelling calculations and for the great support in reviewing this report.

We also wish to thank our colleague **Fabio Monforti Ferrario** for his important contribution in reviewing this report.

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LIST of ACRONYMS

AEZ	Agro-Ecological Zones
AGLINK-COSIMO	Worldwide Agribusiness Linkage Program + COmmodity SImulation MOdel
CAPRI	Common Agricultural Policy Regional Impact Analysis
CARD	Center for Agricultural and Rural Development
CGE	Computational General Equilibrium
DDGS	Distillers Dried Grains with Solubles
FAO	Food and Agriculture Organization of the United Nations
FAPRI	Food and Agricultural Policy Research Institute
FQD	Fuel Quality Directive (Directive 2009/30/EC)
GDP	Gross Internal Product
GHG	Green House Gas
GTAP	Global Trade Analysis Project
IE	Institute of Energy of the European Commission
IFPRI	Food Policy Research Institute
ILUC	Indirect Land Use Change
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
JRC	European Commission’s Joint Research Centre
LCA	Life Cycle Analysis
LEI	Agricultural Economics Research Institute
LHV	Low Heating Value
LUC	(direct) Land Use Change
MJ	Megajoule
Mtoe	Million Tons of Oil Equivalent
NUTS	Nomenclature of Units for Territorial Statistics
OECD	Organisation for Economic Co-operation and Development
PBL	Netherlands Environmental Assessment Agency
PE	Partial equilibrium (models)
RED	Renewable Energy Directive (Directive 2009/28/EC)

EXECUTIVE SUMMARY

This study is performed under the request of DG CLIMA, in support to the preparation of the policy proposal on the assessment of the effects of Indirect Land Use Change (ILUC) and to the Commission's internal debate on how to address ILUC emissions in legislation.

Where we started off from

Until we launched this initiative, different modellers modelled different biofuels policy scenarios, describing different mixes of different amounts of biofuels in different regions. That made it almost impossible to make meaningful comparisons between the models. In this initiative, we persuaded different modellers to report the crop area changes for a marginal change in demand for particular biofuels in particular regions.

Which models?

This study compares the ILUC results produced by different economic models for marginal increases in biofuel production from different feedstocks. The work is the result of a survey of marginal calculations launched by the JRC-IE during 2009, involving some of the best known models worldwide. The partial and full equilibrium models compared in this study are:

- AGLINK-COSIMO (from OECD)
- CARD (from FAPRI-ISU)[1]
- IMPACT (from IFPRI)
- G-TAP (from Purdue University)
- LEI-TAP (from LEI)
- CAPRI (from LEI)

An overview of the key modelling parameters of the models used for these calculations is presented in chapter 5.

The modellers were requested by JRC-IE to run scenarios corresponding as closely as possible to the following specification (e.g. marginal runs against existing baseline of the following scenarios):

A marginal extra ethanol demand in EU

B marginal extra biodiesel demand in EU

C marginal extra ethanol demand in US

D marginal extra palm oil demand in EU (for biodiesel or pure plant oil use)

Other additional relevant scenarios (e.g. marginal extra ethanol from Brazilian sugar cane) could also be included.

The results from the different models and various scenarios are compared in this report in terms of hectares of ILUC, because all of the models produced data at that level. To enable direct comparison

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[1] The FAPRI modeling system when used by the CARD is labeled FAPRI-ISU CARD, CARD, and FAPRI-CARD.

of the results reported by the modellers JRC-IE standardised the results to kHa per Mtoe biofuels (Million tonnes of oil equivalent).

Model Linearity

One expects that the area of extra cropland per extra tonne-of-oil-equivalent (toe) of a particular biofuel should rise faster as the extra demand increases. That is because in general one expects the quality of the new land to decline as more is taken, and that yield increase will show diminishing returns to increasing spending. However, most models are linear in practice: they show changes in crop area which are roughly proportional to the extra demand for a particular biofuel. This is largely because econometric data is too scattered to allow calibration of non-linear behaviour. Only in the case of GTAP, the marginal ha/toe of LUC increases slightly with increasing biofuels demand. This becomes more noticeable if the ratio of marginal to average crop yield is reduced, for example from 0.65 for US production to 0.5, which indicates the non-linearity depends on the amount of extra area.

Non-linearity in IFPRI-MIRAGE model

However, this is not the main cause of the strong non-linearity of results for increasing EU biofuel targets from the IFPRI-MIRAGE study commissioned by DG-TRADE. As the target for first-generation EU biofuels is increased, the model forecasts a shift of marginal EU-biofuel mix from mostly extra sugar-cane ethanol to mostly extra biodiesel. As the model finds greater emissions-per-toe for biodiesel than for sugar-cane ethanol, the emissions per toe biofuel increases as the overall target increases.

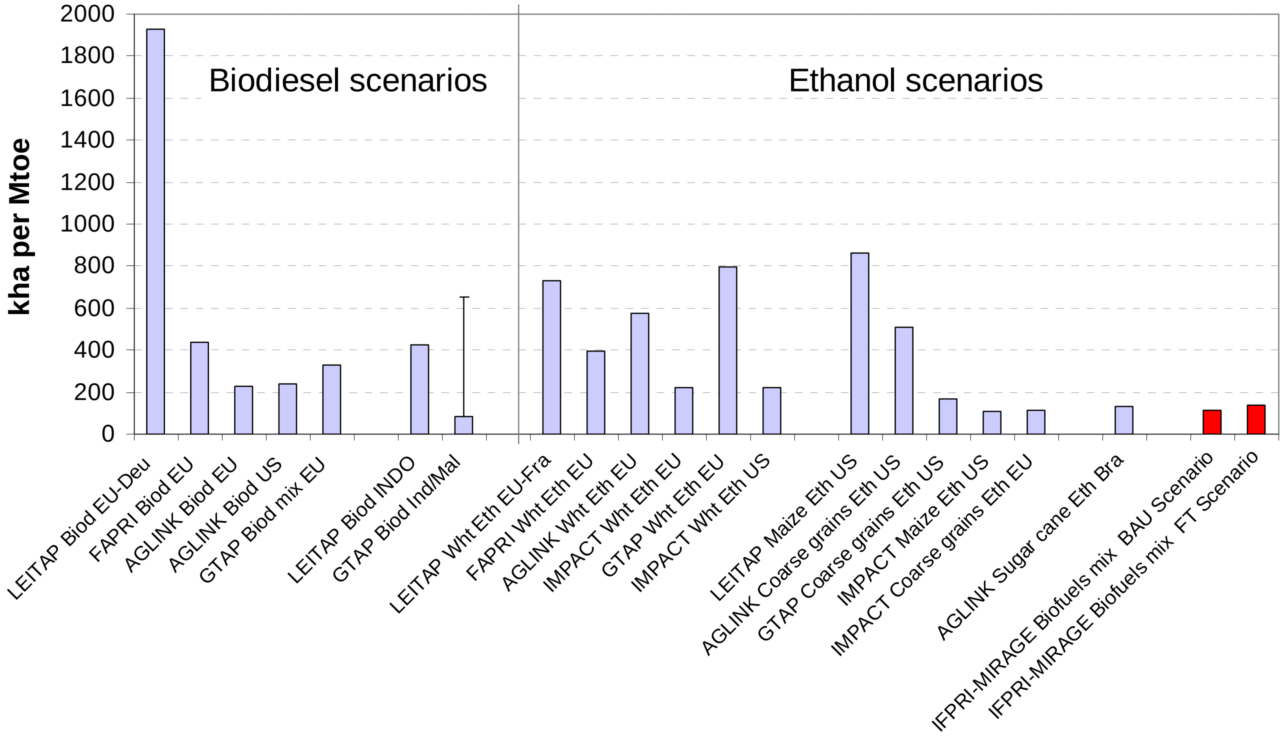
Marginal Scenarios

Since models are roughly linear, it makes sense to calculate the marginal land use change in terms of hectares per toe for particular biofuels;

- in order to compare the results for different biofuels in the same model
- in order to compare the results for the same biofuels in the same model of different models for the same size of shock
- in order to see to what extent LUC depends on the type of biofuel, and to what extent it depends on the region the shock occurs.
- to potentially form the basis for specifying “ILUC factors” for incorporation in policy

Overall results in hectares per toe

In the EU ethanol scenarios, the total estimated ILUC (in the world) ranges from 223 to 743 kHa per Mtoe. For most of the EU ethanol scenarios the models project that the largest share of ILUC would occur outside the EU, with the exceptions of the FAPRI scenario that forces all production to come from within the EU, and the LEITAP model. In the EU biodiesel scenarios, total ILUC ranges from 242 to 1928 kHa per Mtoe with the highest value coming from the LEITAP scenario for EU biodiesel in Germany. In all of the EU biodiesel scenarios the models project that the largest share of LUC would occur outside the EU. In the US ethanol scenarios total ILUC ranges from 107 to 863 kHa per Mtoe. The AGLINK-COSIMO model and GTAP models project that most of the ILUC would occur outside the US. However, in contrast the LEITAP model projected that 90% of the ILUC would occur within the US. In the extra palm oil scenarios (only modelled by LEITAP and GTAP), the two models projected a range of ILUC from 103 to 425 kHa per Mtoe. In the LEITAP model all of the ILUC would occur in Indonesia, whilst in the GTAP model the largest share would occur outside the Malaysia/Indonesia region. The AGLINK-COSIMO model was the only model to report for extra ethanol from Brazilian sugar cane. The model projected LUC of 134 kHa per Mtoe with all of the ILUC occurring in Brazil.



All models show significant LUC in all biofuels scenarios. LEITAP generally shows the highest LUC per toe biofuel. For ethanol scenarios this can be explained by underestimation of the by-products effects, but for EU biodiesel, this explanation is insufficient to account for the large difference.

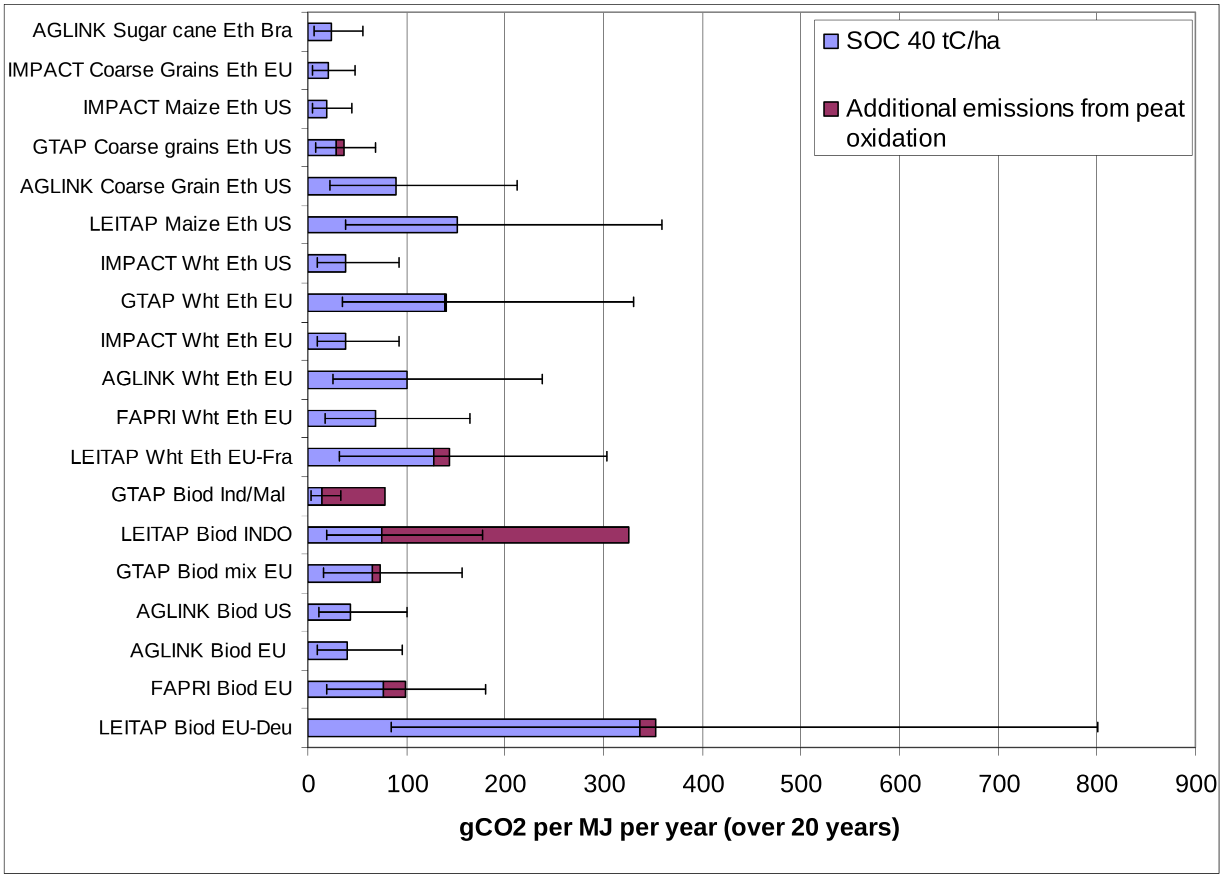
The lowest LUC/toe is shown by the IFPRI-MIRAGE (for DG-TRADE, with a mixed scenario consisting principally of sugar-cane ethanol and rapeseed biodiesel) and IFPRI-IMPACT models. If we take into account that the IFPRI-IMPACT model reported here has no correction for by-products, the results are similar for all IFPRI models. The IFPRI-IMPACT model projects greater yield improvements than the non-IFPRI models. We did not fully analyse the IFPRI-MIRAGE results, but it looks like this model also has a much larger fraction of extra production coming from extra yield than other models, and this requires relatively large quantities of extra fertilizer. It would be interesting to estimate the extra emissions from those extra fertilizers.

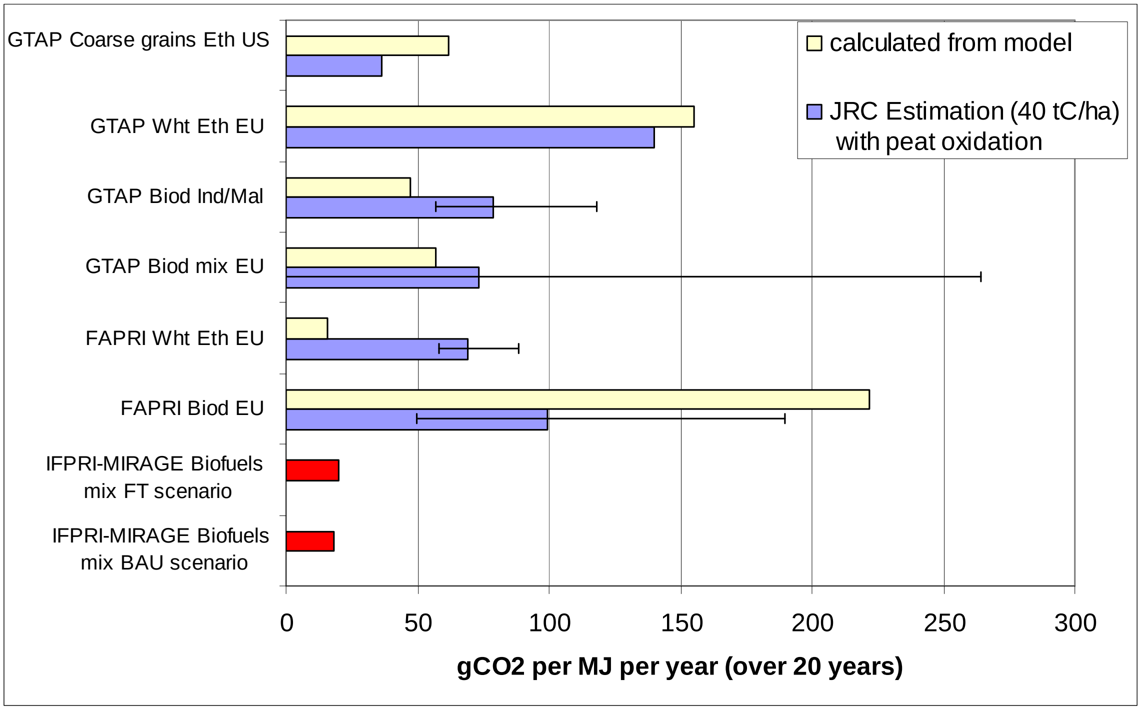
FAPRI EU-wheat ethanol results involve an increase in meat from ranching which could have significant LUC impact.

Overall results in approximate GHG emissions per MJ biofuels

Here we roughly estimated the range of GHG emissions which one could expect to correspond to the areas of LUC reported by all the models. The central carbon stock change is 40 tC/ha (IPCC default values report 38 to 95 tC/ha for conversion to cropland in EU and North America). The error bars represent the maximum range using 95 tC/ha (value also used in Searchinger et al, 2008), and the minimum derived from the lowest carbon stock change we came across: 10 tC/ha for abandoned EU cropland according to GreenAgSim.

Actual results from the two models who reported LUC emissions are compared with the JRC ranges in the second chart below. We argue that GreenAgSIM currently underestimates emissions for the FAPRI-CARD results for EU wheat.





Emissions from peat oxidation

All models except IFPRI-MIRAGE ignore emissions from the oxidation of tropical peat caused by drainage of tropical peat for planting oil palms. Even with a conservative estimate of emissions from peat oxidation (19 tCO_2/y/ha of oil palm, see appendix III), all biodiesel results show significant extra emissions[2].

In the IFPRI-MIRAGE model the emissions per ha of oil-palm are about an order of magnitude too low, because:

-: the proportion of *new* oil-palms planted on peat is too low,

- the emissions from peat oxidation consider an IPCC default carbon stock change value which is very low because it does not include the effects of the drainage needed for oil palm, and averages that with a an estimate for the minimum emissions.

Fraction of LUC in EU or US

All models agree that in biodiesel scenarios, most of the land-use change effects occur outside the EU. For EU-wheat bioethanol this is also true, if it is not specified that the feedstock must be *grown* in EU (as in FAPRI-CARD). For US maize ethanol scenarios, all models except LEITAP predict that most of the ILUC effects will be outside US.

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[2] We are still working on extracting palm oil data for AGLINK-COSIMO.

Reasons models disagree

The version of LEITAP used had some issues in treating vegetable oils and meals because the oilseeds are not disaggregated into these components. That seems to cause it to underestimate by-product credits in general, and give anomalous results in the EU biodiesel scenario.

IFPRI-IMPACT has low LUC results because it has the largest contribution from price-induced yield increases, resulting in relatively low area changes even though the model does not consider by-products. The same thing appears to apply (perhaps even more so) to IFPRI-MIRAGE results for DG-TRADE[3].

GTAP apparently has modest contributions from increased yields, but we should bear in mind that part of the price-induced yield increase has been countered by the effect on the average of the considerably lower yield assumed in GTAP for the crop produced on new area. So the effect of *price* on yield may not be much different from that in IFPRI-IMPACT. FAPRI-CARD and AGLINK-COSIMO give relatively modest price impacts on yield.

The other factor causing model results to diverge for similar scenarios is the extent to which production is shifted from countries with high yields to relatively less developed countries with lower yields. In our view, for changes over a time period of decades, the models using Armington elasticities probably concentrate crop production too much on the developed world (for biofuel production in the developed world), where yields are higher. The problem is that if one smoothes out annual variations in national market data to find long-term correlations, it becomes impossible to disaggregate these from trends with time.

The same problem affects the determination of long-term substitutability between different vegetable oils, or between different cereals: long-term data is almost impossible to separate out, and so short-term data tends to be used instead, even though we know this underestimates substitution elasticity. This becomes important if peat land oxidation from palm oil is included in biodiesel emissions: models tend to show rather modest impacts of rapeseed biodiesel on palm oil production, even though long-term trends suggest it is the world’s main marginal source of vegetable oil.

The FAPRI-CARD scenario for EU-wheat ethanol gives deceptively low crop area changes because the ethanol-induced shortage of feed-cereals in the EU results in meat imports from grazing land rather than cereals imports. By contrast the FAPRI-CARD EU rapeseed biodiesel scenario gives high LUC because it predicts a surprisingly large rapeseed area increase in India, where yields are comparatively low. By coincidence, these differences are further exaggerated by assumptions in the GreenAgSim model for the accompanying emissions.

Models Crop displacements within a region are mostly ignored, underestimating LUC

All models, except GTAP, assume that the area of cropland expansion depends on the yield of a particular crop whose production increases, whereas in fact it depends on the yield of the crops at the frontier of cultivation. These are typically significantly lower than the yields for the feedstocks (maize, wheat and rapeseed) assumed in these scenarios. (For oilseeds, one should compare cereals-equivalent yields here). For the EU the yield of crops on the marginal crop area is much lower than considered in any of the models, leading to a large underestimation in LUC area.

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[3] When considering the results of the IFPRI-MIRAGE modelling for DG-TRADE, one should bear in mind that a large proportion of the extra biofuels in that (not marginal) scenario come from Brazilian sugar cane. AGLINK-COSIMO results indicated that this feedstock has the lowest LUC impact in terms of ha/toe.

Partial Equilibrium vs. general equilibrium models and sensitivities

General equilibrium models attempt to model the whole world economy, whilst partial equilibrium ones stick to the most important aspects affecting agricultural markets. Neither type of model gives consistently higher or lower results. General-equilibrium models appear very sensitive to the choice of yield elasticities. All models are sensitive to the **ratio** of yield to area elasticity in different countries, and this ratio is more easily calibrated against historical data than the individual elasticities. The partial equilibrium models would be improved by a proper consideration of crop displacements within regions.

Yield increases on price

Farmers will hardly increase yields beyond baseline unless they see or expect a crop price increase. We distinguish two effects:

- A reversible increase in yield due to price increase. This is taken into account by all models, although they disagree about the size of the effect because of scatter and disagreements about interpretation of econometric data
- An irreversible price-driven increase in the *rate of increase* of yield (so-called "research spending effect"). We show that this can at most have a moderate effect on increasing the elasticity of yield on price.

Indirect Land use change emissions are only part of indirect emissions.

Indirect emissions are the difference between the overall emissions due to making biofuels and the "direct" emissions considered in the Renewable Energy Directive default values, which reflect the present emissions from farming on the existing area. Apart from the emissions due to indirect land use change addressed by these models, these include the extra emissions per tonne from farming crops on the new land compared to the existing area, and the extra emissions per tonne of crops produced by intensification on the existing area.

1. BACKGROUND: WHY MODELS AND WHY MARGINAL CALCULATIONS?

The European Commission (EC) is debating internally how to address Indirect Land Use Change (ILUC) emissions in biofuels legislation. The Directives 2009/28/EC (Renewable Energy Directive - RED) and 2009/30/EC (Fuel Quality Directive - FQD) contain provisions on monitoring and limiting the possible ILUC effects, but also give the Commission the task to further explore the issue, in order to establish the most appropriate mechanism for minimising ILUC: *"the Commission shall, by 31 December 2010, submit a report to the European Parliament and to the Council reviewing the impact of indirect land-use change on greenhouse gas emissions and addressing ways to minimise that impact. The report shall, if appropriate, be accompanied by a proposal, based on the best available scientific evidence, containing a concrete methodology for emissions from carbon stock changes caused by indirect land-use changes".*

Direct and Indirect Land use change

If the crops needed to make a particular batch of biofuels crops are grown on uncultivated land, this will cause direct land use change. If crops grown on existing arable land are used to make biofuels instead of food, this will likely cause ILUC because of the necessity to replace the food.

However, the distinction between direct- and indirect- land use change only makes sense for a ***particular batch*** of biofuels. If one is talking about the land-use implications of a policy or a certain overall production of biofuel, there is just one land use change effect, which one can think of as the sum of all the direct and indirect effects of the particular batches. The models do not distinguish which feedstock is grown on “new” or “old” land: they simply look at the consequences of crop demand changes on land area. Thus one can call the effect simply land-use-change; but since it gives rise to one of several indirect *emissions* (as shown further in this report), **people use the term LUC and ILUC interchangeably in the context of model results.**

Time accounting

Most ILUC emissions can be generally thought of as one-time, short-term emissions due to loss of soil carbon and standing biomass occurring within a few years of the land being converted. For accounting purposes, these must be combined with annual emissions by amortization (20 years in the EU legislation) or discounting. However, that is not always the case. For example, when young forests are converted, or when the effect of biofuels is to maintain croplands in production, the emissions from ILUC are the foregone carbon sequestration that would otherwise occur on these lands.

In addition, some effects of biofuel expansion are second level. For example, cropland expansion can occur into grassland, which causes not only carbon releases from soils but a loss of production of animal products. Some of the lost production can be compensated by expansion of grazing land into forest. Some models attempt to model this effect, but most ignore it, predicting only the expansion of cropland. Similarly, palm oil may displace local food production or small scale rubber production, causing displacement of these uses. In both cases, ILUC occurs where ever plant growth is being replaced.

ILUC emissions are essential to seeing if biofuels save GHG

Some people may view ILUC as a secondary effect of biofuel production, but it is really a critical component of answering the question of whether diverting the photosynthetic capacity of land to biofuels from its present use results in greenhouse gas reductions or not. Biofuels do not reduce tailpipe emissions (Searchinger et al, 2009). Their potential to reduce greenhouse gas emissions flows from the carbon absorbed by plants turned into biofuels. Life Cycle Analysis studies (LCA) give a credit to biofuels for this carbon, typically by treating it as offsetting tailpipe emissions of carbon. Without this credit, biofuels would virtually always increase emissions. But using plant carbon is not free because it means the carbon, or the ability of land to support photosynthesis of other plants, cannot be used for other purposes (Searchinger, 2010). Sometimes that means a direct loss of carbon sequestration. Sometimes it means the diversion of carbon in crops from serving their typical purposes as food or feed. It is necessary to calculate both direct and indirect land use change to determine if there is in fact a net gain to diverting plants or the land that produces them to biofuels.

ILUC emissions are just one of the indirect emissions caused by biofuels production

When crop prices and hence production increases as a result of biofuels, emissions arise from at least three separate sources:-

1. **Intensification for higher yields**
   As crop price increases, the economically-optimum spending on all inputs ($ per tonne of crop) increases, in order to increase yields. In general this can be expected to mean higher emissions per tonne of crop. This is dealt with further in the discussion section..
2. **Annual emissions from farming the newly-planted areas**
   In general one expects the poorer yields on the expanded part of the crop area, because in most of the world the best land is farmed first. This is likely to cause higher annual farming emissions per tonne of crop (compared to growing the same crop on more fertile land[4]))
3. **Emissions from converting more land to cropland**
   Emissions arise from the net loss of standing biomass, and from net loss of soil carbon due to farming.

None of these emissions correspond to the average annual GHG emissions from farming the actual crop which goes into making biofuel, but these are the only farming emissions that are known with any certainty, and are used as the basis for estimating “direct” emissions from biofuels, such as those used in the Renewable Energy directive. The difference between the sum of emissions 1-3 above and “direct” cultivation emissions from biofuels has become lumped together as “indirect emissions”.

However, models of ILUC emissions only consider the last of these, even though some models do involve calculating changes in spending on farming inputs including fertilizer, which could be used to estimate the emissions from intensification. More research is needed for estimating especially the difference between average emissions from the existing crop area and the emissions from the marginal crop area.

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[4] The extra crops which are grown in response to diverting one particular one for biofuel production need not be in the same region, or even be same crop. For example wheat diverted from animal feed to ethanol production in EU could (for example) be partly replaced by extra cassava grown in Africa. The extra African farming emissions would then be part of the emissions caused by EU-wheat ethanol.

Why models?

A simple consequential approach to crop and by-product substitutions can be useful in showing the upper or lower limits of LUC corresponding to simplified best- or worst-case assumptions.

However, in reality many different chains of crop substitutions and displacements occur simultaneously; to cope with these a model of world agricultural markets is essential.

Partial-equilibrium models concentrate on modelling agricultural markets. They are based on linear relations between prices, demand and production described by linking elasticities. The elasticities are derived from statistical data of past market movements. However, they are generally sophisticated in treating substitutions between crops, by-products and yield changes.

General-equilibrium models are more ambitious: they seek to model the whole world economy, so that, for example, interactions with fertilizer/chemicals and fuels sectors are integrated.

Models for the impact of biomass on agricultural markets generally start with a baseline which describes the model's "best estimate" description of the present or future state of the world's markets and agricultural policies. Then this baseline is "shocked" with a change in policy or directly by a change in biofuels demand. The results then show changes in production, prices and crop area. Some models go on to estimate the resulting greenhouse gas (GHG) emissions.

Comparing models

The problem one faces with comparing the published results from different models for LUC is that each has been used to model different scenarios, with different amounts of biofuels produced in different parts of the world using a different mix of feedstock. If one wishes to compare one with another, the first requirement is that the comparison is made on the basis of the same change in biofuels production. Secondly, they should only change one type of biofuel at a time. This also serves the purpose of giving policy input on which type of biofuels cause how much LUC (emissions).

In fact policy–making needs to be informed to what extent LUC emissions depend on the type of biofuel feedstock (for example, between the cereals sector and vegetable oils sector), and to what extent it depends on where, geographically, the increased production of biofuel takes place. If one considers the world market to be a single-market, the site of the biofuel production would not make any difference to the ILUC results.

To provide support to the debate and to contribute to the understanding and accounting of ILUC emissions, the JRC-IE developed contacts with the worlds' main agricultural modelling groups. First it initiated an expert consultation to discuss the issue of model comparison and to recommend standard scenarios to compare. That was achieved principally during the Paris workshop jointly organized with EEA and OECD[5]. The original aim was to get modellers to agree to voluntarily run standard scenarios so that the results could be compared. However, although there was enthusiasm for the concept, most modelling groups (with the exception of OECD and DART) did not find resources to run extra scenarios beyond those already contracted in their work plans. Therefore JRC issued contracts for calculating the appropriate scenarios from various groups.

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[5] Another outcome of the Paris workshop was a working group of EU modellers aiming to align baselines.

Linearity and marginal scenarios

If the ILUC emission per MJ is independent of the size of the biofuel shock, a model is said to be linear[6]. At the JRC-EEA-OECD expert consultation[7] in Paris, the modellers were asked whether their models were linear with varying levels of demand for a particular biofuel from a particular feedstock. All modellers agreed that models were linear for small shocks, and most believed the linearity would be satisfactory up to the limits of the shocks imposed by biofuels policy, but more testing would be needed to confirm this for general equilibrium models. This is discussed further in the light of results from this exercise in section 7. The implication is that it makes sense to compare the marginal results of different models for small changes in biofuels demand, expressed on the basis of marginal change per unit of biofuel production.[8]

If the models are linear, the marginal effects should be additive between:

- different biofuels in different amounts
- different crops and by-products

For modelling the GHG efficiency of different feedstocks, the experts agreed that the "extra biofuel" scenarios could be marginal increases in demand for different biofuels-feedstocks in different regions. These results would be relatively easy to compare between scenarios, and the JRC-IE commissioned work on these scenarios from various modelling groups.

The JRC-IE did not seek to impose a uniform baseline as a pre-condition for this work. This was for two reasons. Firstly, expediency: in the time available there was no possibility to align the baselines of all the models (a separate initiative for baseline alignment between some EU modellers was a separate outcome of the Paris workshop). Secondly, different baselines are part of the differences in the world-view reflected in different models. Therefore, to save time, the JRC-IE asked the modellers to run these marginal calculations against the existing baseline of their models, without requiring them to be aligned beforehand. In fact, up to the limits of biofuels policy in the EU and US, the ILUC effects per unit of biofuels are fairly constant (i.e. models are rather linear - see discussion on linearity in chapter 4), and it does not make much difference what the level of biofuels demand is in the baseline scenario.

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[6] A linear model is not the same thing as a *static model,* which does not consider yield changes. No models dealt with here are static.

[7] JRC-EEA expert consultation on "*Review and inter-comparison of modelling land use change effects of bioenergy*" (OECD Paris, 29-30 January 2009), EU Report 24137 EN, 2009. Outcomes are also available at http://re.jrc.ec.europa.eu/biof/html/iluc_bioenergy_policies_paris.htm).

[8] The modelling of ILUC emissions due to EU biofuels targets commissioned by DG-TRADE using IFPRI-MIRAGE model gives results which are strongly non-linear with biofuels shock. However this is not due principally to non-linearity of the model applied to one type of biofuel. Instead, it is mostly due to the change in the mix of different types of biofuels (biodiesel: ethanol) as the total policy shock increases. (Personal communication, David Laborde).

2. THE MARGINAL SCENARIOS

2.1 Scenario comparison

The ideal output from the models, for the purpose of policy development, would be the marginal tonnes GHG/toe biofuels for every biofuel from every feedstock. However, some models are not capable of defining one feedstock: they can only deal with policy drivers. Others can only deal with one crop at a time. So there was no exact set of scenarios that all the models could work on, given the time constraints, and differences between model structures and baselines. The JRC-IE negotiated the most disaggregated results which each model was capable of providing in the time-frame. This was on the basis that it is easier to aggregate results than disaggregate them.

The modellers were requested to run scenarios in their models corresponding as closely as possible to the following specification (e.g. marginal runs against existing baseline of the following scenarios):

A marginal extra ethanol demand in EU

B marginal extra biodiesel demand in EU

C marginal extra ethanol demand in US

D marginal extra palm oil demand in EU (for biodiesel or pure plant oil use)

Other additional relevant scenarios (e.g. marginal extra ethanol from Brazilian sugar cane) could also be included.

Experts were asked to report results *per marginal toe (tonne of oil equivalent) of biofuel*. The size of the shock was left to the discretion of the modellers, on the provision that it was small enough to allow linear behaviour to be assumed, whilst large enough to allow easy visualization of the results. In practice, most modellers chose shocks of around 1 Mtoe.

It was not possible to co-ordinate the time-frames of the models, because some models work year-by-year, whereas others give a shock to a model of the world agro-economic system which is set in time. However, all results were for the period between 2010 and 2020. Between 2010 and 2020 world arable area is projected to increase by around 0.25%. (OECD-FAO Outlook). Models estimate the fractional change in area, so the time difference will result in a small error. Of course in some parts of the world particular areas of high or low C stock may become converted in the baseline between 2010 and 2020, but the overall effect on emissions must be regarded as negligible compared with the enormous uncertainties elsewhere in LUC estimates.

All of the data provided are expressed as marginal effects per toe change of biofuel production. If the model showed that an increase in the marginal biofuel in the EU leads to (always small) decreases in biofuels use in other countries, these interactions were not suppressed. However, the change in global biofuel consumption was reported to provide a divisor representing the net increase in biofuel use.

Certain intermediate results and model characteristics from the marginal calculations were also requested, to help explain differences in the final results. It should be noted that not all models could provide answers to all of the questions asked. All of the data provided are expressed as marginal effects per toe of the biofuel in question. Some of the indicators in the boxes below need figures to be aggregated for different crops which are changing production in the scenario. It was then suggested they be expressed as an equivalent amount of cereals, based on the yield ratio of each crop to that of the most common cereals crop on the same land, or weighted by economic value. However, this proved a difficult calculation for the modellers, who reported the effect in terms of the effect on the hectares of LUC in the results.

One could propose to compare model results at various levels: production change per country per crop, crop area change, and ILUC emissions. The JRC-IE decided to compare principally crop area change (also broken down by region and crop, when data was available), because all models gave such an output. Only two of the models attempted to predict GHG emissions, and this introduces another layer of differences. The JRC-IE has provided a rough estimation of the emissions from LUC predicted by the models, using a range of emission factors representative for a wide variety of land-types.

LUC results also capture most of the information on the distribution of production changes by region and crop, because most of the models ultimately relied on FAO data for the average yield per country (with the exception of FAPRI-CARD which uses PSD/USDA, which is not always consistent with FAO data, but not wildly different). Furthermore, data on production changes are difficult for the reader to relate to possible LUC emissions, whereas the reader may have some rough idea of the typical land use change emissions per hectare.

Results of these studies were discussed during a workshop organized by the JRC in Ispra on 10th and 11th of February 2010[9]

2.2 Scheme to compare model characteristics

From the point of view of a modeller who is used to a particular model, the most useful way to compare models is to compare the values of all the various types of elasticities built into their model, for different crops and regions. Unfortunately, though, other models are so different in structure that a straight comparison of these internal constants is impossible. Furthermore, the elasticities cannot be compared one by one because it is often the *relative* size of elasticities which is important. Therefore some higher-level comparison of the models is needed, aiming to find meaningful indicators which can be compared between models.

The original aim of this comparison was to allow modellers to report the high-level comparison parameters for their own models, using whatever method was most convenient for their model. But we found that some parameters could not be found for some models, and that different modellers interpreted the requested parameters in different ways, so that many of the the parameters provided could not be compared directly.

At the start of the marginal scenarios initiative[7], Peter Witzke of EuroCARE GmbH was invited to attempt to build an economic meta-model made up of parameters reported by the different modelling groups. Accordingly, the results of the modelling results were forwarded to him for analysis[10]. His method[11] starts with the area which *would* be required to grow the gross biofuel-feedstock without imports in the shock country, and decomposes the actual area results into the savings in area due to:

- reduction in other domestic use (comprising by-product replacement and reductions in food and feed use)
- reduction in net exports
- increases in yield

This works best for scenarios (e.g. US maize ethanol) where a large part of the extra feedstock production comes from the region of the biofuels shock.

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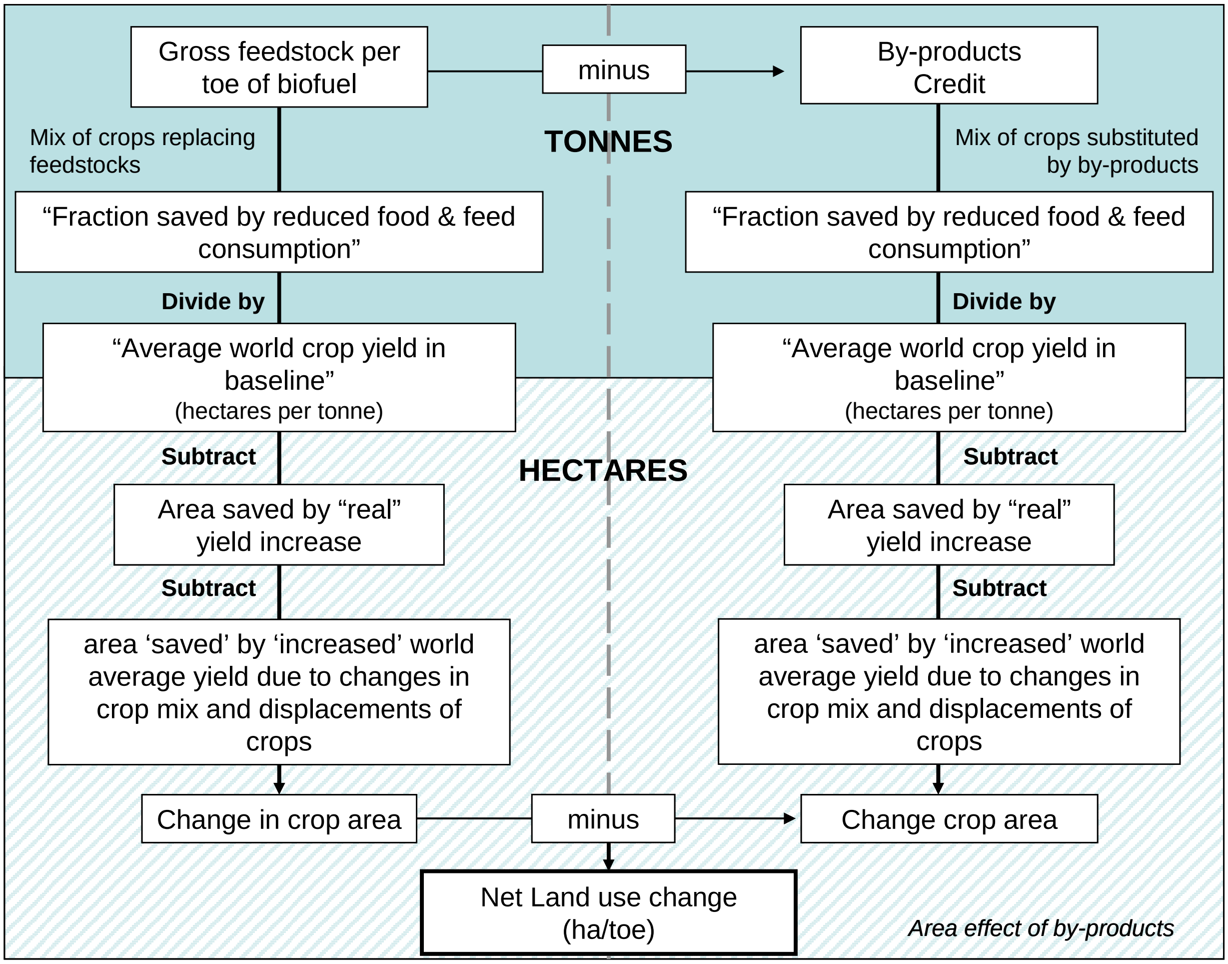
[9] Workshop on "*The Effects of increased demand for Biofuels feedstocks on the world agricultural markets and areas*". (Ispra, 10-11th February 2010). Material from the workshop is available on-line at http://re.jrc.ec.europa.eu/bf-tp/.

[10] The models used in the study which are in common to the JRC-IE comparison are GTAP, FAPRI-CARD and IMPACT. The study also includes AGLINK-COSIMO in the analysis, but it source of data is not the same as in the JRC-IE report.

[11] "A decomposition approach to assess ILUC results from global modeling efforts", P.Witzke, J. Fabiosa, H. Gay, A. Golub, P. Havlik, S. Msangi, S. Tokgoz, T. Searchinger. In press.

The results are reported for a selection of models in a forthcoming paper (Witzke et al 2010). We recommend it for the use of economists who want to understand the differences between the functioning of models.

The approach described above is rigorous, but does not indicate parameters which are particularly interesting for policy makers; for example the separate contributions of reduced food consumption or by-product replacements. The problem is that these effects are very difficult to separate in terms of their effects on hectares of crop area, and probably cannot be distinguished working only from output data without additional information. Therefore, we have tried to distinguish these effects in terms of tonnes of production. The fraction of production saved is not the same as the fraction of area saved, as the by-products substitute crops with different yields, but at least it gives some indication, and the mass-balance approach enables us to estimate the effect of food separately. This is explained in more detail below.



In the diagram above we show a simplified representation of the main effects in the modelling of LUC from biofuels.

The left half of the diagram shows the main feedstock pathway. Let us first consider this in isolation. The best factor to take first is the reduction in food consumption (although it’s not the easiest to estimate) because it depends directly on the tonnes of extra feedstock demand for biofuel. The net feedstock crop taken out of the food market (food includes animal feed in this context) is compensated by more production also of other crops which can substitute it. Some of that comes from imports and some from the region where the extra biofuels are produced.

The net tonnes of production need to be converted to hectares using an average yield for the crops needed to replace the “hole” in the food market, in the areas they will come from. That will not be the same as the average yield of the feedstock crop itself (because it is a mixture of crops), nor will it be the average yield of all crops in the world. Here we choose to *compare* it to the world average crop yield using a ratio.

Now the calculations are in terms of area. The fractional saving due to yield increases is expressed as an area saving because it is rather easy to do this from output tables which include yield changes[12]. The models calculate the change in crop area per region per crop using an estimate of the yield on the extra land (sometimes though, this is only expressed as a component of change in the average yield of a crop in a region). However, it is not simple to find an average value for this because other factors complicate it, as explained below.

The effect of yield increases due to crop price increase can be conveniently introduced at this stage because it is easy to express it as an area. However, it could also have been introduced earlier as a saving on tonnes of crops needed.

Each of these steps is mirrored in the right-hand side of the “flow” diagram, which pertains to the mix of crops which substitutes the by-products.

The problem is that the output data of each model are not conveniently divided into “main-feedstock” and “by-product” data. The only models which ran experiments with the by-products “turned off” were full-equilibrium models where many other side-effects occur at the same time, so that only approximate indications about the by-products can be obtained.

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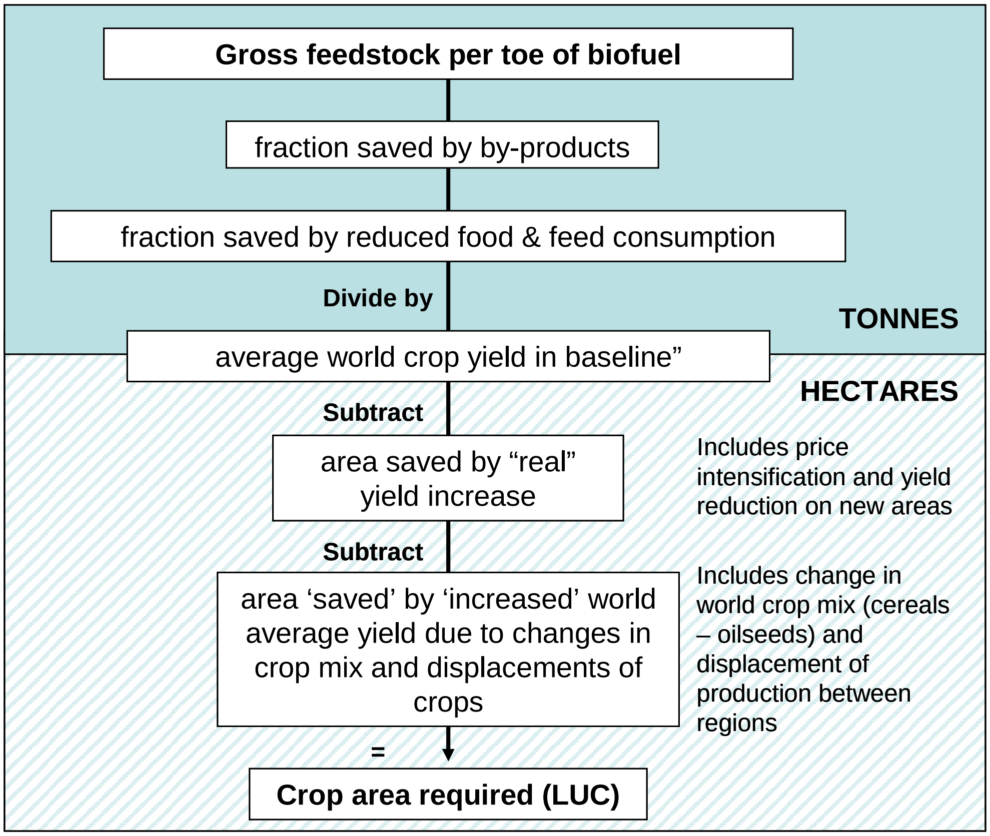
[12] (area saving = fractional yield saving x total crop area)

In order to attain parameters which could be calculated from the output of each model in the same way, we had to combine the “main-product” and “by-product” sides of the diagram, so that the parameters always refer to the “effect for the feedstock crop(s) minus the by-product crop(s). This also makes it difficult to define a “marginal yield”, so we had to express yield changes differently in the combined scheme.



This analysis leads to the following table of parameters (a preview of the results from FAPRI-CARD model as it happens)

Preview of FAPRI-CARD results as an example of our analysis of model parameters.

PER TOE BIOFUEL		**EU Wheat Ethanol**			**EU Rapeseed Biodiesel**				**Calculation**
			adjustment			adjustment			
I	Gross tonnes of feedstock	**5.40**			**3.0**				
			-	31%		-	61%	A	fraction of gross feedstock saved by by-products
II	...net of by-products (tonnes)	3.71			1.16				
			-	34%		-	97%	B	fraction of net feedstock supplied by reduction in food use
III	...net of reduction in food use (tonnes)	2.45			0.03				
			÷	3.7		÷	3.7	C	baseline production/baseline area (tonnes/ha)
IV	corresponding hectares at average baseline-yield-of-all-crops	0.66			0.01				
			-	0.07		-	0.12	D	baseline area * (fractional yield increase (per region per crop) weighted by baseline area (per region per crop)) (ha/toe)
V	...net of area from increased yield on baseline crop distribution (ha)	0.59			-0.11				
			-	0.20		-	-0.5	E	fractional change in (total crops/total area) x baseline area (ha/toe)
VI	…minus the area 'saved' by 'increased' yields due to crop/regional displacements (ha)	**0.39**			**0.40**				**LUC (ha/toe)**

How to read the table:
The calculation starts off from the reported tonnes of feedstock the modellers assume are needed to make 1 toe of biofuel. That is 5.4 tonnes of wheat/toe ethanol for the first scenario. That number of tonnes is diminished by 31% (parameter A as described in the calculation column on the right of the table) by the contribution of by-products, leaving 3.71 tonnes/toe net crops required. That net result is further reduced by a further 34% (OF THE NET RESULT, NOT 34% OF THE GROSS FEEDSTOCK REQUIREMENT) to 2.54 tonnes of net feedstock by the reduction in crops used for food and feed (parameter B).

Dividing by the world average yield gives a nominal extra crop area of 0.66 ha/toe (parameter C), if the crops were produced at the world average yield. Subtracting 0.07 hectares/toe (parameter D) from this extra crop area accounts for the small net increase in average yield, caused by a combination of the effects of higher price and area extension. A subtraction of 0.20 ha/toe (parameter E) representing the area change saved by the 'virtual' yield changes (caused by crop displacements and change in crop mix; see below) brings us to the final LUC result of 0.39 (ha/toe).

Finding the fraction of feedstock saved by by-products (parameter A)

We know what the models assume for the amount of feedstock needed to generate one toe of biofuel[13], and for the tonnes of by-product co-produced, which is more or less fixed by the process (ethanol or biodiesel) and feedstock type. FAPRI and AGLINK-COSIMO both have animal-feed substitution modules which deal in tonnes of feed. On the basis that these substitution calculations

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[13] In the case of biodiesel, the feedstock is oilseeds (not 'vegoil'): in the case of palm oil it is fresh-fruit-bunches

will approximately balance the carbohydrate and protein intake of the livestock, it is reasonable to approximate the total tonnes of feed replaced to the tonnes of by-product.

To be consistent, we made a similar mass-balance calculation for GTAP. Although the assumption holds less well for that model, (since substitution is based on economic value of the by-products) the results agreed remarkably well with the fraction of area saved by by-products which was estimated by GTAP experiments with by-products suppressed. However, both these methods may somewhat underestimate the effects of by-products and consequently over-estimate the effects of reductions in feed and food consumption for GTAP.

For LEITAP it was better to back-calculate the by-product contribution from the changes in feed and food *consumption*, which are reported for this model. [14]

Finding the reduction in food and feed consumption (parameter B)

Some models report the reduction in crops used for food and feed due to biofuels production. This is often reported as "reduction in food and feed consumption", which can give an exaggerated idea of the impact of biofuels on world hunger if one does not realize that this figure is only for *crops* used for feed and food; a large part of this can be due to the replacement of crops for animal feed by by-products of biofuel production.

We find the 'real' or net reduction in food and feed consumption using mass balance:-

	comment
(net increase in tonnes world crops)	*known from output tables*
=	
(gross feedstock requirements for biofuels)	*known from output tables*
-	
(tonnes of crops replaced by by-products)	*estimated (see text)*
-	
(reduction in food+feed consumption)	*usually calculated by mass-balance*

...where each quantity is in total tonnes of crops.

World Average Yield (parameter C)

The world average yield for each model is shown for a reference point on yields. Dividing by this gives a first-estimate for the area required to provide the net increase in tonnes of crop reported by the models. It is calculated from the output tables after adjusting sugar crops output to sugar-equivalents (otherwise the high water content in those crops skews the average). This removes the largest distorting factor, but another one is the difference in yields between oilseeds (especially the effective oil yield) and cereals. One could correct for this by weighting the yields by the economic value of the crops. However, unfortunately not all the models reported crop-price data.

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[14] There is a problem to estimate the tonnes of crops saved by feedstock in LEITAP. In this model each tonne of by-products saves much less than one tonne of crops. Although LEI also reported results for the model with by-product production switched off, the area of LUC was hardly affected. However, we know this method tends to underestimate the actual by-product effects in the full model, because the area effects of suppressing by-products are partly compensated by reactions in yields, competing consumptions and meat production not using crops. However, fortunately LEI reported detailed *consumption* data. On the basis of the changes in consumption in different sectors, we were able to calculate directly the reduction in crop consumption for food and feed. Subtracting this from the overall increase in tonnes of crop production gives the effects of the by-products.

The fractional change in world average yield is tiny for the marginal shocks in these models, so it does not matter if we take the average yield in the baseline or in the scenario for this calculation.

Why don't we calculate the marginal yield?
It is tempting to calculate an "average marginal yield" as the (total increase in production) / (total increase in area). However, that is difficult to interpret because it includes the effect of the simultaneous *change in the yield of the crops on the baseline area*, and that has three components:

- the change in the yield caused by price changes (in the scenario compared to baseline).
- the change in the average yield caused by the change in the mix of crops: high-yielding crops replacing lower-yielding ones or visa-versa.
- the change in the distribution of a given crop between regions: for example, a greater proportion of wheat production may come from Canada compared to US.

Furthermore, each of these components has to be evaluated for the crops-replacing-feedstock minus the crops-replacing-by-products. Nevertheless, we think it may be possible to find the effective ratio of marginal to average yield with deeper analysis.

Area saved by 'real' yield increases (parameter D)

When one thinks of yield increases due to biofuels one thinks of the 'real' effects of increased crop prices and area extensions, as described by yield elasticities and discussed in section 7. This is fine as long as we are looking at the yield of a particular crop in a particular region. The problem comes when we want an average value of this for our descriptive parameters. If we just calculate the change in average yield, we find that average yields also go up or down because of changes in the crop-mix between the scenario and baseline, and because of production of individual crops shifting from one country to another. We disentangle these effects by:

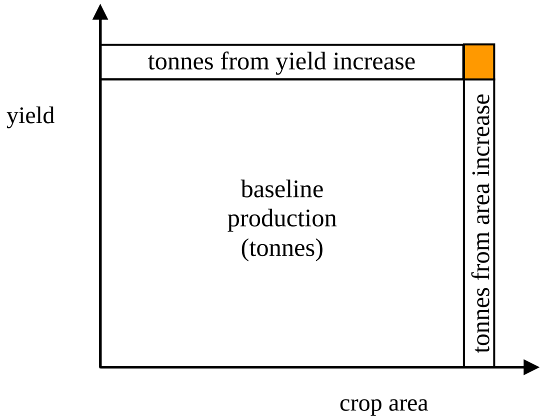
1. Finding from the output tables of the models a table of all the fractional-yield-changes-per-crop-per-region.
2. Multiplying each cell with the corresponding area per crop per region.

This gives the area saved by the 'real' change in yield whilst ignoring 'virtual' yield changes caused by crop displacements. Dividing by the total crop area[15] gives the average fractional increase in 'real' yield. It is the average yield increase weighted by area per crop per region.

Area 'saved' by crop displacements (parameter E)

The inverted commas indicate that this area can be positive or negative, but we call it positive if area is saved. This is found by:

1. taking the primitive estimate of fractional yield change (i.e. the fractional change in (total tonnes of crop/total area of crop),
2. converting to an area by multiplying by baseline crop area
3. subtracting the part of this area reduction due to "real" decreases in yields, already calculated in (D)



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[15] There is no significant difference between dividing by the total crop area in the baseline or in the scenario, since the fractional change in area is tiny.

For the IFPRI-IMAGE model, we found time to disaggregate this area saving further into:

- area ‘saving’ due to yield ‘increase’ caused by a change in crop mix, and
- area ‘saving’ due to yield ‘increase’ due to displacements of the same crop from one country to another.

We found that the first effect dominated. We notice that in the FAPRI-CARD results above, area is saved by an increase in the average yield in the EU wheat-ethanol scenario because there is an increase in wheat area (a high-yielding crop) at the expense of oilseeds and other lower-yielding crops. Conversely, in the EU rapeseed biodiesel scenario, there is a negative value of parameter E, denoting an increase in crop area caused by a reduction in yield due to oilseeds (with lower yields) displacing cereals (with higher yields).

2.3 Models compared

In this report the results provided by the following institutes are discussed and compared:

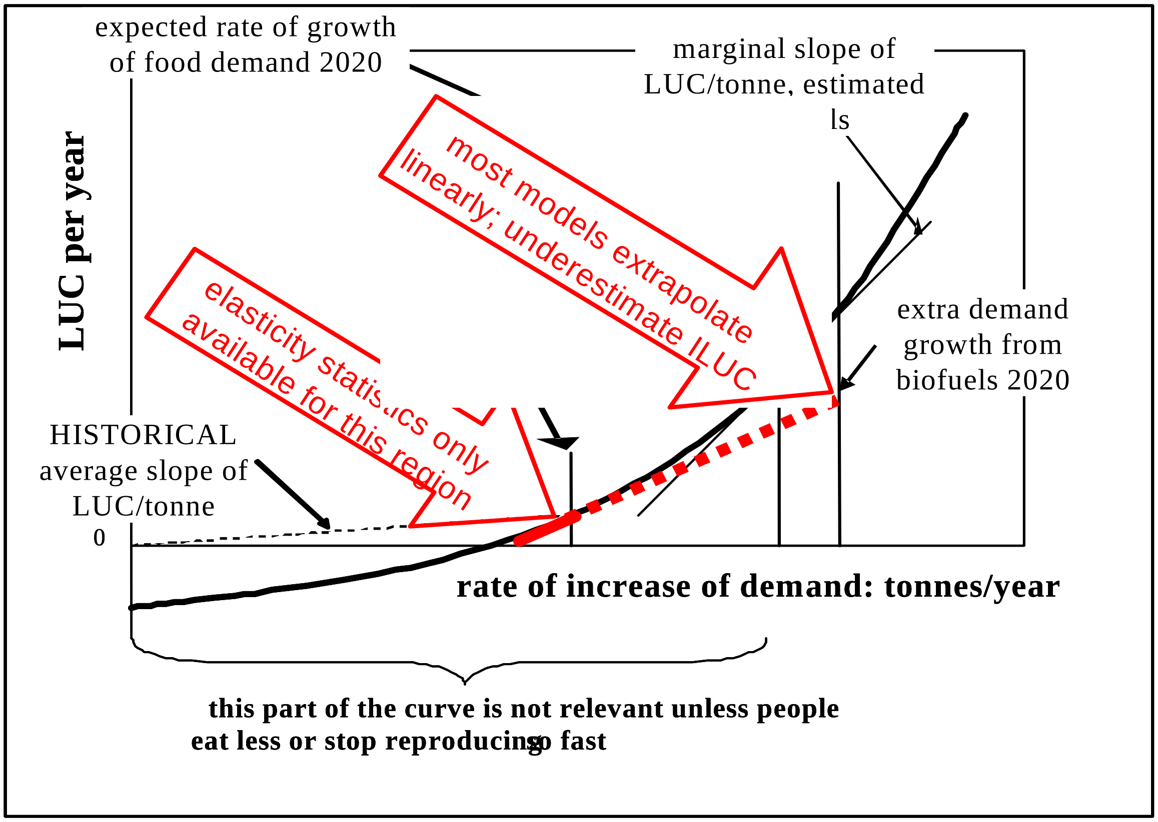
- Purdue University (US) - model: G-TAP
- Life Cycle Associates (US) - model: G-TAP
- OECD (EU-Paris) - model: AG-LINK
- FAPRI (US) - model: CARD
- IFPRI (US) - model: IMPACT
- LEI (EU - NL) - model: LEI-TAP
- LEI (EU – NL) - model: CAPRI (LUC in EU only)

The DART modelling team at Kiel (Institute for the World Economy) submitted results, but their model assumes fixed land area, so could not estimate LUC.

3. MODEL LINEARITY

The most critical parameter in cropland expansion is the rate of crop demand increase compared to the rate of yield increase (See Figure 1 below). If the rate of demand increase equals the rate of yield increase, no net land use change occurs. In the past few decades, demand increase has run ahead of yield increase, so that about 5% of the extra demand over time has come from world crop area increase. This is indicated by the “historical average slope” of LUC/tonne, and has no relation with the marginal rate of land use change for a marginal increase in demand.

Figure 1: Marginal vs. Average LUC impacts



The slope of the LUC curve can be expected to increase with increasing rate of demand increase. That is because, firstly, land brought into production gets progressively less productive, and secondly, because of diminishing returns to spending money on measures to increase yield growth. The area increase associated with an extra Mtoe of biofuel is given by the slope of the curve (the “historical average LUC” is irrelevant). In the future, exponential population growth, increased prosperity in the developing world, and biofuels are likely to increase the annual rate of demand increase. That will increase the slope and hence the LUC/toe biofuels.

The results of agro-economic models depend on the proportionality parameters used in the equations which link production changes to prices, inputs, yields and area. These parameters (“elasticities”) are found wherever possible by statistical analysis of historical data. Because of the noise caused by weather variations, it is already difficult to get statistically valid linear relationships, without also trying to fit curvatures to the historical data. For this reason most relations are assumed to be linear, even though modellers are aware that there are non-linearities in practice. Since the (essentially linear) models are fitted to the region of the curve (the thick dashed red line on the figure) corresponding to historical rates of demand increase, they fail to take into account the upward curvature of the curve which accompanies higher rates of demand increase caused by biofuels. This implies that in principle the models underestimate future LUC, but this error may not be large compared to other approximations.

In other words, although we do not expect LUC to be linear, models are forced to assume that it is linear.

Two models did run shocks of different sizes to check for linearity. CAPRI model was used to estimate LUC due to different demand shocks (respectively 2%, 4%, 6% and 8%) on biofuels consumption in the EU. The model shows that within this range, the relation with percentage of land use is highly linear (See Figure 2 and Figure 3).

Other model outputs were also linear with the size of the shock. However, it should be noted that this relates to a single crop. It may be the case that with higher levels of demand the attractiveness of different feedstocks could change and this might then mean that the results would not appear to be linear.

Figure 2: Effects on land use change from marginal shocks on ethanol demand for the EU27 with CAPRI model (I. Perez, LEI

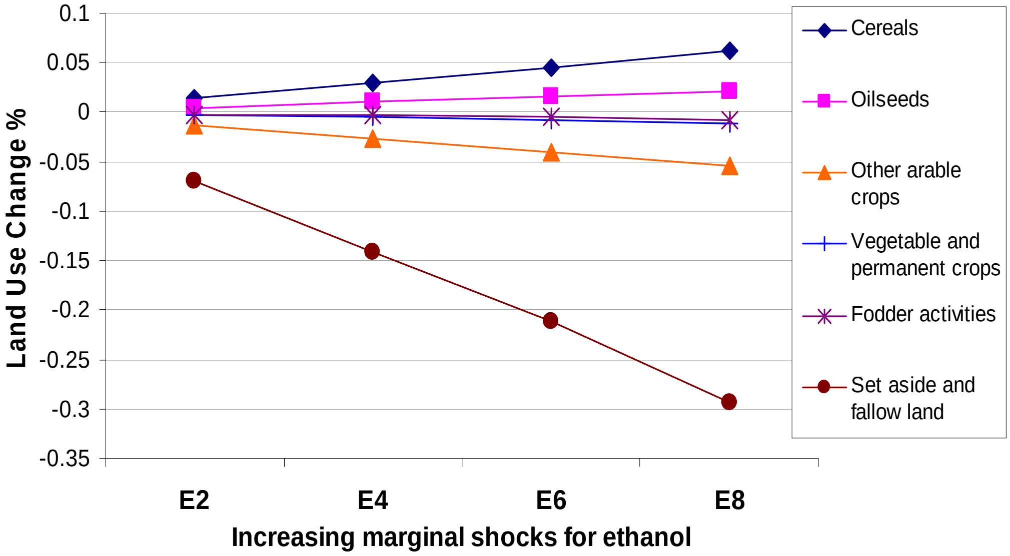
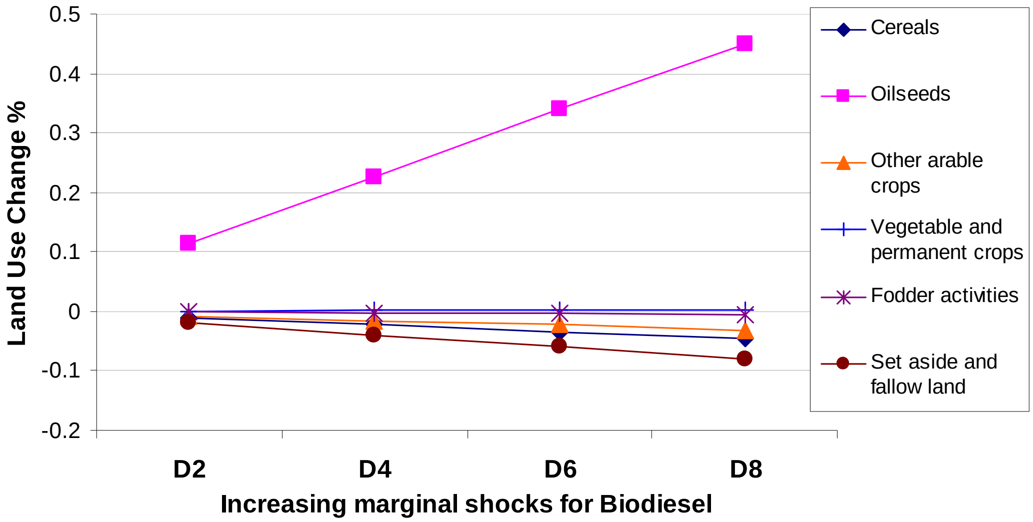
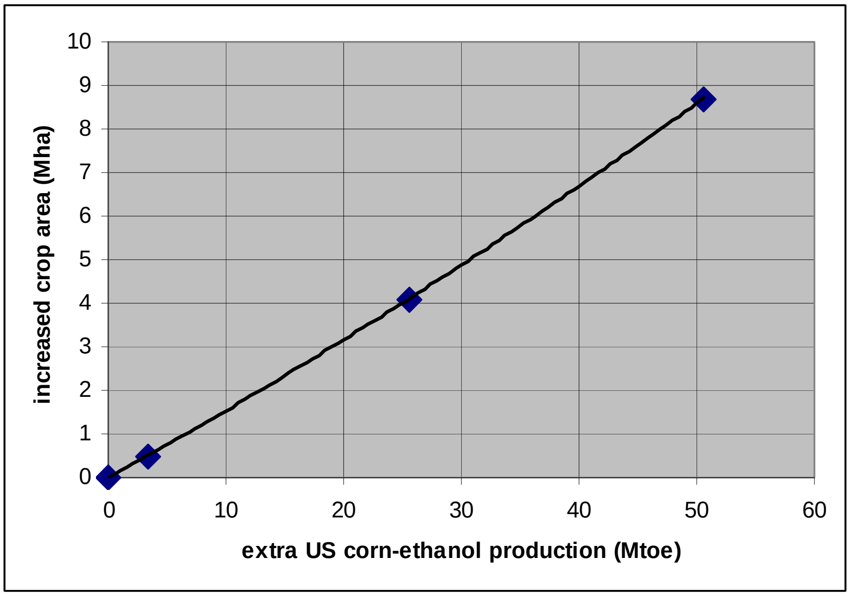


Figure 3: Effects on land use change from marginal shocks on vegetable oil demand for the EU27 – in % changes (I. Perez, LEI)



G-TAP, although not linear by its structure (equations of the model are usually non-linear in absolute quantities), has proven to be almost linear in practice for small shocks like 1 Mtoe. The GTAP results from Life Cycle Associates (LCA) show that the land area change (and also their estimated emissions) appears to be only slightly non-linear right up to shocks of the size of US biofuels legislation (see Figure 4)[16]

Figure 4: Land Use Change results from GTAP with different volumes of US maize ethanol production (data from S. Unnasch, Life Cycle Associates) (yield elasticity = 0.65)



However, GTAP experiments by LCAssociates show that this behaviour is sensitive to the value chosen for the ratio of marginal to average crop yield is reduced, for example from 0.65 for US

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[16] See Preliminary Analysis of Indirect Land Use Change for the EU using the GTAP Model (Stefan Unnasch) in 'The effects of increased demand for biofuel feedstock on the world agricultural markets and areas – Outcomes of a workshop 10-11 February 2010". available at: http://re.jrc.ec.europa.eu/bf-tp/index.htm

production to 0.5, which indicates the non-linearity depends on the amount of extra area rather than the demand as such.

OECD indicated that the AGLINK-COSIMO model results are basically linear with the size of the “shock”, unless there is a threshold in the description of a policy (e.g. due to a limit on imports) which is not thought to be of importance in the scenarios reported in this study.

4. MODEL CHARACTERISTICS

There are different modelling approaches for analysing the land use effects of different feedstocks and of bioenergy policy. The two categories included in this study being "economy-wide" Computable General Equilibrium (CGE) models (e.g. LEITAP, GTAP) and "sector-confined" partial equilibrium (PE) models time-series (e.g. AGLINK-COSIMO, CAPRI, IMPACT, CARD). An overview of the modelling approaches, including their qualities and weaknesses in the context of bioenergy has been recently published by the Netherlands Environmental Assessment Agency (PBL, 2010) and may be found in literature (e.g. Van Tongenen et al., 2001).

The main characteristics and key modelling parameters (e.g. biofuels used in the model, scenarios modelled etc.) for each model, included in this comparison exercise, are reported in the following sub-sections.

4.1 The G-TAP model (Purdue University)

4.1.1 Model general description

The Global Trade Analysis Project **(GTAP)** model and data base developed at the Department of Agricultural Economics at Purdue University (Indiana, U.S.) is a multiregion, multisector CGE model with perfect competition and constant returns to scale (Hertel, 1997). GTAP has been steadily expanding its capability towards facilitating global economic analyses of GHG emissions abatement: **GTAP-E** (Environment and Energy) (developed by Burniaux and Truong (2002); revised by McDougall and Golub (2007)) in particular has also been extended with biofuels, and has been augmented by adding the possibility for substitutability between biofuels and petroleum products. The percentage change in demand for ethanol depends on the change in aggregate demand for liquid fuels and on changes in the intensity of ethanol use in liquid fuels. This is governed by a constant elasticity of substitution amongst liquid fuel products consumed which pre-multiplies changes in the ratio of ethanol prices to changes in the composite price of liquid fuels.

The marginal calculations, referred to in this analysis, were made with a modified version of the GTAP-E model called GTAP-BIO (Hertel, Tyner et al. 2010), designed specifically for analysis of global impacts from expanded biofuels production policy. This new version has an improved treatment of biofuel by products and represents more accurately global land use, incorporating also the potential for biofuels to substitute for petroleum products in consumption, as well as demand for ethanol as a fuel additive.[17]

The baseline of the model used for this study is version 6 of the GTAP database representing the World economy in 2001, with 87 GTAP regions aggregated into 19 regions. Within each region, land endowment is divided into Agro-Ecological Zones (AEZ)[18]. There may be as many as 18 AEZs in a region. The reason why GTAPv6 was used instead of v7 (representing world economy in 2004) is because land use data consistent with global economic data are available only for 2001.

In the GTAP model, crop replacement depends on trading patterns. The Armington approach is used here, instead of an integrated-world-market (IWM) assumption. The choice is supported by recent

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[17] This second type of demand for ethanol as a fuel additive is not price responsive and moves together with the aggregate demand for liquid fuels.

[18] Definition of AEZ used in GTAP may be found at https://www.gtap.agecon.purdue.edu/resources/download/3671.pdf

econometric work by Villoria and Hertel (2009) who formulate an econometric model which permits them to test two competing hypotheses: Armington and IWM. They reject the IWM hypothesis in favour of the Armington model. This is discussed further in the discussion section.

4.1.2 Biofuels in the model

The modified database used in the GTAP-BIO model for this study includes data on production, consumption and trade of biofuels including grain based ethanol, sugarcane ethanol, and biodiesel from oilseeds, as well as data on biofuel by-products (for by-products, see Taheripour et al., 2007). Some elements of the model and the data base used in the analysis reported here differ from the data and model used for the California Air Resources Board. With respect to the data base, the differences in particular include a) new structure of oilseeds biodiesel production and production of oilseeds meal-by-product of vegetable oil[19], and b) improved representation of the EU wheat ethanol sector. More specifically, in the data used in this project, oilseeds meal is a by-product of vegetable oil, not a by-product of oilseed biodiesel. Because vegetable oil is produced in all 19 regions of the model, oilseed meal is represented in all 19 regions as well.

Values of produced biofuel products across the world in 2001 (GTAPv6 database) are based on the IEA data base (see Taheripour et al., 2007).

4.1.3 Accounting for by-products

Two types of by-products were considered in the model:

- Distillers Dried Grains with Solubles (DDGS), by-product of maize and wheat ethanol (produced only in the regions where ethanol is produced, i.e. 6 out of 19 regions in the GTAP database).
- Oilseeds meal, by-product of crude vegetable oil (VOBP) was separated out of the standard GTAP sector “vegetable oils and fats”. In contrast to DDGS, oilseeds meal reported here covers all types of oilseeds meal produced across the world. The replacement is made in equal-economic value terms in the markets for oilseed cake. Purdue-GTAP has assumes a fixed ratio of oilmeal to vegoil for the oilseeds from a particular region. Since one type of oilseed tends to predominate in a particular region, this should not cause big problems.
- GTAP shows a significant reduction in net LUC area due to considering by-products. By “switching off” the production of by-products and re-running the model Purdue estimated the following reductions in net LUC area resulting from the consideration of by-products:
    - 30% recovery of net cropland for EU wheat ethanol
    - 52% recovery of net cropland of EU oilseeds biodiesel
    - 46% recovery of net cropland for US maize ethanol
    - 22% recovery of net cropland for palm oil biodiesel

These values are remarkably close to the percentage savings calculated by JRC-IE on the basis of tonnes of by-product (see below). As far as JRC-IE can tell, GTAP realistically models DDGS by-product from ethanol in the US. It replaces both energy-feeds and some oilmeal feed. In the US much of the DDGS is not dried, but supplied to local cattle lots, replacing mostly maize-feed. However, JRC-IE thinks that in Europe, a greater proportion of oilmeals would be replaced because the DDGS is usually dried and blended with other concentrate feeds. This allows it to replace more protein feed,

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[19] GTAP website (https://www.gtap.agecon.purdue.edu/default.asp)

which should somewhat increase the area of LUC saved by the DDGS in the EU wheat scenarios compared to US maize; however the opposite is observed. GTAP would capture this effect better if it used up-to-date local prices for DDGS, which are now higher in the EU than in the US.

4.1.4 New Yield specifications

G-TAP is "static" in the sense that it does not make calculations year-on-year, but arrives at an equilibrium response ("solution") to the change in biofuels demand through iteration and interpolation. The biofuels calculations are made in the version of GTAP which describes the world economy in 2001 (because this can connect to the land use database for the same year). To make the best estimate of the situation in 2010, all yields and all demands in the baseline are incremented by extrapolation of historical data. Of course, this yield increase applies to both the baseline and the scenarios, so in the first approximation does not affect the ILUC result. However, ILUC area due to biofuels does depend on the marginal yield of the crops planted on the new crop area. If that marginal yield increases by more than the historical trend, (for example 12% instead of 10%) then the model overestimates the ILUC area, (in this example, by 2%). If the rate of yield-increase decreases (which is the general trend in recent years) the model will overestimate the ILUC area. However, we can suppose that these errors will be small compared with the uncertainty in determining the yield on the new crop area in the first place.

The model is more sensitive to changes in the relative yield increase between the region where the extra demand for feedstock occurs (i.e. US or EU), and Latin America, where the land credits for protein feed substitution tend to occur.

Two important assumptions of G-TAP are related to changes in crop yields:

1. Intensification is modelled considering a yield-on-price elasticity of 0.25: for all crops and regions. That means a permanent increase of 10% in crop price, relative to variable input prices, would result in roughly a 2.5% rise in yields. The yield increase emerges from the model structure by allowing substitution of non-land inputs for land quantity of non-land inputs.[20].
2. The ratio of the yield on the new cropland (marginal yield) to the average yield of existing cropland of the same crop within the region is taken to be 2/3 (0.66) for all crops in all regions. In a recent work Tyner et al. (2010) have estimated regional land conversion factors at the AEZ level using a Terrestrial Ecosystem Model (TEM). These land conversion factors estimate productivity of existing cropland versus new cropland. Future econometric work aimed at estimating this parameter more precisely is a high priority at Purdue.

Some have proposed that increased crop prices should increase not only the current yield (taken into account) but also the rate of increase of yield, because of increases in the investment in agricultural research. GTAP does not have such a link; this can be rationalized on the basis that the long time-lag between research spending and effects in the field puts such an effect outside the time-frame of the study.

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[20] The production function in crop sectors of the GTAP-BIO model is different from one used in standard GTAP model. The top of the CES production function includes land, labour, capital-energy composite and all intermediate inputs. The elasticity of substitution among these inputs is calibrated to provide 0.25 long run yield-on-price elasticity. Thus, in contrast to standard GTAP model production structure, in this work the crop production function is not Leontief.

4.1.5 Scenarios modelled

The shock introduced in the model (1 Mtoe shock) to the baseline assumptions is relatively small to guarantee the results truly represent the marginal ILUC effect (see discussion points in chapter 4), but still large enough to allow the assessment of the effects of increased production of biofuels feedstocks.

The following scenarios were considered:

Scenario A: marginal extra ethanol demand in EU (1 Mtoe = 0.53 billion gallons increase of ethanol production from wheat). EU uses of ethanol from sugar cane and biodiesel, as well as EU imports of biodiesel are fixed at the baseline levels.

Scenario B: marginal extra biodiesel demand in EU (1 Mtonne biodiesel = 0.314 billion gallons increase of biodiesel from oilseeds). EU uses of ethanol from wheat and ethanol from sugar cane and biodiesel, as well as EU imports of biodiesel are fixed at the baseline levels.

Scenario C: marginal extra ethanol demand in US (1 Mtoe increase in production of ethanol from coarse grains in US). Total biofuel use in EU is fixed at the baseline level.

Scenario D: marginal extra palm oil demand in EU for biodiesel (1 Mtonne increase in biodiesel use in EU). Domestic biodiesel production in EU is fixed at baseline level, increased biodiesel demand being supplied with imports from Malaysia/Indonesia.

Note that scenario B is for 1 Mtonne biodiesel, equivalent to 0.88 Mtoe, because biodiesel has a lower energy content than fossil oil. The world increase in biodiesel production in scenario D was further reduced, because GTAP predicts that 5% of the extra biodiesel demand in the EU is diverted from the Malaysian-Indonesian market, rather than coming from increased production. JRC-IE corrected for this in the charts and tables below.

4.1.6 Main results

This section presents the results of the GTAP modelling. The regional codes and commodity codes are shown in appendix 1. Detailed tables of the change in area and yield results (crop and region), by scenario, are also included in the appendix. Within the Malays_Indo (Malaysia and Indonesia) region, under the US ethanol and EU ethanol scenarios the total harvested area is reduced. However, looking at the harvested area by crop (See the tables in the Appendix) it can be seen that the oilseeds harvested area increases, while other crops (rice and coarse grains) are reduced. So reduction in the harvested area in Malays_Indo is not due to a reduction in oilseeds area (oil palm in this region), but a reduction in other crops.

The marginal changes in area (kHa per Mtoe) projected for the four scenarios are shown in Table 1. Table 3 shows the share of total LUC within the regions of the scenarios and LUC in the rest of the world. In the EU wheat ethanol and EU biodiesel scenarios 55.7% and 59.1% of total LUC, respectively, is projected to occur outside the EU. The largest share of LUC in the US coarse grains ethanol scenario occurs outside the US. Although in the palm oil production scenario the largest share of LUC occurs outside Malaysia and Indonesia, 42.5% (29 kHa) of the LUC is located within this region.

Table 1 Marginal change in area – GTAP

Region	kHa per Mtoe change in area (total crops)			
	EU Wheat Ethanol	US Coarse grains Ethanol	EU Biodiesel (mix)	Malay_Ind Biod
EU27	352	13	154	6
SS Africa	142	30	77	10
Canada	99	17	33	6
Brazil	40	11	41	4
USA	58	68	14	3
Other CIS+CEE	43	7	15	2
Rest of America	18	6	15	3
Malays Indo	-4	-1	1	35
MidEast N Africa	23	3	10	1
Oceania	22	5	10	2
India	12	2	10	6
Russia	-16	-3	-9	-0
C.Amer +Carib	9	3	4	0
China	-7	2	-2	1
World	**794**	**165**	**377**	**82**

Table 2 compares the size of the yield effects which contribute to the final area. The derivation of these area contributions is described in the scheme in section 2.2. When one thinks of yield effects one generally has in mind the “real” yield effect caused by increase of yield on the existing area. We see this is small compared to the result for the first scenario in table 1, important in the middle two scenarios and very important in the last one.

Table 2 Breakdown of yield effects per Mtoe biofuel

Break-down of yield effects (kha):	EU Wheat Ethanol	US Coarse grains Ethanol	EU Biodiesel (mix)	Malay_Ind Biod
Area saved by total net yield effects	-449	106	-171	550
of which, area from increased yield on existing area	27	115	246	227
of which, area from "increased" yields due to crop/regional displacements	-476	-10	-416	324

One would expect the extra DDGS from ethanol scenarios to depress soybean-meal price, making soybean oil less competitive compared to palm oil (which has less meal associated), and thus increasing palm oil area. Although table 1 shows a reduction of total area in Malaysia/Indonesia under the ethanol scenarios, the model reports that harvested areas of oilseeds increase, but these are offset by reduction of other crops, as described before. As oil palm is the only one of the crops considered which grows on peat-land, the *net* area reduction in Indonesia and Malaysia does NOT mean that there is a saving in emissions from peat oxidation. (See Appendix III).

Table 3 Percentage of total LUC within the region of the scenario and the rest of the world.

Scenario	% of total LUC			
	EU Wheat Ethanol	US Corn Ethanol	EU Biodiesel (mix)	Malay_Ind Biod
Region of scenario	44.3%	41.3%	40.9%	42.5%
ROW	**55.7%**	**58.7%**	**59.1%**	**57.5%**

The regional differences in LUC are shown in Figure 5 and Figure 6. The total LUC changes significantly between all the scenarios.

Figure 5 Marginal changes in area by region - GTAP ethanol scenarios

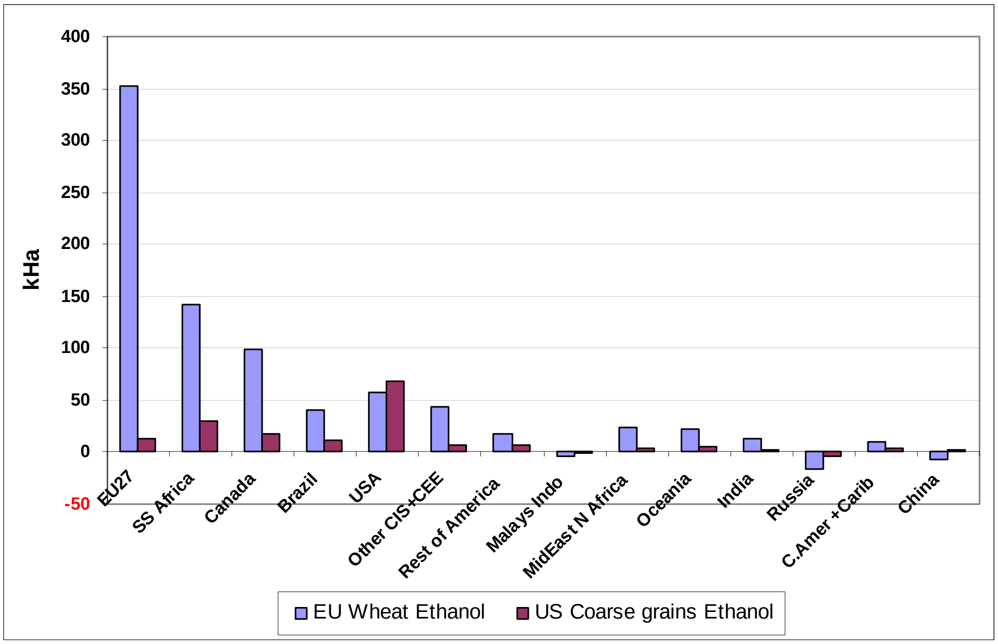
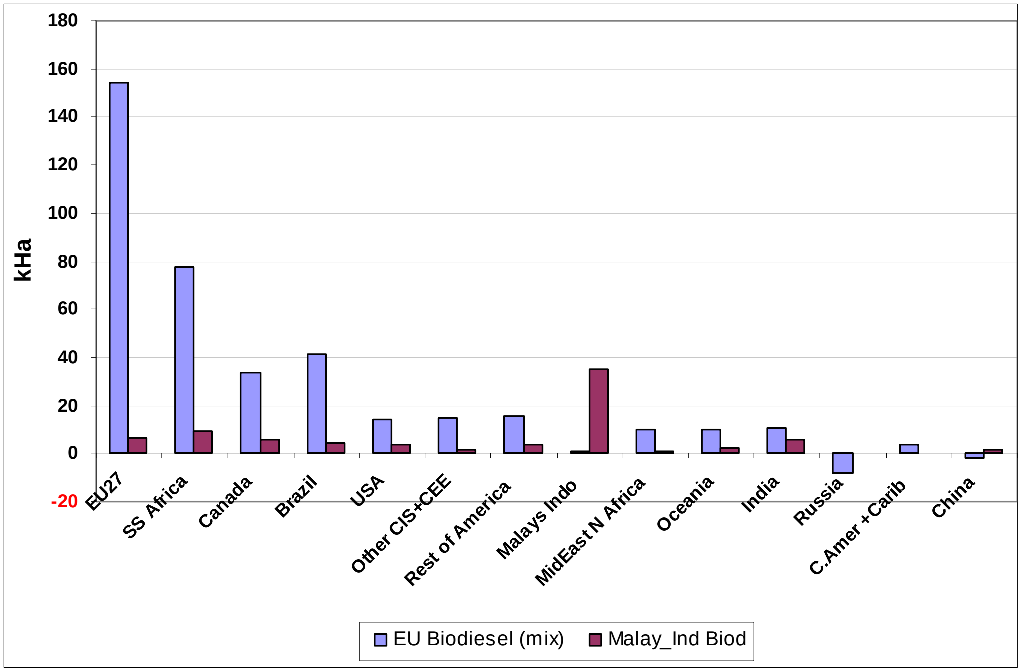


Figure 6 Marginal changes in area by region - GTAP biodiesel scenarios (with corrected values)



The parameters which describe the GTAP model and LUC (ha per toe) reported by GTAP are shown in the following Table 4 and Figure 7.

Table 4 GTAP model parameters and LUC

	PER TOE BIOFUEL	EU Wheat Ethanol			US Coarse grains Ethanol			EU Biodiesel (mix)			Malay_Ind Biodiesel			Calculation	
			adjustment			adjustment			adjustment			adjustment			
I	Gross tonnes of feedstock	**5.25**			**4.6**			**2.4**			**5.1**				
			-	32%		-	31%		-	52%		-	22%	A	fraction of gross feedstock saved by by-products
II	...net of by-products (tonnes)	3.55			3.14			1.16			3.97				
			-	46%		-	52%		-	1%		-	12%	B	fraction of net feedstock supplied by reduction in food use
III	...net of reduction in food use (tonnes)	1.91			1.50			1.14			3.50				
			÷	5.5		÷	5.5		÷	5.5		÷	5.5	C	baseline production/baseline area (tonnes/ha)
IV	corresponding hectares at average baseline-yield-of-all-crops	0.34			0.27			0.21			0.63				
			-	0.027		-	0.12		-	0.25		-	0.23	D	baseline area *average of fractional yield increase (per region per crop) weighted by baseline area (ha/toe)
V	...net of area from increased yield on baseline crop distribution (ha)	0.32			0.15			-0.04			0.41				
			-	-0.48		-	-0.01		-	-0.42		-	0.32	E	Area saved by total net yield effects - D (ha/toe)
VI	…minus the area 'saved' by 'increased' yields due to crop/regional displacements (ha)	**0.79**			**0.16**			**0.38**			**0.08**				**LUC (ha/toe)**

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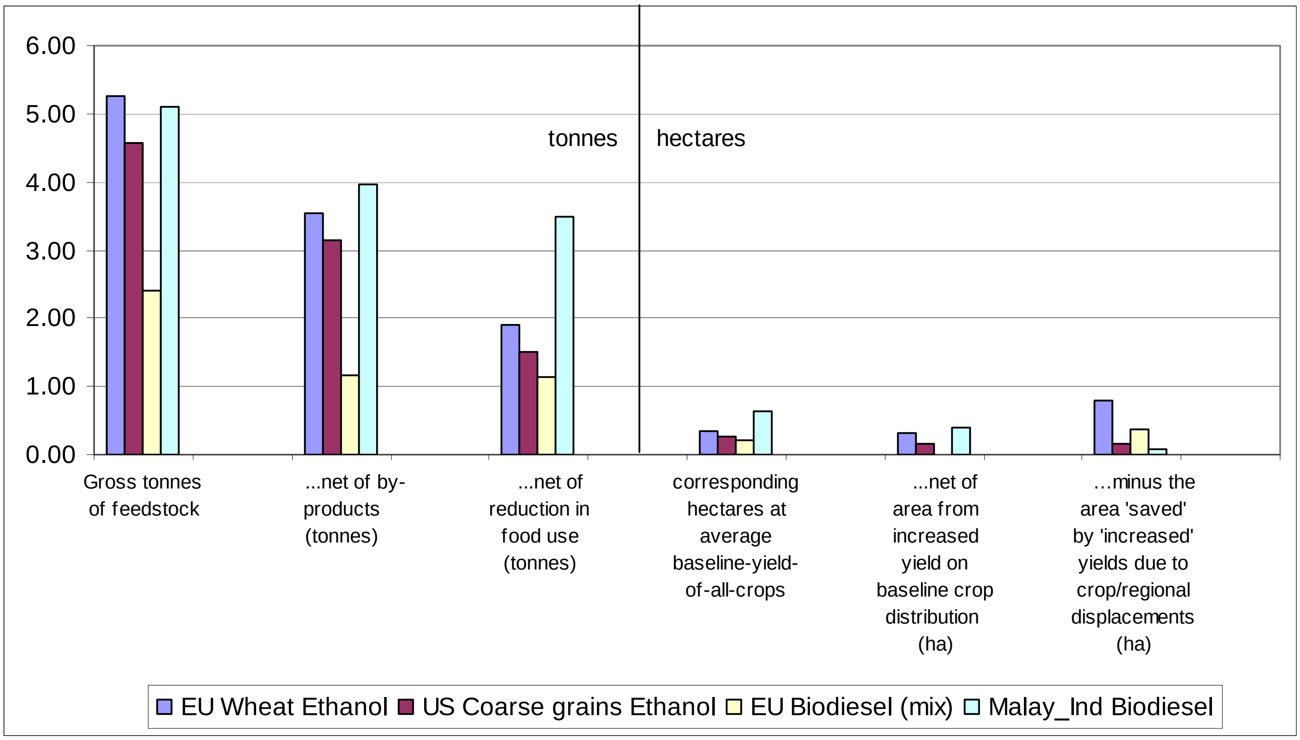
Figure 7 Feedstock requirements and savings/constraints to reach potential LUC per toe.



The first three categories are in tonnes (after savings in feedstock are removed) and the last three categories are area in hectares (with savings in area removed).

Discussion of results between scenarios

The most significant difference between the two ethanol scenarios is the ILUC saved by increases in yields. In the EU wheat ethanol scenario there is only a very small area saving due to the increase in 'real yield', but a large area increase due to a reduction in average crop yield due to increase in the proportion of wheat and cereals production in Africa and other low-yielding regions.

By contrast, in the US maize scenario there is a significant area saving from increased maize yield in US and almost no effect on the world average crop yield of the displacement of crops outside US.

The low feedstock requirements of the EU biodiesel mix to meet 1 Mtoe and the large amount offset by by-product (52%) reduce the ILUC. However, the displacement of cereals by oilseeds leads to a reduction in average crop yield increases the final amount of ILUC.

The low ILUC reported in the Malaysia/Indonesia scenario are as a result of large increases in yields of oilseeds in Malaysia and Indonesia (0.871%). This is in contradiction to historical trends, which has seen the great majority of increased palm oil production come from increased area.

4.2 The FAPRI-CARD model

4.2.1 Model general description

FAPRI-CARD has the same structure as the model used to generate the annual FAPRI agricultural outlook, widely used for market outlook and policy analysis throughout the world (FAPRI, 2009) but with modifications.[21]. It was developed by the Food and Agricultural Policy Research Institute (**FAPRI)** and the Center for Agriculture and Rural Development **(CARD)** at Iowa State University. FAPRI-CARD is not a monolithic model, but an interconnected network of several partial-equilibrium models describing in a rather detailed way the markets for different agricultural commodities. These sub-models include econometric relations and simulations as appropriate. They cover all major temperate crops, sugar, ethanol and biodiesel, dairy, and livestock and meat products for all major producing and consuming countries and calibrated on most recently available data. The models provide 15-year projections of supply, utilization, and prices for modelled commodities by country or region.

The linkages between the sub-models reflect derived demand for feed in livestock and dairy sectors, competition for land in production, and consumer substitution possibilities for sets of close substitutes such as vegetable oils and meat types. The CARD model and associated numerical analyses have been validated through numerous academic publications, external reviews, and internal annual updates.

The modelling system captures the biological, technical, and economic relations among key variables within a particular commodity and across commodities. The model is based on historical data analysis, current academic research, and a reliance on accepted economic, agronomic, and biological relationships in agricultural production and markets. For each commodity sector, world prices are found at which supply equals demand. For smaller producers, the world price is modified by a price transmission equation, which takes into account transport costs, policy effects and quality. However, in general, major producers have dedicated sub-models embedded in the world model, which endogenously calculate domestic prices.

4.2.2 Biofuels in the model

The CARD Biofuel model is composed of the ethanol and biodiesel models. The model structure varies from country to country depending on availability of data. They are separately described below.

i.Ethanol

The ethanol model covers 8 countries and an aggregated region for the 'rest-of-the-world'. The world representative ethanol price is the anhydrous ethanol price in Brazil. The U.S. model has the most detailed structure. The predominant feedstock used in the U.S. is maize. Total ethanol production is the sum of ethanol produced from maize through the dry and wet-milling processes, ethanol produced from non-maize sources, and ethanol produced from cellulosic feedstock. Maize ethanol production is based on production capacity and capacity utilization which are both driven by net revenue from ethanol production. The revenue side accounts for both the revenue contribution coming from the main product – ethanol as well as from the by-products such as distillers grain and maize oil. In the cost side, the largest proportion is the cost of feedstock, followed by fuel and electricity, and then other operating costs. The amount of maize that is required for the level of ethanol production is derived by dividing the ethanol production with the ethanol yield. This derived demand for ethanol

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[21] For example, the US DDG specification is applied in the rest of the world. Moreover, a long-run equilibrium condition is imposed.

feedstocks connects the ethanol sector to the maize sector. On the demand side, there are three major components for ethanol: the additive, voluntary E-10, and E-85 markets. In the ethanol additive market, oxygenation requirements and blend mandates determine the ethanol demand. The E-85 demand is the most elastic relative to the ratio of ethanol price to unleaded gasoline price. Net trade is based on the relative price of U.S. and world ethanol.

Brazil is the only exporter of ethanol in the CARD model and uses sugarcane as the predominant feedstock. Sugarcane production in Brazil is a product of area planted to sugarcane and the yield of sugarcane. The area planted to sugarcane is expressed as a function of a composite price which includes the price of sugar as well as the price of ethanol. Sugarcane production is then allocated into feedstock for sugar production and ethanol production based on the relative profitability of both competing uses. **Ethanol yield from sugarcane is a function of trend to capture technological improvements over time**. Ethanol consumption is based on transport fuel demand and the required blend of ethanol. Being the residual supplier of ethanol in the world, Brazil faces an aggregate excess demand from the rest of the countries in the model. The anhydrous ethanol price in Brazil clears the world ethanol market.

The standard EU ethanol model has a price transmission specification where domestic EU ethanol price is derived from the world price, expressed in Euro, and includes border duties[22]. Ethanol consumption specification is expressed as a function of real EU ethanol price and policy parameters (i.e. EU's biofuel target). Ethanol production is a function of real ethanol price and real feedstock price (e.g. wheat). Ethanol net trade is the residual to balance the market. Other countries such as Canada, China, and India have a similar specification as that of the EU, where price is determined by transmission, net trade is residual, and both ethanol production and consumption are specified.

Japan, South Korea, and the rest-of-the-world have net trade equations only, which are functions of the world ethanol price.

ii. Biodiesel

In response to its growing importance on agricultural markets in general, and oilseeds markets in particular, an international biodiesel model was developed and incorporated to the CARD modelling system. This model is able to project prices, and supply and utilization of the biodiesel by the main market participants, as well as the derived demand for the different feedstocks. The countries covered are the major producers and consumers, with varying detail depending on data availability. Supply and utilization are modelled for Argentina, Brazil, EU, and Indonesia. Net trade is projected for Malaysia, Japan, and the rest of the world. For the case of the U.S. a detailed module for supply, demand, and price projections is embedded in the domestic CARD crops model. Drivers of supply and demand are chiefly biodiesel and diesel prices, vegetable oil costs, and relevant policies. Policies affecting supply, domestic utilization (e.g. consumption mandates and tax incentives), and trade of biodiesel are explicitly included. The model endogenously solves for a price that matches world supply to demand.

As mentioned above, the model projects the derived demand for vegetable oils used as feedstock for biodiesel in the different countries covered. The dominant type of vegetable oil utilized by the biodiesel industry varies by country/region. For countries in the Americas, soybean oil is the dominant feedstock. Rapeseed oil is the most commonly used raw material in the EU, and that role is

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[22] For the High EU Wheat Ethanol Consumption scenario a price solver was introduced to allow domestic production to respond.

occupied by palm oil in south-eastern Asian countries. The feedstock needs derived from the biofuels production directly impact the international oilseeds market, and these interactions are captured by linkages between the international biodiesel and oilseeds models.

4.2.3 Accounting for by-products

CARD has a sophisticated description of what commodities are displaced by by-products. Ethanol by-products are modelled in the U.S. and the EU. In particular, distillers grain (DG) by-product is derived from the maize (and other grains) used in dry mill ethanol production using an exogenous DG yield. DG use is determined by three factors specified by meat product (i.e. beef, dairy, pork, and poultry) including adoption rate, maximum inclusion rate, and displacement rate. A DG export equation is also specified and the DG price is solved to clear the market in the U.S. The displacement rate is used to estimate the equivalent maize and soymeal that is displaced by DG, which is subtracted from the maize feed demand (and other grains), and soymeal (and other oilseed meals) feed demand.

The same structure is used in the EU except that the displaced feedstock is an aggregate grain, and the specific feed grain that is displaced is a function of the relative price of the different grains used in the EU such as wheat, maize, and barley.

Efficiency gains from the use of DDGS in feed rations are accounted for in the case of ruminants but not in the case of monogastrics.

Moreover, the proportion of dry mills that adopt fractionation and extract oil from DDGS is endogenous in the US biofuel model driven by net revenue from fractionation.

4.2.4 New Yield specifications

The crop yield assumption is a key parameter in accounting for land-use changes for greenhouse gas emissions analysis. In particular, three specific aspects of the yield specification are of significant importance, including the parameter associated with the trend, sensitivity of yield response to price changes, and yield impact of extensification. To better address these concerns, the estimates of the trend parameter in the yield equation for all countries were updated, using more recent data to ensure that parameters used in yield equations are recent. Second, a method was developed to calibrate the own-price yield elasticity and the extensification elasticity for the rest of the countries covered in the CARD model with no direct parameter estimates due to data limitations.

CARD re-specified its yield equation in its current model version to include several explanatory variables in order to account for price response as well as the impact of extensification. That is, the yield of crop ***i*** is a function of trend, ratio of total revenue to variable cost in period ***t***, moving the average of the ratio of total revenue to variable cost, and total area planted. The last explanatory variable captures the effect of extensification on yield from the additional new land brought into production. That is, the yield drag is captured as more marginal area is brought into production. The first two explanatory variables capture the short-run and long-run effects of intensification. As an example, in the U.S. Corn Belt, the short-run elasticity to the ratio of total revenue to variable cost is 0.013 and the long-run elasticity is 0.074. The elasticity to additional land brought into production is -0.023.

That is, the same structure of the yield equations in the U.S. model is used for all the other countries covered by CARD. Since there are constraints by data limitations to estimate the parameters, the U.S.

parameters were used as the base values and country-specific parameters were calibrated using some reasonable assumption**.** First, the response of yield to price was considered in the short-run as primarily an allocative adjustment and it was assumed that it is the same across all other countries. Second, the response of yield to long-run price trend involves some adjustment in technology. As such, it was assumed that a country whose actual yield is far from its yield frontier (or potential yield) has more opportunities to adjust its technology in response to long-term price changes. In the example below, the U.S. yield is 2.94 times larger than Brazil's yield. Using this as the adjustment factor to calibrate the price response of maize yield in Brazil to changes in long term price trends gives an elasticity of 0.184 for Brazil. For the yield drag due to the increasing use of marginal lands we use the relative proportion of available land is used as the basis to establish a calibration factor. For example, a calibration factor of 0.81 is used which gives an extensification elasticity of -0.018 for Brazil. The same procedure is applied to all of the other countries covered by CARD.

4.2.5 Scenarios modelled

The FAPRI-CARD model was run for two scenarios:

Scenario One – High EU Wheat Ethanol Consumption

The initial shock in the first scenario is an increase in the baseline EU ethanol consumption by **5%**, beginning in 2010. The ethanol consumption equation remains active so that the higher ethanol price that results from this initial shock can still dampen consumption as the model solves for a new equilibrium. Also, the EU imports of ethanol are held at the baseline level so that all the increase in ethanol consumption is sourced from domestic production. Importantly, ethanol production from all feedstocks, with the exception of wheat, is held at the baseline level so that all the increase in ethanol production is produced from wheat as the feedstock.

Scenario Two – High EU Rapeseed Oil Biodiesel Consumption

The initial shock in the second scenario is an increase in the baseline EU biodiesel consumption by **5%**, beginning in 2010. The biodiesel consumption equation remains active so that the higher biodiesel price that results from this initial shock can still dampen consumption as the model solves for a new equilibrium. Also, CARD holds the EU imports of biodiesel at the baseline level so that all the increase in biodiesel consumption is sourced from domestic production. Moreover, biodiesel production from all feedstocks, with the exception of rapeseed oil, is held at baseline level so that all the increase in biodiesel production is produced from rapeseed oil as the feedstock.

4.2.6 Main results

In scenario one the modellers assumed a **5%** increase in EU production of ethanol-from-wheat compared to their baseline, from 2010 onwards (and in scenario 2 the equivalent assumption is made for EU-biodiesel-from-rapeseed). That means a 5% shock in 2010 and a smaller year-on-year increase from then on. The initial shock leads to dampened oscillations in the response in successive years. The annual results are reported up to 2023. In order to reduce the (moderate) effects of the oscillation, JRC-IE averaged the results from 2017 to 2023, so the effects are the average effect to be expected around the year 2020.

The results are normalized to the actual change in world biofuel production in the given year, in Mtoe. This is not quite the same as the increase in EU ethanol production (in scenario one[23]) because, in the model, price movements slightly reduce bio-ethanol and biodiesel consumption in the rest of the world (and biodiesel in the EU). The use of the energy content accounts for the difference in energy-density between bioethanol and biodiesel.

The regional codes and commodity codes are shown in Appendix I (section 2) .Detailed change in area and yield results (crop and region), by scenario, are also included in the appendix.

Changes in area, production and yield

Projected LUC, production and yield (standardized to 1 Mtoe and averaged between 2017 and 2023) for the category of 'Total Crops" reported by FAPRI-CARD are shown in **Table** 5. Changes in production include sugar cane and sugar beet shown as sugar equivalent.

Table 5 Marginal changes in area, production and yield - FAPRI-CARD

Country/Region	**Area**		**Production**		**Yield**	
	kha per Mtoe		kt per Mtoe		% change per Mtoe	
	EU Wheat Ethanol	**EU Rapeseed biodiesel**	**EU Wheat Ethanol**	**EU Rapeseed biodiesel**	**EU Wheat Ethanol**	**EU Rapeseed biodiesel**
Latin America, Other	0.3	0.7	0.9	3.9	0.002	0.015
Algeria	0.3	1.8	0.7	4.5	0.002	0.030
Argentina	-1.1	-22.8	-9.0	-89.5	-0.001	0.001
Australia	3.2	-1.8	1.3	-20.1	-0.002	-0.000
Brazil	-19.9	3.5	-82.4	109.7	0.004	0.015
Canada	4.2	20.2	8.0	-161.7	-0.000	0.001
China	2.1	-5.4	161.1	-779.4	0.004	0.003
Eastern Europe, Other	0.0	0.5	-0.3	1.6	-0.001	0.008
Egypt	0.1	0.8	-0.2	5.4	0.000	0.000
EU	407.9	34.6	2417.2	-315.5	0.000	0.004
Africa, Other	-2.0	11.3	-3.2	22.5	-0.001	0.009
Indonesia	-0.2	2.0	-0.6	133.7	-0.000	0.001
India	12.2	211.2	161.8	379.1	0.007	0.005
Japan	0.0	0.7	0.6	3.3	0.000	0.001
South Korea	0.0	0.1	0.2	0.4	-0.001	0.006
Middle East, Other	-0.3	3.4	-0.7	5.7	-0.001	0.003
Malaysia/Indo	0.1	51.0	0.4	165.2	0.000	-0.000
Mexico	0.2	-2.8	-0.8	-4.6	-0.000	0.002
Philippines	0.1	1.6	0.5	7.8	0.000	0.002
Pakistan	3.6	8.4	13.2	34.5	-0.000	0.002
CIS	0.2	-1.6	0.2	-1.3	-0.001	0.010
Russia	1.9	12.9	6.7	55.1	-0.000	0.007
Asia, Other	0.3	3.9	0.1	8.3	-0.001	0.016
South Africa	0.8	-1.0	2.9	-1.5	-0.002	0.001
Taiwan	-0.0	0.0	-0.0	0.1	-0.002	0.005
Thailand	0.1	0.6	0.4	2.3	0.001	0.001
United States	-3.6	44.6	-84.6	389.6	-0.001	0.005
Ukraine	0.6	-1.6	1.4	7.9	-0.000	0.003
Vietnam	-0.1	0.3	-0.7	2.4	-0.003	0.011
Rest of World	-7.7	60.0	**-8.5**	88.5	0.000	0.001
World	**394**	**437**	**2574**	**117**	-0.019	-0.008

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[23] Using the European Lower-Heat-Value definition of energy content, and data from JEC-WTW,
1 million gallons of ethanol = 3.79 Million litres = 80.6 million MJ = 1927 toe
1 million gallons of biodiesel = 0.125 Million GJ = 2998 toe

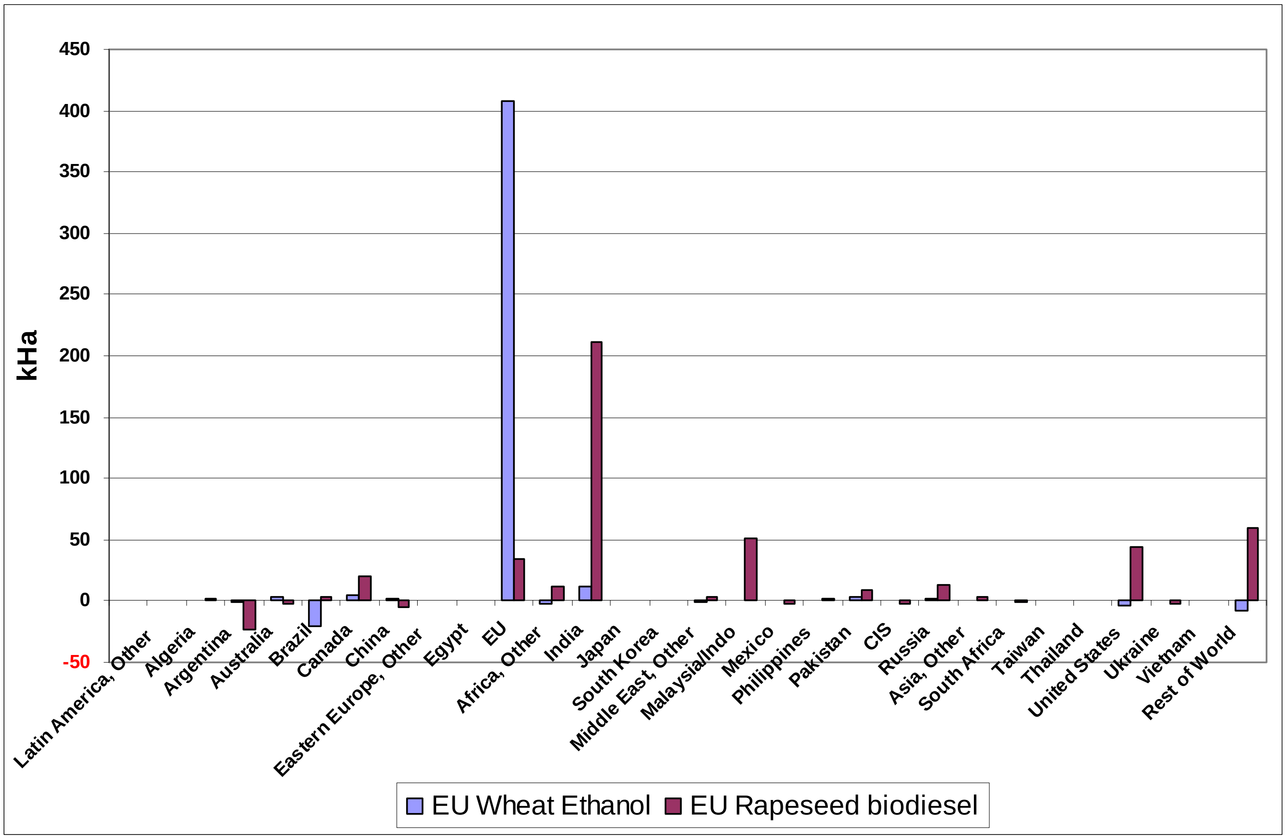
In the EU ethanol scenario all of the LUC increase occurs within the EU, whilst for the biodiesel scenario more than 90% of LUC occurs outside EU (See Table 6). This is because CARD uses "EU wheat" as a feedstock, (rather than "ethanol made in the EU from wheat") and the other land use changes are the knock-on effects of the resulting competition for land in the EU. With the EU being a net exporter of wheat, much of the additional wheat feedstock comes from domestic sources first. In contrast, with the EU being a net importer of rapeseed complex, a large proportion of LUC in the biodiesel scenario is due to expansion of rapeseed outside of the EU, particularly in India (see Figure 8). This seems at first surprising, since rapeseed is usually considered a crop for temperate climates. However, rapeseed already accounts for about 12% of Indian crop area.

The summary results from CARD omitted the increase in oil palm area. This is only significant for the rapeseed biodiesel scenario, where total oil palm area increased by 51 kha per toe. This occurred mostly in Malaysia and Indonesia, and for simplicity we assigned all the increase in palm oil area to this region.

Table 6 Percentage of total LUC within the region of scenario - FAPRI-CARD

Scenario	% of total LUC	
	EU wheat Ethanol	EU rapeseed Biodiesel
Region of scenario	103.4%	8.0%
ROW	-3.4%	92.0%

Figure 8 Marginal changes in area by region - FAPRI-CARD ethanol and biodiesel scenarios

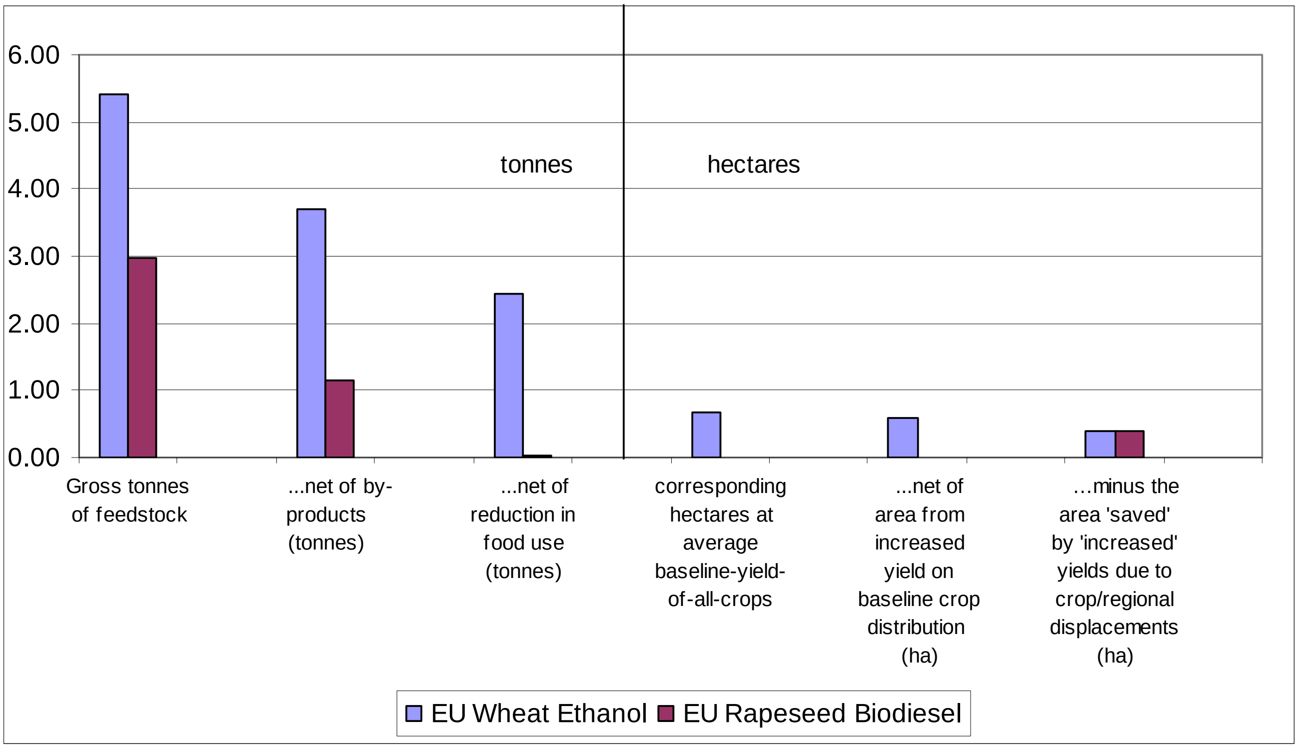


The model parameters which describe the FAPRI-CARD model and LUC (ha per toe reported by FAPRI-CARD) are shown in Table 7 and Figure 9.

Table 7 FAPRI-CARD model parameters and ILUC

	PER TOE BIOFUEL	**EU Wheat Ethanol**	adjustment		**EU Rapeseed Biodiesel**	adjustment			**Calculation**
I	Gross tonnes of feedstock	**5.40**			**3.0**				
			-	31%		-	61%	A	fraction of gross feedstock saved by by-products
II	...net of by-products (tonnes)	3.71			1.16				
			-	34%		-	97%	B	fraction of net feedstock supplied by reduction in food use
III	...net of reduction in food use (tonnes)	2.45			0.03				
			÷	3.7		÷	3.7	C	baseline production/baseline area (tonnes/ha)
IV	corresponding hectares at average baseline-yield-of-all-crops	0.66			0.01				
			-	0.07		-	0.12	D	baseline area *average of fractional yield increase (per region per crop) weighted by baseline area (ha/toe)
V	...net of area from increased yield on baseline crop distribution (ha)	0.59			-0.11				
			-	0.20		-	-0.5	E	Area saved by total net yield effects - D (ha/toe)
VI	…minus the area 'saved' by 'increased' yields due to crop/regional displacements (ha)	**0.39**			**0.40**				**LUC (ha/toe)**

Figure 9 Feedstock requirements and savings/constraints to reach potential LUC per toe.



<u>Discussion of results</u>

The EU-wheat-ethanol scenario of FAPRI-CARD has almost no LUC outside the EU (it is actually slightly negative). The reason is that most of the scenario assumes that all the wheat is *produced* in Europe (rather than just bought in the EU), and wheat used for marginally more ethanol production in the EU is diverted from animal feed. If this animal feed were replaced by imports (or less exports) of cereals, this would cause LUC outside the EU. However, FAPRI-CARD predicts that the extra imports will be in the form of meat rather than cereals, because meat production in the EU becomes less competitive. Furthermore, the extra meat is predicted to come from countries which produce meat on ranches rather than using cereal feed (e.g. Brazil or Australia). This may cause expansion of ranching area, (indeed, if the stock density does not increase significantly as a result of the higher meat price, this would be much greater than the LUC from growing the feed cereals); however, FAPRI-CARD only reports changes in *crop* area, so this LUC is not captured.

As few crops are displaced outside the EU, the average world crop yield goes up as wheat displaces lower-yielding crops in the EU.

For the EU rapeseed scenario, the net feedstock requirement, after taking into account the credit from by-product use, is almost completely supplied from a reduction in animal feed (and food) use. However, this hides a reduction in cereals consumption matched by an increase in tonnes of oilseed consumption. There is a significant increase in land use because the oilseeds displace cereals around the world, reducing average yields; in particular how much rapeseed is imported from India at low yield.

4.3 The AGLINK-COSIMO model (OECD)

4.3.1 Model general description

AGLINK-COSIMO is a dynamic supply-demand model of world agriculture, developed by the Organisation for Economic Co-operation and Development (OECD) Secretariat in close co-operation with Member countries. Since 2004 the geographical coverage of AGLINK has been improved through collaboration with FAO's COSIMO (COmmodity SImulation MOdel), which shows a comparable design and represents the agricultural sectors and policies of many developing countries.

The AGLINK-COSIMO model is now one of the tools used in the generation of baseline projections underlying the OECD/FAO Agricultural Outlook [http://www.agri-outlook.org/]. The model represents annual supply, demand and prices for the principal agricultural commodities produced, consumed and traded in OECD and certain non-OECD countries.

For years, DG-AGRI chose the OECD/FAO world outlook model to integrate with its own ESIM model projections of EU agriculture, in order to produce its annual agricultural outlook. Being a partial-equilibrium model, AGLINK-COSIMO only covers agricultural commodities, using simple elasticities to assess the effect of prices on demand, rather than modelling all other economic sectors to do this. However, these elasticities are in practice easier to estimate from historical data than the production functions used in general-equilibrium models. Non-agricultural sectors are not modelled, and are treated as exogenously to the model.

The model results presented in this report show the changes in the global production and price of the main world crops (wheat, coarse grains, rice, oilseeds, vegetable oils, rice, sugar beet and sugar cane) due to an increase in demand for biofuel feedstocks in different world regions, compared to the baseline of the 2009 OECD-FAO outlook result for 2018 [http://www.agri-outlook.org/].

4.3.2 Biofuels in the model

The current version of the model covers 94% of global ethanol fuel production and 81% of world biodiesel production, and represents production of biofuels, production and use of by-products, and biofuel use for transport (OECD, 2008). Separate markets are represented for the two major types of biofuels: ethanol and biodiesel.

With respect to previous version, the model used for this study also includes second generation technologies and the Sugar Market model has been fully integrated.

Agricultural commodities considered for first generation biofuels are cereals and sugar crops for ethanol and vegetable oils for biodiesel. Concerning second generation biofuels, biofuels made from dedicated biomass production (i.e. cellulose ethanol and synthetic biodiesel from biomass crops), from crop residues (in particular from straw) and other biofuels (including biofuels from e.g. algae, municipal waste etc.) are included. However, they are not varied in these marginal scenarios.

First-generation biofuels from agricultural commodities are modelled fully endogenously in the model, while the production of second-generation and other biofuels enter as exogenous variables.

4.3.3 Accounting for by-products

Animal feed by-products from biofuel production are integrated in the model, by physical replacement of protein and energy feeds differentiated between ruminant and non-ruminant production. On the same basis, the market price of DDGS is derived from the prices for oilmeals and coarse grains.

4.3.4 New Yield specifications

AGLINK-COSIMO does not take into account the differences between the average yield in each world region and the yield at the boundary of cultivation: there is only one yield per crop per region that depends on the crop price through yield elasticity.

However, where an intensive crop expands at the expense of a less-intensive one (e.g. wheat displacing barley or rye), one expects the extra wheat-land to be less fertile than the average land already under wheat. Furthermore, if a “frontier crop” like rye or sugar cane expands onto uncropped land (e.g. pasture), the new land brought into use is likely to be considerably less fertile than the average land already in use in the same country/region.

The marginal yield per crop, for each marginal scenario compared to baseline, is the extra tonnes of production divided by the extra area. In AGLINK-COSIMO for the principal crop involved in each scenario, this is not far from the average yield for that crop in the baseline, but varies because the distribution between regions of the marginal production will not be the same as the existing production. For the *other* crops, which suffer displacements as well as net area changes, the marginal yield is hardly meaningful. Where net area change is very small, apparently anomalous values (very high or negative) can result.

For each scenario, the combined effect of the marginal yields of all the crops combined can be judged by looking at the value-weighted average of the marginal yields per crop (these are weighted according to the contribution of each crop to the marginal additional value of crop production in the marginal scenarios).

4.3.5 Scenarios modelled

The scenarios run with the AGLINK-COSIMO model are:

- Marginal extra ethanol from EU-wheat - *EU WH-ET*)
- Marginal extra biodiesel from EU VegOil (a mix of vegetable oils determined by the model, but starting with the current mix, so predominantly rapeseed oil.) - *EU biodiesel*
- Marginal extra biodiesel from USA VegOil (from a mix of vegetable oils determined by the model, but starting with the current mix, so predominantly soybean oil) - *US biodiesel*
- Marginal extra ethanol from USA coarse grains (representing maize) - *US MA-ET*
- Marginal extra ethanol from Brazilian Sugar Cane - *Bra-SC-ET*

In each scenario, the size of the modelled demand “shock” is 100 M litres of biofuel (0.08 to 0.24% of world biofuel demand). In the raw data, the supply change is slightly smaller than the demand shock because the model estimates the effect of increased crop prices on slightly reducing biofuel production (compared to baseline) in the rest of the world. The baseline scenario is shown in Table 8.

Table 8 AGLINK-COSIMO Baseline Scenario (2018)

	World Prices (USD/t or USD/hl)	World Biofuel Production million litres (million MJ)
Wheat	221.80	
Maize	166.35	
Vegetable oil	932.26	
Oilseeds	393.89	
Oil meal	265.97	
Raw sugar equivalent	303.28	
Ethanol	43.86	143,018 (3,043,303)
Biodiesel	134.78	41,090 (1,360,401)

4.3.6 Main results

The results are not dealt with in the same way as for the other models because we initially received only an extract of the output database. However, now we have obtained the full output database, and are analysing it in the same way as the other models. On the other hand, because prices and consumption results were included in the extract, we could calculate some parameters which we could not do for other models, so we left these in.
The extract of results transmitted to JRC-IE show the changes in the global production and price of the main world crops (wheat, coarse grains, rice, oilseeds, vegetable oils, rice, sugar beet and sugar cane) due to an increase in demand for biofuel feedstocks in different world regions, compared to the baseline of the 2009 OECD-FAO outlook result for 2018.
JRC-IE normalized the results for 1 Mtoe increase in total biofuel consumption in each scenario. In the 2006 impact assessment of the revision of the biofuels directive, the 2020 EU road-fuel demand was assumed to be about 300 Mtoe, so 1 Mtoe is about 0.33% of that demand.

Marginal effect on commodity prices.

The main price changes are marked in bold in Table 9. It can be observed that the prices of maize and wheat themselves are not very strongly connected. However, if we consider a composite “cereals price” the two cereals-ethanol scenarios are similar. The price changes for biodiesel in the EU and US are also very similar to each other. The effect of the by-products can be seen on the reductions in oil-meals price, which are greater for EU-wheat ethanol than for US maize ethanol, but about the same for the two vegetable oil scenarios. Price changes drive the rest of the effects in the AGLINK-COSIMO model.

Table 9 World crop price changes

Scenario	**EU biodiesel**	**EU WH-ET**	**US biodiesel**	**US MA-ET**	**Bra-SC-ET**
Item	**% change in world crop price per Mtoe biofuel**				
wheat	0.004%	**0.832%**	-0.068%	0.116%	0.015%
maize	0.022%	0.172%	0.008%	**0.880%**	0.018%
Veg Oil	**1.284%**	0.058%	**1.411%**	0.041%	-0.010%
Oilseeds	**0.188%**	-0.065%	**0.204%**	0.032%	-0.040%
Oilmeals	**-0.605%**	-0.225%	**-0.667%**	-0.018%	-0.045%
Sugar	0.007%	0.092%	**-0.173%**	**0.239%**	**2.457%**
Average (value-weighted)[1]	**0.18%**	**0.24%**	**0.14%**	**0.31%**	**0.51%**
Average without palm oil[2]	0.114%	0.247%	0.047%	0.320%	0.539%

1. Change in production-weighted average crop price including palm oil, per Mtoe
2. No palm oil, per Mtoe

The "average" figure is the value-weighted average change in world crop (bearing in mind that oilseeds are counted twice in the table above: as oilseeds and also as vegetable oil + meals). This average includes palm oil. For the purpose of calculating supply, area and yield elasticities (see below), we also need the average without palm oil.

We see that when production-weighting is applied, AGLINK-COSIMO predicts that world crop prices are affected more by bioethanol than the same Mtoe of biodiesel, even though biodiesel has a larger effect on vegetable oil price than bioethanol has on cereals price.

Table 10 shows the results re-scaled to show how much commodity prices (value-weighted averages) change for each extra 1% biofuel in the EU 2020 road-fuel demand. 2020 EU road-fuel demand is taken to be 300 Mtoe, so 1% is 3 Mtoe):

Table 10 Change in World crop prices.

Scenario	**EU biodiesel**	**EU WH-ET**	**US biodiesel**	**US MA-ET**	**Bra-SC-ET**
Item	**% change in world crop price per 3 Mtoe biofuel**				
wheat	0.012%	2.497%	-0.204%	0.348%	0.045%
maize	0.065%	0.515%	0.024%	2.639%	0.054%
Veg Oil	3.853%	0.174%	4.233%	0.122%	-0.030%
Oilseeds	0.563%	-0.194%	0.612%	0.096%	-0.120%
Oilmeals	-1.814%	-0.674%	-2.000%	-0.053%	-0.135%
Sugar	0.021%	0.276%	-0.520%	0.718%	7.371%
Average (value-weighted)[1]	**0.54%**	**0.72%**	**0.41%**	**0.93%**	**1.54%**
Average without palm oil[2]	**0.34%**	**0.74%**	**0.14%**	**0.96%**	**1.62%**

1. Change in production-weighted average crop price including palm oil
2. No palm oil

Marginal crop production changes

Changes in crop production (See Table 11) mirror changes in price. The two biodiesel scenarios are broadly similar to each other, as are the two cereal-ethanol scenarios.

Table 11 Marginal changes in crop production

scenario>	**EU biodiesel**	**EU WH-ET**	**US biodiesel**	**US MA-ET**	**Bra-SC-ET**
Crops	**% change in production per Mtoe biofuel**				
Wheat	-0.006%	0.472%	-0.012%	-0.006%	-0.002%
coarse grains	0.002%	-0.041%	-0.002%	0.247%	-0.008%
Rice	0.008%	0.008%	0.008%	0.001%	-0.005%
Oilseeds	0.114%	-0.049%	0.126%	-0.029%	0.012%
sugar beet	0.004%	-0.293%	-0.007%	-0.154%	0.609%
Sugar cane	0.027%	0.071%	0.013%	-0.011%	0.858%
Vegetable oils [1]	0.356%	-0.019%	0.389%	-0.009%	0.004%
Value weighted av. [1]	0.031%	0.075%	0.029%	0.052%	0.100%
Value weighted average [2]	0.033%	0.077%	0.031%	0.054%	0.103%

[1] Including palm oil (using % palm oil estimated as below)

[2] Not including palm oil in the average

Note that "vegetable oil" includes palm oil, but "oilseeds" does not. Thus vegetable oil from oilseeds is counted twice in the crops. Biodiesel scenarios cause a greater percentage increase in vegetable oil than oilseeds because of the increase in palm oil production.

In calculating the value-weighted average, we have to compensate for this if we wish to include palm oil in the production. Instead of including all vegetable oils, we should include only palm oil (since the oilseed-oil already appears in the oilseed production). The percentage of palm oil in the vegetable oil mix is not stated: therefore the JRC-IE had to estimate it approximately to produce a meaningful average. The FAPRI-CARD outlook model disaggregates vegetable oils. It foresees palm oil accounting for 41% of world vegetable oil production in 2018, and for 47% of the increase in production from 2008 to 2018. We took these proportions of palm oil. The exact assumption does not change the average much, as can be confirmed by comparing with the average-for-all-crops with palm oil taken out of the average (of course in this case the equivalent quantity of biodiesel is also taken out of the "per Mtoe of biofuels" divisor), so that this represents "biodiesel from oilseeds".

Marginal changes in yield in biofuels scenarios

AGLINK-COSIMO projects a much larger yield response from cereals than from oilseeds as shown in Table 12. These yield changes include effects of price-driven intensification, extensification onto new land and displacement of crops across frontiers.

Table 12 Marginal changes in yield

Scenario>	EU biodiesel	EU WH-ET	US biodiesel	US MA-ET	Bra-SC-ET
Crops	**% change in crop yield per Mtoe biofuel**				
wheat	0.007%	0.112%	0.001%	0.028%	0.006%
coarse grains	0.008%	0.004%	0.006%	0.036%	0.016%
rice	0.002%	0.006%	0.001%	0.017%	0.014%
Oilseeds[1]	-0.001%	0.002%	-0.001%	0.007%	0.005%
sugar beet	0.005%	-0.058%	-0.004%	0.049%	-0.078%
Sugar cane	0.004%	0.015%	-0.016%	0.016%	0.065%
Value weighted average [1]	**0.004%**	**0.026%**	**0.000%**	**0.022%**	**0.015%**

[1] NOT including palm oil

Marginal changes in world area-per-crop, by scenario

In Table 13 the effect of competition for land between cereals, sugar beet and oilseeds can be seen, whilst extra sugar cane demand for ethanol in Brazil drives up the price of sugar and so increases also sugar beet production.

Table 13 Marginal changes in area per crop

Scenario>	EU biodiesel	EU WH-ET	US biodiesel	US MA-ET	Bra-SC-ET
Crops	**% change in crop area per Mtoe biofuel**				
wheat	-0.014%	0.360%	-0.017%	-0.034%	-0.008%
coarse grains	-0.005%	-0.046%	-0.009%	0.211%	-0.024%
rice	0.009%	0.002%	0.010%	-0.016%	-0.019%
Oilseeds[1]	0.143%	-0.051%	0.162%	-0.036%	0.007%
sugar beet	0.000%	-0.236%	-0.005%	-0.203%	0.687%
Sugar cane	0.030%	0.056%	0.032%	-0.027%	0.793%
Value weighted average [1]	0.029%	0.052%	0.031%	0.032%	0.088%

[1] NOT including palm oil area.

The area for palm oil is not modelled by AGLINK-COSIMO, but we provide the value-weighted average area of crop area expansion per Mtoe of biofuels for the *other* crops, by removing the estimated contribution of palm-oil biodiesel to the total biofuel production in each scenario. JRC-IE subsequently calculated the marginal changes in area including for palm oil. These results are presented later in this chapter.

Marginal changes in area of modelled crops per region

AGLINK-COSIMO projects that, overall, the biodiesel scenarios increase world cropped area by 223 +/- 7 kha per Mtoe biofuel (See Table 14). This area change is equivalent 0.22 ha per toe biofuel, or 53 m^2 per GJ biofuel). This figure is for production from *oilseeds* and it does not include the contribution of palm oil either to the cropped area or to the vegetable oil supply. The distribution of area change between all world regions is very similar for the two biodiesel scenarios. The area change hardly depends on where the extra demand comes from. In the biodiesel scenarios, EU area increases much more than US area.

The cereals-ethanol scenarios increase world crop area by 544 +/- 33 kha per Mtoe biofuels (or 0.54 ha per toe biofuels, or 130 m^2 per GJ biofuel). The distribution of the area change between countries is broadly similar, but less than for the biodiesel scenarios.

Table 14 Marginal changes in area of modelled crops per region

Not including palm oil		**kha change per Mtoe biofuel [1]**				
Region	**baseline area**	**EU biodiesel**	**EU WH-ET**	**US biodiesel**	**US MA-ET**	**Bra-SC-ET**
Brazil	61,450	10.022	24.359	10.275	41.533	165.267
Argentina	31,037	33.712	-0.358	36.895	37.581	-14.243
Mexico	11,083	0.338	-13.155	0.382	10.975	-0.218
Other Lat Amer	18,223	6.551	7.308	7.016	21.814	7.034
USA	91,841	4.349	65.786	3.369	45.869	0.512
Canada	25,302	5.304	15.784	5.759	2.652	0.138
EU 27	72,834	71.099	202.072	77.426	39.490	0.406
Switzerland	200	0.000	0.000	0.000	0.000	0.000
Norway	328	0.000	0.000	0.000	0.000	0.000
Turkey	15,138	-0.547	8.160	-0.965	22.173	-0.902
Russia	52,196	8.563	18.880	9.706	-10.006	-0.250
Other ex communist	28,773	11.746	27.027	12.768	24.053	9.865
China	101,232	2.867	1.620	2.940	4.436	15.383
Japan	1,975	0.001	0.000	0.001	0.002	0.018
Korea	1,094	0.000	0.000	0.000	0.000	0.000
India	125,787	32.200	11.497	35.447	45.561	0.332
Other Asia [1]	139,841	9.870	127.708	9.541	59.122	-12.979
Australia	22,176	15.972	32.949	17.683	11.400	1.065
New Zealand	102	0.000	0.000	0.000	0.000	0.000
South Africa	5,163	1.126	5.655	1.115	9.989	8.461
Other Africa	107,551	3.033	41.264	0.802	144.325	-46.633
***Total LUC** [1]*	*913,326*	***216***	***577***	***230***	***511***	***133***

[1] Not including oil palm

The percentage change in area (over the baseline) of modelled crops per Mtoe is shown in Table **15.** The largest area increases occur in the EU wheat ethanol scenario and the US maize ethanol scenario.

Table 15 Percentage change in area

kha area of modelled crops [1]		**% crop area change per Mtoe biofuel**				
Region	**baseline area**	**EU biodiesel**	**EU WH-ET**	**US biodiesel**	**US MA-ET**	**Bra-SC-ET**
Brazil	61,450	0.016%	0.040%	0.017%	0.068%	0.269%
Argentina	31,037	0.109%	-0.001%	0.119%	0.121%	-0.046%
Mexico	11,083	0.003%	-0.119%	0.003%	0.099%	-0.002%
Other Lat Amer.	18,223	0.036%	0.040%	0.038%	0.120%	0.039%
USA	91,841	0.005%	0.072%	0.004%	0.050%	0.001%
Canada	25,302	0.021%	0.062%	0.023%	0.010%	0.001%
EU27	72,834	0.098%	0.277%	0.106%	0.054%	0.001%
Switzerland	200	0.000%	0.000%	0.000%	0.000%	0.000%
Norway	328	0.000%	0.000%	0.000%	0.000%	0.000%
Turkey	15,138	-0.004%	0.054%	-0.006%	0.146%	-0.006%
Russia	52,196	0.016%	0.036%	0.019%	-0.019%	0.000%
Other ex communist	28,773	0.041%	0.094%	0.044%	0.084%	0.034%
China	101,232	0.003%	0.002%	0.003%	0.004%	0.015%
Japan	1,975	0.000%	0.000%	0.000%	0.000%	0.001%
Korea	1,094	0.000%	0.000%	0.000%	0.000%	0.000%
India	125,787	0.026%	0.009%	0.028%	0.036%	0.000%
Other Asia [1]	139,841	0.007%	0.091%	0.007%	0.042%	-0.009%
Australia	22,176	0.072%	0.149%	0.080%	0.051%	0.005%
New Zealand	102	0.000%	0.000%	0.000%	0.000%	0.000%
South Africa	5,163	0.022%	0.110%	0.022%	0.193%	0.164%
Other Africa	107,551	0.003%	0.038%	0.001%	0.134%	-0.043%
Average	*913,326*	***0.373%***	***1.444%***	***0.445%***	***1.139%***	***0.290%***

[1] Not including oil palm

For EU ethanol, the share of area increase in EU is about the same as for biodiesel, but for US maize-ethanol, there is less area change in the EU and US and more in third-country maize-producers like Brazil (See Table 16). Conversely the area changes for EU-wheat-ethanol are more concentrated on wheat producers like Australia.

Table 16 Percentage regional share of crop area increase

kha area of modelled crops [1]		**% regional share of crop area increase per scenario**				
Region	**baseline area**	**EU biodiesel**	**EU WH-ET**	**US biodiesel**	**US MA-ET**	**Bra-SC-ET**
Brazil	61,450	4.6%	4.2%	4.5%	8.1%	124.0%
Argentina	31,037	15.6%	-0.1%	16.0%	7.4%	-10.7%
Mexico	11,083	0.2%	-2.3%	0.2%	2.1%	-0.2%
Other Lat Amer	18,223	3.0%	1.3%	3.0%	4.3%	5.3%
USA	91,841	2.0%	11.4%	1.5%	9.0%	0.4%
Canada	25,302	2.5%	2.7%	2.5%	0.5%	0.1%
EU 27	72,834	32.9%	35.0%	33.6%	7.7%	0.3%
Switzerland	200	0.0%	0.0%	0.0%	0.0%	0.0%
Norway	328	0.0%	0.0%	0.0%	0.0%	0.0%
Turkey	15,138	-0.3%	1.4%	-0.4%	4.3%	-0.7%
Russia	52,196	4.0%	3.3%	4.2%	-2.0%	-0.2%
Other ex communist	28,773	5.4%	4.7%	5.5%	4.7%	7.4%
China	101,232	1.3%	0.3%	1.3%	0.9%	11.5%
Japan	1,975	0.0%	0.0%	0.0%	0.0%	0.0%
Korea	1,094	0.0%	0.0%	0.0%	0.0%	0.0%
India	125,787	14.9%	2.0%	15.4%	8.9%	0.2%
Other Asia [1]	139,841	4.6%	22.2%	4.1%	11.6%	-9.7%
Australia	22,176	7.4%	5.7%	7.7%	2.2%	0.8%
New Zealand	102	0.0%	0.0%	0.0%	0.0%	0.0%
South Africa	5,163	0.5%	1.0%	0.5%	2.0%	6.3%
Other Africa	107,551	1.4%	7.2%	0.3%	28.2%	-35.0%
Total	*913,326*	*100%*	*100%*	*100%*	*100%*	*100%*

[1] Not including oil palm

For Brazilian ethanol from sugar cane, Brazilian crop area apparently increases even at the expense of that one in other countries. However, we should remember that not all crops are in shown in these results: the crop area in the region "other Africa" may be lost to crops such as cassava, fruit, vegetables, etc. rather than to grazing.

Overall apparent world crop production elasticities by scenario (averaged for all modelled crops except palm oil).

JRC-IE calculated the overall supply elasticities for all crops from the AGLINK-COSIMO results for each modelled crop in each marginal scenario compared to baseline (See Table 17)

Table 17 Supply elasticities

derived from AGLINK results	**marginal scenario (vs. baseline)**				
elasticity on price	**EU biodiesel**	**EU WH-ET**	**US biodiesel**	**US MA-ET**	**Bra-SC-ET**
overall supply elasticity	0.29	0.31	0.67	0.17	0.19
overall area elasticity	0.25	0.21	0.66	0.10	0.16
overall yield elasticity	0.04	0.10	0.00	0.07	0.03
fraction from yield increase	0.12	0.33	0.00	0.41	0.15

$$\text{The overall supply elasticity} = \frac{\text{\% value increase of crops at constant price}}{\text{\%value increase of crops at constant production}}$$

Where:

%value increase of crops at constant production
= production-weighted price increase

% value increase of crops at constant price
= average % increase in crops production, value-weighted at baseline prices.

The overall crop area elasticity

$$= \frac{\text{\% value increase of crops due to area increase at constant yield}}{\text{value-weighted price increase}}$$

where:

% value increase of crops due to area increase at constant yield
= value-weighted average % area increase of crops

The overall crop yield elasticity

$$= \frac{\text{\% value increase of crops due to yield increase at constant area}}{\text{value-weighted price increase}}$$

where:

% increase of crops due to yield increase at constant area
= value-weighted average % yield increase

When calculating the production of vegetable oil, AGLINK-COSIMO assigns some of the production to palm oil (as a function of vegetable oil price and time), but does not calculate the yield of palm oil or the area of oil palm (since it is not considered to compete with other modelled crops for land area). If uncorrected, this would upset the calculation of elasticities. Rather than making its own assumptions on palm oil area vs. yield elasticity to estimate the missing palm-area and yield data, JRC-IE worked from the aggregated “oilseeds” results, not from the separate data for ‘vegoils’ and oilseed meals, so that palm oil is not included in the averages. Thus in the crop-averaged elasticities table, the figures for biodiesel scenarios are for “biodiesel production from oilseeds”.

The row “fraction from yield increase” shows which proportion of the extra crop production in the marginal scenarios AGLINK-COSIMO estimates to come from increasing yields (the rest comes from increasing area). **We see that in the bioethanol scenarios, yield increases contribute 33-41% of the extra production of crops, whilst in the biodiesel scenarios, it only accounts for 0-12%.** The difference is logical, because, after removing the effects of palm oil on area, yield and production, the increase in vegetable oil is mainly soybeans replacing cereals (leading to slightly lower average crop yields, even on a value-weighted basis[24]) and soybeans expanding onto relatively cheap, uncropped, land.

Elasticity of consumption

Consumption figures were reported only for grain (food and feed) and meat. In the grain-based ethanol scenarios, the global ratio of (% change in food-grain consumption / % change in grain price)

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[24] In biodiesel scenarios, farmers change from maize to soybeans even if the value of the maize crop per ha is still slightly higher, because soybeans have lower farming costs (less fertilizer etc.)

is about -0.05. This overall elasticity for consumption of all cereals is logically lower than consumption elasticities in the literature for individual grains, which allow consumers to switch to another grain.

The interpretation of figures for feed-grain and meat consumption is complicated by the availability of animal feed by-products. In biodiesel scenarios, people in poor countries like India actually eat more grains to compensate for reduced vegetable oil consumption.

Marginal vs. Average Yields

The marginal yield per crop, for each marginal scenario compared to baseline, was calculated by taking the extra tonnes of production divided by the extra area (See Table 18*)*.

Table 18 Marginal yields

Tonnes/hectare	**marginal scenario (vs. baseline)**					**Average yield for crop [2]**
Marginal yield per crop	**EU biodiesel**	**EU wheat ethanol**	**US biodiesel**	**US maize-ethanol**	**Brazil sugar cane ethanol**	
Wheat	1.6	**4.2**	2.9	0.6	0.9	**3.2**
Coarse grains	-1.9 [3]	3.5	1.2	**4.5**	1.3	**3.9**
Rice	3.7	15.1[3]	3.2	-0.1 [3]	0.7	**3.1**
Oilseeds	**2.3**	2.3	**2.3**	1.9	3.9	**2.4**
Sugar beet (sugar equivalent)	182 [3]	9.9	15.0 [3]	6.0	7.0	**7.9**
Sugar cane (sugar equivalent)	13.8	15.6	6.3	5.0	**13.3**	**11.0**
value-weighted average marginal yield for all crops [1]	**3.9**	**5.4**	**2.5**	**4.8**	**11.7**	**4.1**

[1] Sugar beet and cane considered as sugar equivalents

AGLINK-COSIMO does NOT take into account the differences between the average yield in each world region and the yield at the boundary of cultivation: it simply only has one yield per region per crop, which however is dependent on the crop price through yield elasticities.

[2] Value-weighted average. Differences in average world yields between baseline and the marginal scenarios is less than 0.5%

[3] Very small yield change due to displacement of production, divided by almost zero net area change.

Conclusions (not including palm oil)

The most important conclusions from analysis of the AGLINK-COSIMO data are:

- The changes in crop area for the EU and US biodiesel are very similar.
- The overall changes in crop area for EU-wheat- and US-maize-bioethanol are also similar to each other, but tend to be more concentrated on regions producing the same type of grain.
- Brazilian sugar cane-ethanol gives a smaller crop-area increase per toe biofuel, mostly affecting Brazil.
- AGLINK-COSIMO does not take into account the difference between yields on existing and new crop-area, and for this reason the model generally underestimates the area of indirect land use change.

AGLINK-COSIMO results including palm oil

JRC-IE calculated marginal changes in area including palm oil (that was not included in AGLINK-COSIMO results described above), from OECD's output data tables, assuming a palm oil yield of 4 tonnes/ha (a representative figure taken from FAPRI projection). Taking into account palm oil, LUC in both EU and US biodiesel scenarios is reduced in the EU (compared to the results without palm oil) but increased in the region 'other Asia' (See Table 19). This is important as the 'other Asia' region includes Indonesia and Malaysia where the additional land required may result in conversion of peatland. The EU wheat ethanol, US maize ethanol and Brazil sugar cane ethanol scenarios are relatively unaffected by the inclusion of palm oil.

Table 19 Marginal changes in area per modelled scenarios per region - AGLINK-COSIMO

Country/Region	Baseline area	kHa change per Mtoe biofuel				
		EU Biodiesel	EU Wheat Ethanol	US Biodiesel	US Maize Ethanol	Brazil Sugar cane Ethanol
Brazil	61,450	8.020	24.359	8.035	41.533	165.267
Argentina	31,037	26.978	-0.358	28.850	37.581	-14.243
Mexico	11,083	0.271	-13.155	0.299	10.975	-0.218
Other Latin America	18,223	5.242	7.308	5.486	21.814	7.034
USA	91,841	3.480	65.786	2.634	45.869	0.512
Canada	25,302	4.245	15.784	4.503	2.652	0.138
EU27	72,834	56.896	202.072	60.543	39.490	0.406
Switzerland	200	0	0	0	0	0
Norway	328	0	0	0	0	0
Turkey	15,138	-0.438	8.160	-0.754	22.173	-0.902
Russia	52,196	6.853	18.880	7.589	-10.006	-0.250
Other ex communist	28,773	9.400	27.027	9.984	24.053	9.865
China	101,232	2.294	1.620	2.299	4.436	15.383
Japan	1,975	0.001	0.000	0.001	0.002	0.018
Korea	1,094	0	0	0	0	0
India	125,787	25.768	11.497	27.718	45.561	0.332
Other Asia	139,841	64.644	124.748	69.403	57.718	-12.351
Australia	22,176	12.781	32.949	13.827	11.400	1.065
New Zealand	102	0	0	0	0	0
South Africa	5,163	0.901	5.655	0.872	9.989	8.461
Other Africa	107,551	2.427	41.264	0.627	144.325	-46.633
Total LUC	**913,326**	**230**	**574**	**242**	**510**	**134**

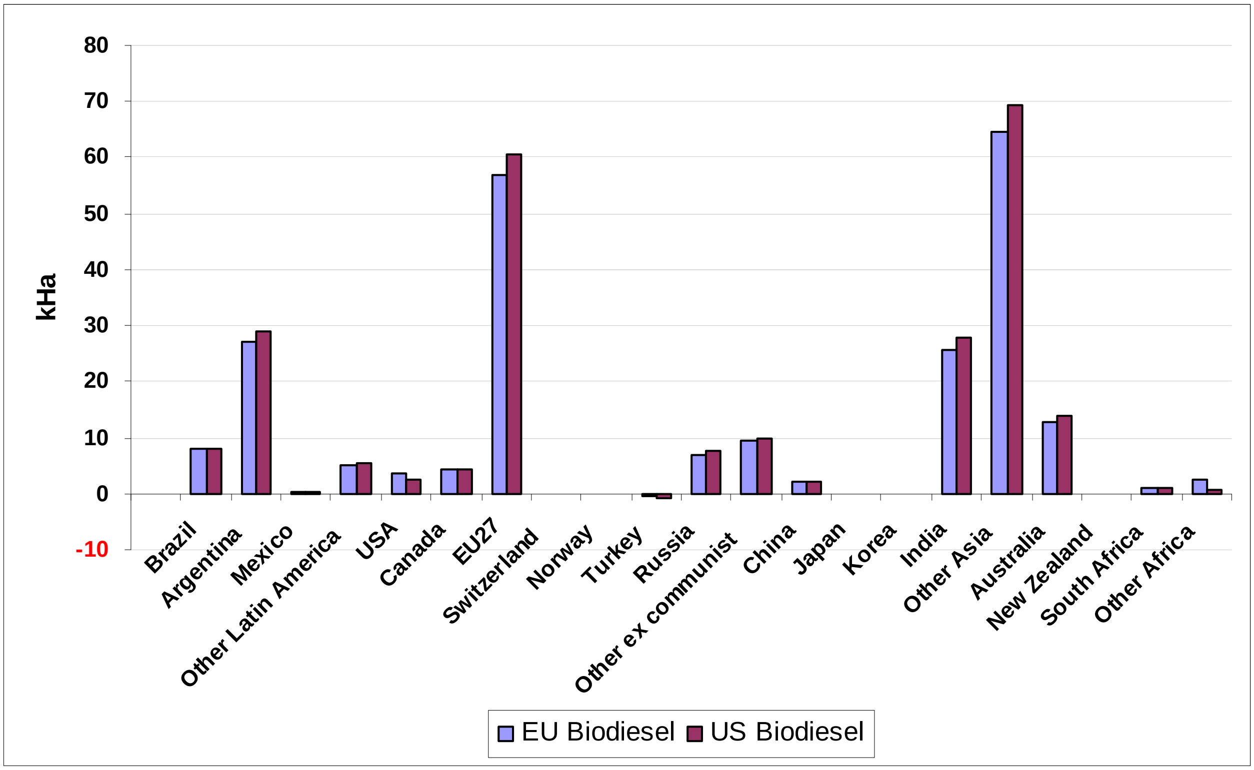
Table 20 shows the share of LUC within the region of the scenario and the rest of the world. In the EU biodiesel and EU wheat ethanol scenarios 75.2% and 64.8% of LUC, respectively, is projected to occur outside the EU. In the US maize ethanol and US biodiesel scenarios more than 90% of the LUC occurs outside the US.

Table 20 Percentage of total LUC within the region of the scenario and the rest of the world - AGLINK-COSIMO

Scenario	% of total change				
	EU Biodiesel	EU Wheat Ethanol	US Biodiesel	US Maize Ethanol	Brazil Sugar cane Ethanol
Region of scenario	24.8%	35.2%	1.1%	9.0%	**123.4%**
ROW	**75.2%**	**64.8%**	**98.9%**	**91.0%**	-23.4%

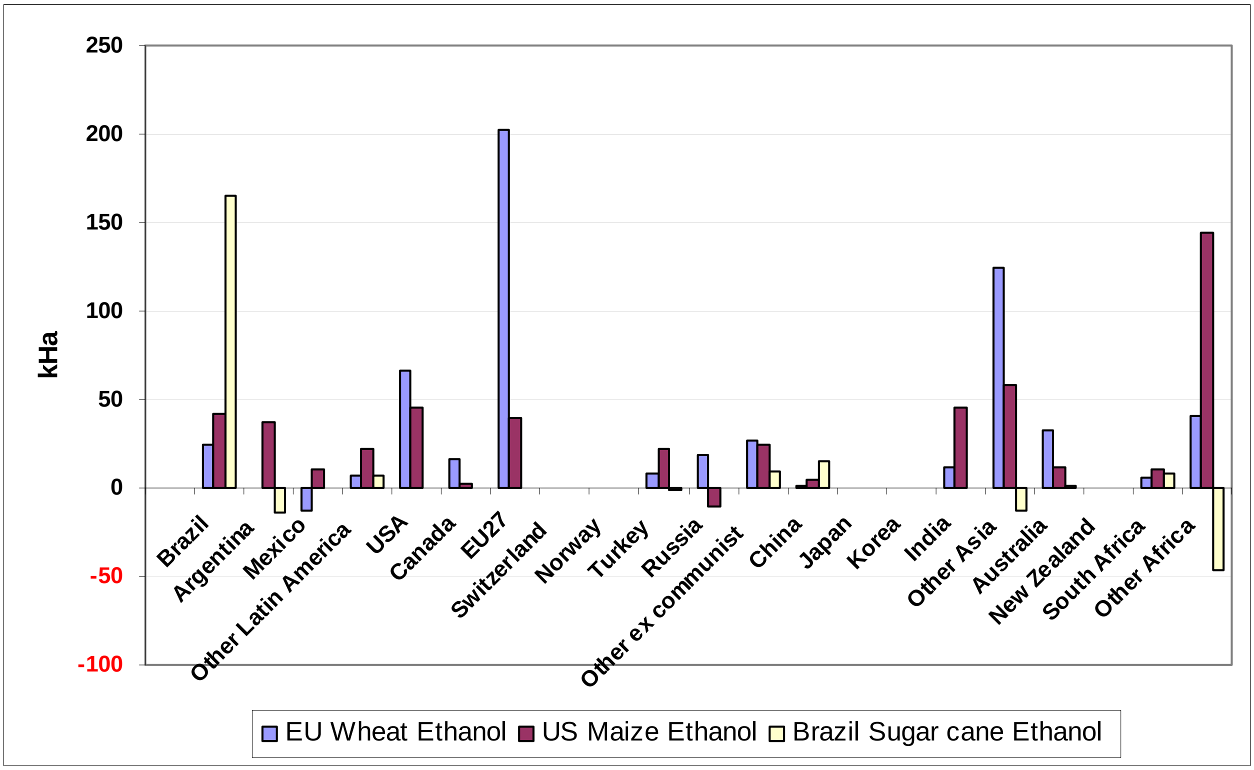
In the biodiesel scenarios, LUC outside the EU is significant in Argentina, India and the 'other Asia' region (See Figure 10).

Figure 10 Marginal changes in area – AGLINK-COSIMO biodiesel scenarios



In the EU wheat ethanol scenarios most of the LUC outside EU occurs in regions of ‘other Asia’, ‘other Africa’ and Brazil (See Figure 11). In the US maize ethanol scenario LUC change outside EU and US is significant in ‘other Asia’, ‘other Africa’, Brazil and India. In the Brazil sugar cane scenario most of the LUC occurs in Brazil while a decrease in area is seen in ‘other Africa’, Argentina and ‘other Asia’.

Figure 11 Marginal changes in area – AGLINK-COSIMO ethanol scenarios



The marginal changes in area by crop (including palm oil) are shown in Table 21. Areas of wheat and coarse grains are reduced in both biodiesel scenarios.

Table 21 Marginal change in area in modelled scenarios per crop - AGLINK-COSIMO

		kHa change per Mtoe biofuel				
Crop/Scenario	**Baseline area**	**EU Biodiesel**	**EU Wheat Ethanol**	**US Biodiesel**	**US Maize Ethanol**	**Brazil Sugar cane Ethanol**
Wheat	224,771	-25.8	808.1	-30.4	-76.4	-18.8
Coarse grains	328,043	-13.3	-150.2	-23.4	691.5	-78.4
Rice	159,240	11.4	2.4	12.5	-25.7	-29.8
Oilseeds	169,289	194.3	-86.8	214.7	-60.9	12.0
Sugar beet	5,136	0.0	-12.1	-0.2	-10.4	35.3
Sugar cane	26,847	6.5	15.1	6.7	-7.2	212.9
Palm oil		56.7	-3.0	61.9	-1.4	0.6
Total LUC	913,326	**230**	**574**	**242**	**510**	**134**

Marginal changes in production

Table 22 Marginal changes in production - AGLINK-COSIMO

	ktonnes change per Mtoe biofuel [1]				
Crop/Scenario	**EU Biodiesel**	**EU Wheat Ethanol**	**US Biodiesel**	**US Maize Ethanol**	**Brazil Sugar cane Ethanol**
Wheat	-40.7	3379.5	-89.5	-43.6	-16.8
Coarse grains	25.1	-526.3	-27.2	3130.9	-99.0
rice	41.5	36.8	40.5	3.5	-22.3
Oilseeds [1]	454.9	-195.7	501.3	-117.1	47.5
Sugar beet	10.9	-746.8	-17.2	-391.7	1549.4
Sugar cane	563.2	1473.6	266.2	-226.9	17748.3
Total	**1055**	**3421**	**674**	**2355**	**19207**

[1] Including palm oil

The AGLINK-COSIMO results file, provided by the OECD, also includes tables of price changes and changes in food consumption. For example, changes in human grain consumption in Africa (except South Africa) for 30 Mtoe biofuels (about the size of the whole 10% biofuels substitution target for the EU, only part of which will be 1st generation):

EU Biodiesel	EU wheat ethanol	US Biodiesel	US Maize ethanol	Brazil SC ethanol
-0.054%	-1.657%	+ 0.081%	-1.411%	-0.228%

These results will be reported more fully in a later report.

4.4. The LEITAP model (LEI)

4.4.1 Model general description

The LEITAP model was developed at the Dutch agricultural research institute LEI, part of Wageningen University and Research (WUR) and is based on the general equilibrium model GTAP, developed at Purdue University, and extended to analyze the impact of the EU biofuel directive on agricultural markets.

The model version used for this study is LEITAP2 (an extended version of the original LEITAP1), which uses the carbon market and the rough characteristics of the production structure of the energy-variant of GTAP, GTAP-E (Burniaux and Truong, 2001; Truong, 2007), the international capital flow accounting system of the dynamic GTAP model GTAP-DYN (Ianchovichina and McDougall, 2000), and includes also some parts of the agricultural variant of GTAP, GTAP-AGR (Keeney and Hertel, 2005).

There are several differences between LEITAP2 and other GTAP-based models, of which the most important is the land supply method (as described below). To predict LUC, LEITAP2 adds a land supply curve approach using information from land allocation models IMAGE and CLUE.

Moreover, the LEITAP2 model includes a lot of extensions compared with the standard GTAP model. The different extensions of the model can be switched on or off through a simple change in coefficients or through closure swaps:

1) An integrated production structure, with energy nesting (including biofuels), feed and fertilizer nesting is included.

2) There is a possibility to include dynamic international investment in the model. This will probably be extended towards a model of sectoral investment in the near future.

3) Production quota can be implemented.

4) EU policy, including first and second pillar measures, can be switched on.

5) Land supply is modelled, based on biophysical model outcomes from IMAGE (Bouwman et al, 2006; Eickhout et al., 2007) and Dyna-CLUE (Verburg et al., 2002; Verburg et al., 2006, Verburg et al., 2008). It distinguishes between marginal and average land productivity.

6) Substitution between different types of land is modelled in a dynamic way.

7) Dynamic mobility of capital and labour between agricultural and non-agricultural sectors can be switched on.

8) Income elasticities of consumption are modelled as a function of Purchasing Power Parity (PPP) corrected real GDP per capita.

The production structure in LEITAP is created in such a way that there is maximum flexibility in the way inputs are substituted. For all sectors the capital/energy nesting structure is used, but only for the petroleum industry ethanol and biodiesel can be used as fuel inputs. The starting elasticities of substitution of substitution between the fuel inputs are set very high at 20 in this sector, because the starting shares of the biofuels are small. When the biofuel shares increase, this elasticity is reduced towards 3 at a market shares of biofuels is about 1/3. The feed-land nest is only active in the livestock sectors, where we assume a high elasticity of substitution of 15.

4.4.2 Biofuels in the model

The agricultural commodities considered in the model are sugar cane (South and Central American ethanol), wheat (EU ethanol), maize (Rest of the World ethanol) and vegetable oils for Biodiesel. All biofuels are assumed to be blended with crude oil in the petrol industry. Trade of biofuels is modelled to a limited extent (see Taheripour et al., 2007).

For the purpose of this study the model was run using biofuel data from 2007 and subsequently endogenously driven by crude oil prices and biofuels blending targets.

4.4.3 Accounting for by-products

By-products are taken into account, but, like all substitutions between inputs in the GTAP structure, animal feed substitutions are done on the basis of relative price, rather than the balancing of protein and energy contents. It was assumed that in the 2001 database the value of by-products equals 20% of the value of maize in ethanol (called DDGS), 15% of the value of wheat in ethanol (also called DDGS), and 30% of the value of oilseeds in biodiesel (called BDBP, i.e. biodiesel by-products). This was added as a substitute to feed the animals with a high elasticity of substitution of 15, while a decrease in the price of feed may lead to more use of concentrates at the expense of fodder crops (elasticity of substitution is 0.2). The reduction in fodder area is not seen on crop area as it falls into a separate land use. Fodder area falls into the AGRI_GRASS sector.

Some puzzling minor effects stem from the lack of oilseed disaggregation into oils and meals in LEITAP2. If oilseeds are replaced, so are vegetable oils.

4.4.4. New Yield specifications

For determining the *marginal yield*, LEITAP uses information from the land allocation module of the IMAGE model (Bouwman et al., 2006).

IMAGE estimates potential rain-fed yields on the basis of land suitability etc. for 0.5 degrees grid-cells (approximately 56 km^2 at the equator). The allocation of new land in IMAGE follows a suitability approach, taking into account population density, distance to existing agriculture, accessibility, and a random factor. In order to provide marginal yields, i.e. yields on the new land compared to the existing yield average, all grid cells are ordered according to their suitability, and a curve of average yield versus cumulative area is constructed.

In most regions, marginal yields are lower than average yields, and are further decreasing with increasing cropland area. However, the fraction of marginal to average is mostly close to 1, except for regions where practically all possibly usable land is already farmed (e.g. North Africa.). This marginal yield is fed back to GTAP, and also used to determine the effect of area expansion on yield, and the resulting area of land use change.

There are two reasons why the factor is mostly close to 1, i.e. why the effect of expansion on average yield is rather small:

1) The factor is based on potential rain-fed yields, not on actual yields. However, the yield gap (difference between potential and actual yield) tends to be larger in remote areas with low population density (Neumann et al., 2010). This means, that even with identical potential yields, actual yields would tend to be lower on newly converted areas than on average. At the same time, of course, further exploitation of land could also bring new technologies and knowledge, thus decreasing the yield gap in remote areas, so that in fact the overall gradient between the smallest and the largest yield gap might not necessarily increase, when agricultural area expands. As the spatial patterns of changes in

intensity and yield gaps is so uncertain, this effect is still ignored in the IMAGE-LEITAP methodology at the moment.

2) Initially, the allocation approach in IMAGE had put a strong weight on yield potentials in determining the overall suitability for expansion. However, yield potentials often only have a minor impact on agricultural expansion (e.g. Soler et al., 2008), and therefore it had been advised to reduce the weight of yield potential in the allocation procedure. But this issue is still under discussion, and an improved allocation module for IMAGE is currently under development.

4.4.5 Scenarios modelled

The LEITAP2 model was run to simulate four different marginal shocks:

- an increase of 1 Mtoe in demand of ethanol in the US, where ethanol is assumed to be produced by maize (i.e. represented by the broader category of "grains") (**Maize Eth US)**
- an increase of 1 Mtoe in demand of ethanol in France, where ethanol is assumed to be produced by wheat (**Wheat Eth Fra**)
- an increase of 1 Mtoe in demand of biodiesel in Germany (**Biod Deu**)
- an increase of 1 Mtoe in demand of biodiesel in Germany, produced completely from palm oil imported from Indonesia (**Biod indo**)

Because by-products are negligible for palm oil, only one variant for the last scenario was calculated.

The first three shocks were calculated using two variants: one with and one without by-products. The differences in results between the scenarios with and without by-products were negligible[25]. Therefore the scenarios without by-products are not reported here.

The increase in global biofuel production in the "1 Mtoe" biofuel scenarios is in fact not exactly 1 Mtoe, but varies slightly from that amount because of resulting reductions in biofuel production outside the target country. The actual increase in world biofuel production in each scenario was:

- Maize Eth US:	0.898 Mtoe
- Wheat Eth Fra:	0.905 Mtoe
- Biod Deu:	1.008 Mtoe
- Biod Indo:	0.876 Mtoe

JRC-IE standardized the LEITAP results to 1 Mtoe using the factors shown above.

4.4.6 Main results

The regional codes and commodity codes for the LEITAP results shown in this section can be found in appendix I. Detailed changes in area and yield (crop and region), by scenario, are also included in the appendix. Results are reported for the total of arable agricultural commodities (LEITAP CLASS: 'total arable') that includes: paddy rice, wheat, other cereals, vegetable oilseeds, sugar beet & cane and other crops.

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[25] At the time of going to press clarification on the LEITAP underestimation of by-products was still ongoing.

LEITAP projects that the largest increase in crop area would occur in the biodiesel in Germany scenario (See Table 23). This is shared between countries producing rapeseed (EU, Russia), and soybean (Brazil), with rather a small area contribution from palm oil. The LUC in the biodiesel scenario in Indonesia is less than the Germany scenario, because of the higher oil yield per ha of palm oil, but this total LUC includes an increase of 526 kHa cropland in Indonesia. The increase in Indonesia is significant as the cropland requirement may be converted from peatland. CO_2 emissions from peatland conversion are estimated by JRC-IE in section 6. The two ethanol scenarios produce similar LUC totals but show differences in regional changes.

Table 23 Marginal changes in area (total arable) per region (2007-2008) – LEITAP

	kha change per Mtoe biofuel			
Countries/regions	**Maize Ethanol US**	**Wheat Ethanol Fra**	**Biodiesel Deu**	**Biodiesel INDO**
All countries in the EU	-10.53	403.49	496.20	-12.38
Canada	68.28	0.39	48.69	-14.19
USA	775.99	51.70	204.60	-58.01
Mexico	4.32	16.90	2.25	-0.38
Rest Central America	0.59	1.46	2.96	-0.62
Brazil	-10.44	1.79	419.26	-11.48
Rest South America	14.50	18.67	79.80	-2.15
Northern Africa	2.08	13.30	9.52	-0.10
West and East Africa	2.99	11.31	95.86	-1.60
South Africa	-2.27	13.17	23.08	-2.16
Rest Western Europe	0.08	5.31	0.67	0.02
Rest Eastern Europe	0.61	0.66	-0.15	-0.03
Turkey	0.24	6.68	18.77	-1.66
Asia Stan	0.32	23.79	32.48	-1.20
Russia	16.26	25.95	234.10	8.18
Middle East	15.08	84.38	7.56	5.25
India	-1.12	16.08	2.73	-1.04
Rest of South Asia	0.82	1.66	1.39	-0.33
Korea	0.07	1.66	0.15	-0.02
China	-6.30	0.02	37.13	-2.50
Southeastern Asia	-3.00	0.71	49.19	4.07
Indonesia	-0.67	4.76	32.89	526.24
Japan	0.02	0.93	0.12	-0.04
Oceania	-5.20	0.06	128.58	-8.56
Total LUC	**863**	**731**	**1928**	**425**

Table 24 shows that in the wheat ethanol in France scenario, 55.2% of the LUC is projected to occur outside the EU, whilst for the biodiesel scenario in Germany, 74.3% of the LUC is located outside the EU. In the US maize ethanol scenario nearly 90% of the LUC is located within the US. Nearly all of the LUC (increased area) in the biodiesel from Indonesia scenario occurs in this country, whilst in the rest of the world most of the changes are reduced area.

Table 24 Percentage of total LUC within the regions of the scenarios and the rest of the World.

Scenario	**% of total LUC**			
	Maize Ethanol US	**Wheat Ethanol Fra**	**Biodiesel Deu**	**Biodiesel INDO**
Region of scenario	89.9%	55.2%	25.7%	123.7%
ROW	10.1%	44.8%	74.3%	-23.7%

The regional changes in area can be seen in

Figure **12** (Ethanol scenarios) and

Figure 13 (Biodiesel scenarios).

In the US maize ethanol scenario LUC predominantly occurs in the US. However, in the EU ethanol scenario a large percentage of LUC (45%) occurs outside EU with crop area increases in the Middle East, USA, Russia and other smaller increases distributed across many other regions.

Figure 12 Marginal changes in area – LEITAP ethanol scenarios

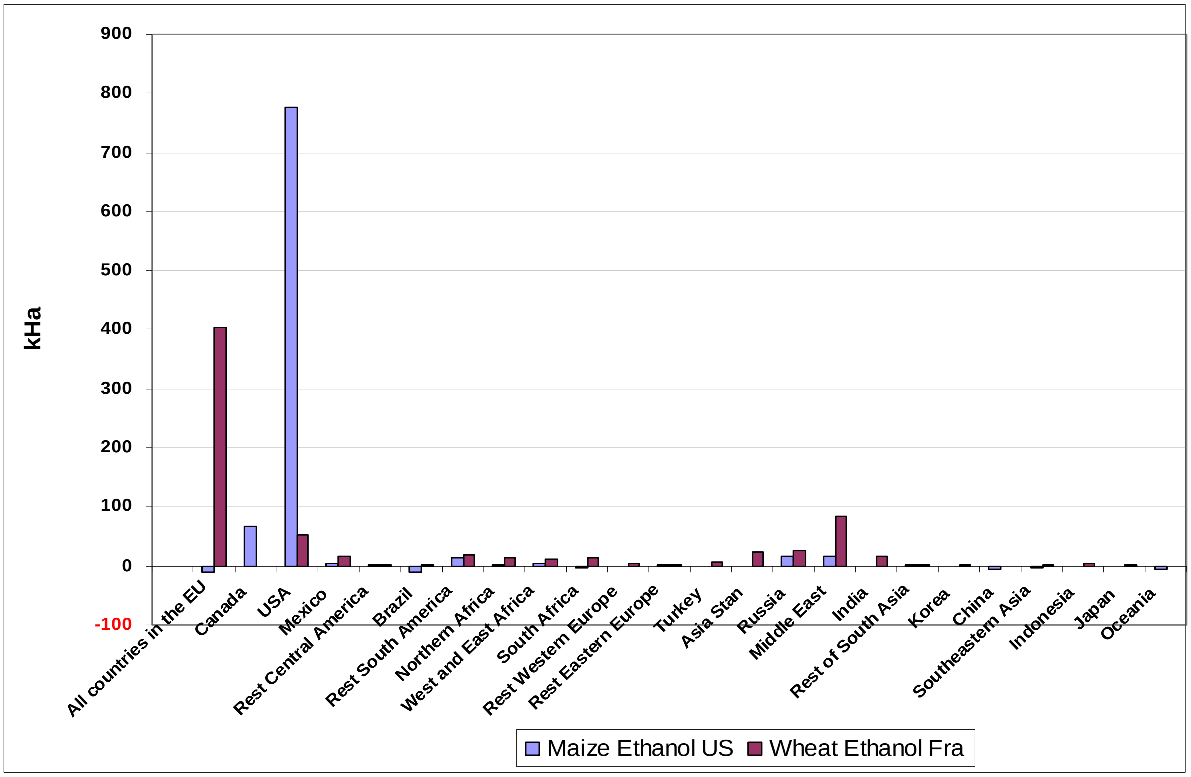
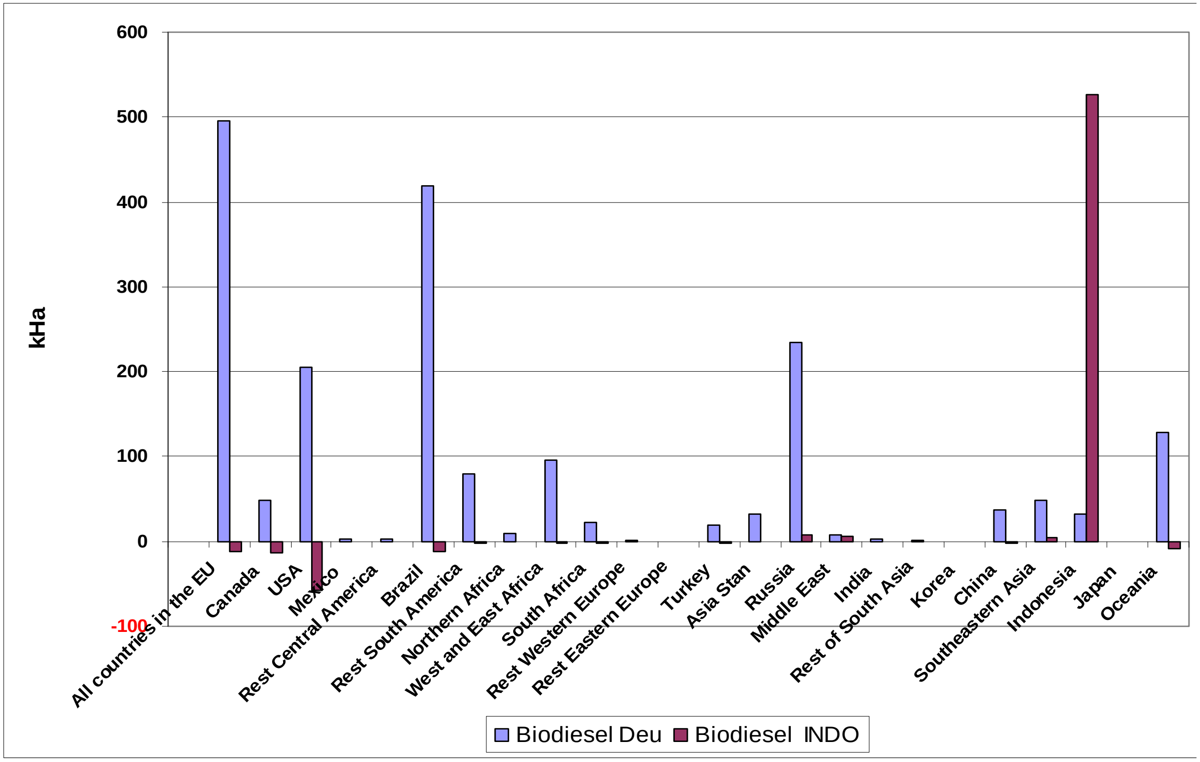


Figure 13 Marginal changes in area – LEITAP biodiesel scenarios



The LEITAP model projects more than double the yield increases (See Table 25) of US maize in the US maize ethanol scenario than for EU wheat in the EU wheat scenario, and for half the price change (See

Table 26). This indicates a major difference in apparent yield elasticity, but this may be affected by the switch of land from soybeans (low yield) to maize (high yield).

Table 25 Marginal changes in yield (total arable) per region (2007-2008) - LEITAP

	% yield change per Mtoe biofuel			
Countries/regions	**Maize Ethanol US**	**Wheat Ethanol Fra**	**Biodiesel Deu**	**Biodiesel INDO**
All countries in the EU	0.012	0.078	-0.304	0.010
Canada	0.055	-0.014	-0.031	-0.003
USA	0.209	-0.021	-0.081	-0.008
Mexico	-0.006	-0.000	-0.002	0.000
Rest Central America	-0.014	-0.002	-0.005	-0.006
Brazil	0.050	0.632	-0.546	-0.060
Rest South America	-0.008	-0.007	-0.059	0.001
Northern Africa	-0.002	-0.022	-0.019	0.001
West and East Africa	-0.001	0.002	-0.019	-0.000
South Africa	0.005	0.008	-0.016	0.002
Rest Western Europe	-0.001	-0.007	-0.017	-0.000
Rest Eastern Europe	0.002	-0.026	-0.019	0.002
Turkey	-0.002	-0.027	-0.031	0.001
Asia Stan	0.001	-0.016	-0.026	0.002
Russia	-0.000	-0.009	-0.088	-0.000
Middle East	-0.021	-0.021	-0.005	-0.008
India	0.002	-0.000	-0.003	0.001
Rest of South Asia	-0.002	-0.001	0.001	0.001
Korea	-0.003	-0.001	-0.005	0.000
China	0.002	0.002	-0.012	0.000
Southeastern Asia	0.003	0.001	0.003	0.002
Indonesia	-0.003	-0.003	0.033	0.627
Japan	0.001	-0.000	-0.001	-0.000
Oceania	0.002	-0.018	-0.059	0.005
World	**0.013**	**0.053**	**-0.079**	**0.024**

The overall change in world crop price is the average change weighted by tonnes of production (without correction for sugar crops to sugar-equivalents) per Mtoe.

We recall that this land use category includes land devoted to fodder (e.g. The LEITAP model projects a smaller increase in price and a larger increase in yield for US maize ethanol than for the same quantity of EU-wheat ethanol, indicating a relatively high value for US maize yield elasticity inherited from GTAP (See Table 25).

In contrast, the biodiesel in Germany scenario predicts yield decreases in nearly all regions. This is due to the shift of crop-mix from towards oilseeds, which have lower yields. In the biodiesel from Indonesia scenario there are significant increases in yield reported in Indonesia, and little effect elsewhere. The apparent yield elasticity in Indonesia is also apparently high, comparable to that of US maize.

Table 26 Marginal changes in price (total arable) per region (2007-2008) - LEITAP

Countries/regions	**% price change**			
	Maize Ethanol US	**Wheat Ethanol Fra**	**Biodiesel Deu**	**Biodiesel INDO**
All countries in the EU	-0.0096	0.0839	0.1056	-0.0064
Canada	0.0058	0.0057	0.0063	-0.0028
USA	0.0426	-0.0004	0.0116	-0.0033
Mexico	0.0018	-0.0000	0.0013	-0.0010
Rest Central America	0.0009	0.0058	0.0089	-0.0008
Brazil	-0.0040	0.0422	0.1107	-0.0058
Rest South America	-0.0037	0.0062	0.0166	-0.0022
Northern Africa	-0.0071	0.0179	0.0123	-0.0047
West and East Africa	-0.0133	0.0080	0.0153	-0.0050
South Africa	-0.0059	0.0055	0.0098	-0.0021
Rest Western Europe	-0.0049	0.0074	0.0075	-0.0031
Rest Eastern Europe	0.0001	0.0212	0.0197	0.0014
Turkey	-0.0040	0.0134	0.0171	-0.0023
Asia Stan	-0.0055	0.0037	0.0073	-0.0025
Russia	-0.0100	0.0042	0.0145	-0.0059
Middle East	-0.0163	0.0017	0.0028	-0.0069
India	-0.0026	0.0069	0.0138	0.0007
Rest of South Asia	0.0011	0.0084	0.0105	0.0002
Korea	0.0033	0.0019	0.0062	-0.0004
China	-0.0017	0.0028	0.0107	-0.0010
Southeastern Asia	-0.0022	0.0041	0.0070	0.0002
Indonesia	-0.0020	0.0030	0.0130	0.1129
Japan	0.0003	0.0003	0.0017	0.0009
Oceania	0.0009	0.0083	0.0211	-0.0014
World	**0.0000**	**0.0158**	**0.0251**	**-0.0001**

Grassland area change

The overall net reductions in grassland area are generally fairly modest (about 1/8 overall) compared to the increases in crop area in LEITAP. In the wheat ethanol in France scenario (See Table 27) the decrease in grassland area in the EU is equivalent to about a quarter of the crop area expansion there. But the grassland area reduction in Brazil is not linked to an increase in crop area there. There are small increases in the regions of ‘Oceania’ (mainly represented by Australia), ‘rest of South America’ and South Africa, presumably caused by increased meat production there as a response to less EU meat production.

In the ethanol in Germany scenario, a decrease in grassland occurs in the EU and Brazil, but its magnitude is still only about a quarter of the increase in the crop area in those countries.

Table 27 Marginal change in grassland area per Mtoe biofuel - LEITAP

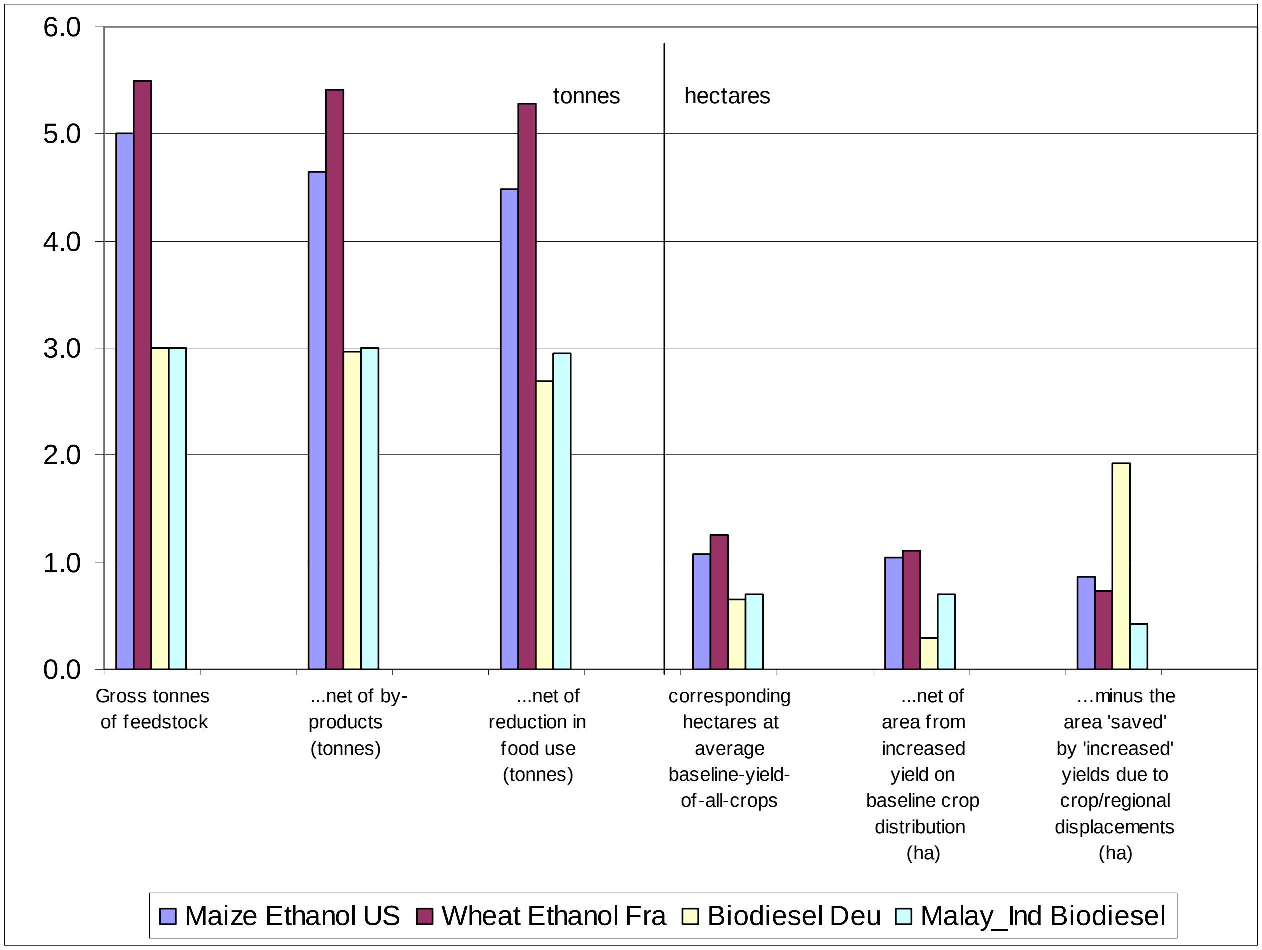
	kha grassland change per Mtoe biofuel			
Countries/regions	**Maize Ethanol US**	**Wheat Ethanol Fra**	**Biodiesel Deu**	**Biodiesel INDO**
All countries in the EU	7.85	-118.73	-82.83	4.61
Canada	0.56	-1.00	0.76	0.14
USA	-57.39	6.26	-9.10	2.47
Mexico	2.67	1.40	2.31	-0.32
Rest Central America	0.53	0.38	0.51	0.01
Brazil	1.25	-50.17	-94.47	4.19
Rest South America	8.18	23.63	7.60	0.23
Northern Africa	-1.30	-9.79	-7.84	0.32
West and East Africa	-13.95	-2.87	-7.10	-4.15
South Africa	5.18	21.17	20.50	0.53
Rest Western Europe	0.11	0.18	0.25	0.01
Rest Eastern Europe	-0.04	-0.32	0.40	-0.09
Turkey	0.00	-1.38	-0.94	0.07
Asia Stan	7.28	-2.11	-3.16	6.35
Russia	3.89	5.13	4.54	1.76
Middle East	-12.92	-13.37	-5.00	-4.29
India	1.12	-1.59	-2.63	1.04
Rest of South Asia	-0.33	-0.55	-0.32	0.22
Korea	0.06	0.06	0.01	0.01
China	8.24	7.01	-17.68	1.13
Southeastern Asia	0.11	0.18	0.32	0.01
Indonesia	-0.06	0.35	0.21	-5.03
Japan	0.00	-0.00	-0.01	0.00
Oceania	48.30	35.60	-31.35	-12.00
World	**9**	**-101**	**-225**	**-3**

The model parameters which describe the LEITAP model and LUC (ha per toe reported by LEITAP) are shown in Table 28 and Figure 14.

Table 28 LUC key model parameters - LEITAP

PER TOE BIOFUEL		Maize Ethanol US			Wheat Ethanol Fra			Biodiesel Deu			Malay_Ind Biodiesel			Calculation	
			adjustment			adjustment			adjustment			adjustment			
I	Gross tonnes of feedstock	**5.0**			**5.5**			**3.0**			**3.0**				
			-	7.2%		-	1.5%		-	1.1%		-	0%	A	fraction of gross feedstock saved by by-products
II	...net of by-products (tonnes)	4.64			5.42			2.97			3.00				
			-	3.5%		-	2.6%		-	9.2%		-	1.4%	B	fraction of net feedstock supplied by reduction in food use
III	...net of reduction in food use (tonnes)	4.48			5.28			2.69			2.96				
			÷	4.2		÷	4.2		÷	4.2		÷	4.2	C	baseline production/baseline area (tonnes/ha)
IV	corresponding hectares at average baseline-yield-of-all-crops	1.07			1.26			0.64			0.71				
			-	0.03		-	0.15		-	0.36		-	0.004	D	baseline area *average of fractional yield increase (per region per crop) weighted by baseline area (ha/toe)
V	...net of area from increased yield on baseline crop distribution (ha)	1.04			1.11			0.29			0.70				
			-	0.18		-	0.38		-	-1.64		-	0.28	E	Area saved by total net yield effects - D (ha/toe)
VI	…minus the area 'saved' by 'increased' yields due to crop/regional displacements (ha)	**0.86**			**0.73**			**1.93**			**0.43**				**LUC (ha/toe)**

Figure 14 Feedstock requirements and savings/constraints to reach potential LUC per toe.



The fraction of crops saved by by-products is much lower in LEITAP than in other models which consider by-products. That is partly because the substitution of animal feed is made on the basis of economic value, and the by-products are given rather low values compared to the crops they replace. But that explanation is not sufficient. Another effect is that as animal feed they reduce the use of land for grazing and fodder (hay) production, which is not included in the cropland area, but contributes to the reduction in the grassland area.

The contribution from reduction in food consumption (change in consumption of food and feed for animals) is also puzzlingly small in all LEITAP scenarios. This may also reflect the “invisible” effects of meat coming from grazed rather than crop-fed animals. On the other hand, both grassland effects together cannot exceed the reduction in grassland area, which is only a quarter of the total for the EU scenarios. So we do not understand fully why the by-products and reduction in food consumption are so low in LEITAP.

The Biodiesel DEU scenario has high LUC mostly because of the displacement of cereals with oilseeds (with lower yields) and the displacement of more production to countries (Brazil, USA Russia) which have lower yields in general. However, there is no obvious reason why this effect (shown as adjustment parameter E in table 28) should be any bigger for LEITAP than other models of EU biodiesel. We suspect that there may be an issue with the LEITAP oilseeds sector in general.

With the exception of the Biodiesel DEU scenario, LEITAP results and the parameters are comparable in magnitude to those of other models if we take into account the small magnitude of the by-product and food consumption effects. Interestingly, though, whereas GTAP shows a higher ‘real’ yield increase for US maize than for EU wheat, it is the opposite way round in LEITAP.

4.5 The IMPACT model (IFPRI)

4.5.1 Model general description

The International Model for Policy Analysis of Agricultural Commodities and Trade **(IMPACT)** developed by the International Food Policy Research Institute **(IFPRI)** is a partial equilibrium agricultural sector model which offers a methodology for analyzing baseline and alternative scenarios for global food demand, supply, trade, income and population. This model has been used by IFPRI for projecting global food supply, food demand and food security to the year 2020 and beyond (Rosegrant et al., 2001, 2002 and 2005). The model contains three categories of commodity demand: food, feed and 'other use'. It is the 'other use' demand category that is manipulated, in order to reflect the utilisation of each particular commodity as a biofuel feedstock.

One of the main features of IMPACT, is its water use module which represents the availability of water to all major consuming sectors (residential, industrial, livestock), in addition to agriculture. By taking hydrological inputs from a detailed global water balance model, and intersecting it with the water requirements for food production, the simulations in IMPACT can also demonstrate the increased demands for irrigation, due to the scaling up of biofuel feedstock production (Rosegrant et al., 2008).

In practice, the IMPACT model was developed with the following typical IMPACT-driven scenarios:

- Looking at the implications of socio-economic growth (income, population) on food/feed demand and other indicators mentioned above.
- Looking at the implications of adverse environmental conditions (water scarcity and climate change effects) on crop yield – and production
- Fairly simple trade liberalization or protection scenarios (with phased changes over time).
- Looking at implications of improved socio-economic conditions (such as access to clean water, secondary schooling for girls and rural roads) on child malnutrition.

Different scenarios are created alongside the main shock of (exogenous) changes in demand for biofuel feedstocks (e.g. area growth and yield growth, population and GDP growth). The model then (endogenously) determines the effects of that shock for each scenario on the area and yield changes in different regions of the world, not only for those feedstocks' areas and yields.

The model components which matter to the analysis are:

- Disaggregation between irrigated and rain-fed area - one can increase yield by expanding more on irrigated versus rain-fed
- Sub-national disaggregation of crop area - gives a better idea of where production changes occur (especially for big regions - US, China, India, Brazil). There are 281 spatial units, but more work needs to be done here.
- Price response for yield as well as for area - allows for yields to increase due to price effects, as well as due to irrigation and technological change (however, technological change is not endogenized to price at the moment)

4.5.2 Biofuels in the model

IFPRI provided marginal results for the main cereal *feedstocks*, not for biofuels as such. Like GTAP, IMPACT currently models all oilseeds as one crop, and could not provide realistic results for biodiesel feedstocks in the time available.

4.5.3 Accounting for by-products

The intention was next to make an external compensation for by-products by subtracting proportions of the marginal LUC effects from coarse grains and soybean meal. However, IFPRI could not provide, with the time and resources available, the disaggregation of the oilseed sector needed to produce the marginal soybean meal data. Thus JRC-IE reports the IMPACT data per tonne of feedstock. However, to help comparison with other models, JRC-IE provides a rough estimate for the likely results per toe biofuel, as described below.

4.5.4 New Yield specifications

The parameters used in the model result in no (significant) difference between yields on new land and on old land. But there is a relatively strong change in yield with price.

4.5.5 Scenarios modelled

The IMPACT model was run by IFPRI for the following scenarios between 2010 and 2015:

- 1 Mtonne (metric) increase in **US maize demand**
- 1 Mtonne increase in **US wheat demand**
- 1 Mtonne increase in **EU coarse grains** demand (432 ktonnes increase in maize and 568 ktonnes increase in other grains).
- 1 Mtonne increase in **EU wheat** demand.

To allow comparison with the LUC results of other models, JRC-IE roughly estimated what the IFPRI-IMPACT results would be if related to 1 Mtoe biofuel, assuming:-

1 Mtoe ethanol requires 4.86 Mtonnes wheat (ENSUS)

1 Mtoe ethanol requires 4.64 Mtonnes maize (ENSUS)

Furthermore, it is necessary to give some compensation for the effects of by-products. For this, JRC-IE used the average percentage area reduction due to by-products in the equivalent scenarios reported in GTAP and FAPRI.

4.5.6 Main results

The **IFPRI-IMPACT** model projects the highest LUC in the EU coarse grains scenario (See Table 29).

The lowest LUC is reported for the US maize ethanol scenario. The results for US wheat ethanol and EU wheat ethanol are the same because IFPRI-IMPACT uses a single-world-market approximation without considering transport costs or import tariffs (Note that FAPRI *does* consider these effects).

Table 29 Marginal change in area for (total of all countries and regions) – IFPRI-IMPACT results for the main feedstock, standardised to a per-Mtoe-biofuel basis by JRC-IE.

	kHa change			
	US Maize Ethanol	US Wheat Ethanol	EU Coarse Grains Ethanol	EU Wheat Ethanol
Total LUC per Mtonne	23	46	24	46
Mtoe per Mtonne	0.216	0.206	0.210	0.206
Total LUC per Mtoe	**107**	**223**	**116**	**223**

JRC-IE could not show regional changes of LUC (as per the previous models) because the IMPACT model results are reported for 281 Food Producing Units based on water basins.

All of the scenarios indicate yield increases (See Table 30). The highest changes in yield occur in the US maize ethanol and EU coarse grains scenarios.

Table 30 Marginal change in yields (total for all countries and regions) – IFPRI-IMPACT

	% yield change			
	US Maize Ethanol	US Wheat Ethanol	EU Coarse grains Ethanol	EU Wheat Ethanol
Total	**0.006%**	**0.003%**	**0.009%**	**0.003%**

Table 31 Marginal change in production (total for all countries and regions) - IFPRI-IMPACT

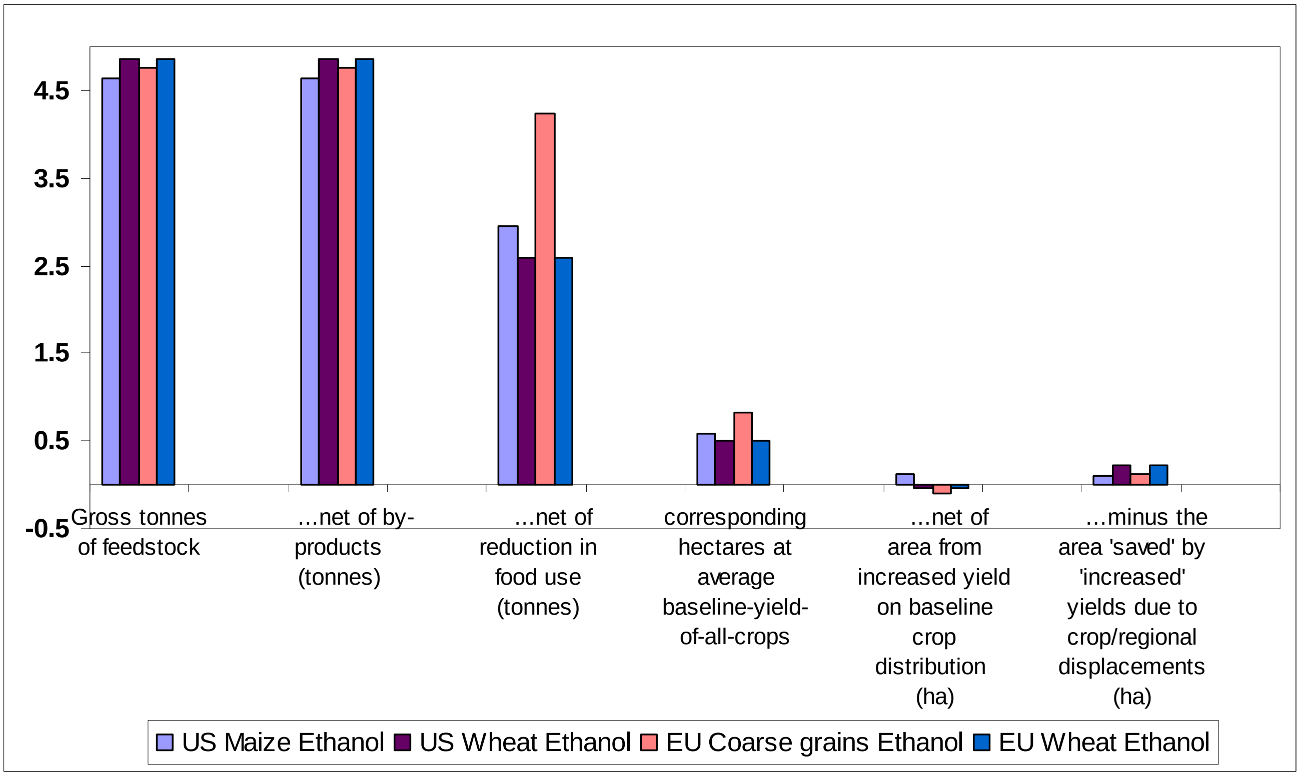
	production change ktonnes			
	US Maize Ethanol	US Wheat Ethanol	EU Coarse Grains Ethanol	EU Wheat Ethanol
Production per Mtonne	671	565	977	565
Production per Mtoe	**3113**	**2744**	**4655**	**2744**

To compare the model parameters with the other models the factors *per toe of biofuels*, using ENSUS values for feedstock per toe are shown in the Table 32 and Figure 15.

Table 32 LUC per TOE bioethanol (JRC-IE working of IFPRI results)

PER TOE BIOFUEL		US Maize Ethanol			US Wheat Ethanol			EU Coarse grains Ethanol			EU Wheat Ethanol			Calculation	
			adjustment			adjustment			adjustment			adjustment			
I	Gross tonnes of feedstock	**4.64**			**4.86**			**4.76**			**4.86**				
			-	0%		-	0%		-	0%		-	0%	A	fraction of gross feedstock saved by by-products
II	...net of by-products (tonnes)	4.64			4.86			4.76			4.86				
			-	36%		-	47%		-	11%		-	47%	B	fraction of net feedstock supplied by reduction in food use
III	...net of reduction in food use (tonnes)	2.95			2.59			4.24			2.59				
			÷	5.1		÷	5.1		÷	5.1		÷	5.1	C	baseline production/baseline area (tonnes/ha)
IV	corresponding hectares at average baseline-yield-of-all-crops	0.58			0.51			0.83			0.51				
			-	0.45		-	0.54		-	0.92		-	0.54	D	baseline area *average of fractional yield increase (per region per crop) weighted by baseline area (ha/toe)
V	...net of area from increased yield on baseline crop distribution (ha)	0.13			-0.03			-0.09			-0.03				
			-	0.02		-	-0.26		-	-0.21		-	-0.26	E	Area saved by total net yield effects - D (ha/toe)
VI	…minus the area 'saved' by 'increased' yields due to crop/regional displacements (ha)	**0.107**			**0.223**			**0.116**			**0.223**			**LUC (ha/toe)**	

Figure 15 Feedstock requirements and savings/constraints to reach potential LUC per toe.



The LUC results for the IMPACT model are lower than for most other models because of:

- a large effect of reduced food consumption, except for the EU coarse grains scenario
- a large fraction of supply coming from higher yields

The two wheat-ethanol scenarios are identical because IMPACT assumes an integrated world market without considering transport costs. They show high yield increases due to price, but the EU coarse grains scenario shows an even higher response, reducing its LUC. The US maize scenario shows a similar yield response but the displacement of other cereals by maize results in a “virtual” increase in average yield, which reduces the LUC.

4.6 The CAPRI model

4.6.1 Model general description

The **CAPRI** (Common Agricultural Policy Regional Impact) model is an agricultural sector economic model covering the EU27, Norway and Western Balkans. The model is based on non-linear regional programming models consistently linked with a global agricultural trade model (Britz et al., 2007). The models principal aim is to analyse impacts of changes in EU agricultural policies and markets on European agriculture and global agricultural markets, mostly at the medium term (8-10 years ahead). Technically, it is a static, partial equilibrium model consisting of four interconnected modules covering (1) regional agricultural supply for EU27, Norway and Western Balkans, (2) global and EU markets for major primary and secondary agricultural products including bi-lateral trade, (3) EU markets for young animals and finally (4) premium schemes and other policy instruments of the Common Agricultural Policy (CAP).

The CAPRI model provides a detailed description of the Common Agricultural Policy (CAP) and the model covers EU with detailed results reported in 250 regions/NUTS (Nomenclature of Units for Territorial Statistics) which were created by the European Office for Statistics (Eurostat). In contrast the rest of the world is treated as one single region.

4.6.2 Biofuels in the model

Since 2007, the CAPRI market part has been extended to cover bioethanol and biodiesel production in the EU, and DDGS as a by-product from bioethanol production. Trade with biofuels is not yet included. At the same time, palm oil was added to the market model. The EU biofuels mandates are introduced as a fixed demand for bioethanol and biodiesel. The model will then endogenously determine changes in supply and other demand (feed, food, processing) for biofuel feedstocks (cereals, vegetable oils). As the CAPRI market part comprises behavioural functions for oilseed processing, the demand for biodiesel processing can be covered either be domestically processed vegetable oils, or be imported ones, and the domestic processing may be sourced by EU produced oilseeds or by imported ones.

4.6.3 Accounting for by-products

The effect of by-products in the animal feed sector is modelled through physical replacement ratios for cereals and soybean meal.

4.6.4 New Yield specifications

Yields are calculated on a fine geographic scale within the EU as exogenous yield improvement with time plus price-induced yield effects.

4.6.5 Scenarios modelled

Marginal increases in processing of cereals-to-ethanol are compared to processing of rapeseed/rapeseed oil- to- biodiesel. Scenarios considered are 1 to 10% increased demand for biofuels, where no geographical differences within the EU27 have been taken into account. All shocks have been performed against the CAPRI medium-term baseline in the year 2020, including the most recent projections on energy consumption (as delivered by the PRIMES model) and 'health-check' reform of the Common Agricultural Policy.

4.6.6 Main results

Table 33 shows the effects of net production, biofuel processing, imports and exports of cereals and vegetable oils from a 1% marginal shock on ethanol and biodiesel for the EU27 – in 1000 tonnes and percentage changes.

JRC-IE calculated the percentage feedstock that comes from production in EU. For the 1% increase in ethanol, 29.8% of the feedstock (cereals) comes from EU production. For the 1% increase in biodiesel, 90.8% of the feedstock (oils) comes from EU production.

Table 33 Effects on net production, biofuel processing, imports and exports of cereals and vegetable oils from 1% marginal shocks on ethanol and biodiesel for the EU27

		BIOF_D0E1				**BIOF_D1E0**			
		Net production	**Biofuels processing**	**Imports**	**Exports**	**Net production**	**Biofuels processing**	**Imports**	**Exports**
Cereals	*1000 t diff*	74.7	290.8	**123.5**	**-52.6**	-13.2	-10.9	-3.1	-0.9
	% diff	0.03	1.04*	**0.45**	**-0.14**	0	-0.04	-0.01	0
Oils	*1000 t diff*	2.4	0.8	-0.3	-1.3	9.7	119.9	**95.5**	0.1
	% diff	0.01	0.01	0	-0.03	0.06	0.89**	**0.65**	0

Where:

BIOF_D0E1: 1% increase of ethanol (processing of cereals) in the EU27 - biodiesel remains constant at the baseline level.

BIOF_D1E0: 1% increase of biodiesel (processing of rapeseed) in the EU27 - ethanol remains constant at the baseline level.

* The resulting % increase in ethanol out of a 1% exogenous shock (endogenous adjustment)

** The resulting % increase in biodiesel out of a 1% exogenous shock (endogenous adjustment)

In both the ethanol and biodiesel shocks the largest increase in feedstock is projected to occur outside the EU (See Table 34)

Table 34 Percentage of feedstock within the EU and outside the EU for 1% increase in biofuel

Region	**% of total change**	
	EU Cereals Ethanol	EU Oilseeds Biodiesel
Within EU	29.8%	9.2%
Outside EU	**70.2%**	**90.8%**

<u>Marginal effects from oilseeds-to-biodiesel and cereals-to-ethanol demand shocks: Trade balances</u>

For biodiesel, the results show that Europe would strongly reinforce its net importing of vegetable oils, with respect to the rest of the world, in order to satisfy the increase in demand for biodiesel. While supply behaves quite inelastically (production increases by 0.51% for a 10% increase in demand), imports increase strongly at a marginal rate of 0.66%. The net exporting position of the

EU27 only diminishes marginally, since exports of vegetable oils in the baseline are minor, with respect to imports.

On the other hand, the bioethanol scenario is different, since cereal exports play an important role in the medium-term baseline. Results show that Europe would increase imports of cereals from the rest of the world in order to satisfy the increase in demand for ethanol (marginal effect of 0.46%) and reduce its exports (marginal effect of -0.16%). Also here supply behaves quite inelastically, increasing production at a rate of 0.02%.

Table 35 shows the estimated ILUC from different demand shocks (respectively 2%, 4%, 6% and 8%) on biodiesel consumption in the EU. It can be observed that effects are diverse:

- Hectares of oilseeds increase through a higher production of rapeseed (marginal rate of 0.056%)
- On the negative side, hectares of cereals, other arable crops (such as potatoes and pulses) and fallow land decrease.

Table 35 Effects on land use change from marginal shocks on vegetable oil demand for the EU27 – in % changes

	D2	D4	D6	D8
Cereals	-0.011%	-0.023%	-0.034%	-0.045%
Oilseeds	0.113%	0.226%	0.339%	0.450%
Other arable crops	-0.008%	-0.016%	-0.023%	-0.031%
Vegetables and Permanent crops	0.000%	0.001%	0.001%	0.001%
Fodder activities	-0.001%	-0.003%	-0.004%	-0.005%
Set aside and fallow land	-0.020%	-0.040%	-0.059%	-0.079%

Effects on land use change from cereals-to-bioethanol demand shocks

Table 36 below shows the estimated ILUC from different demand shocks on ethanol consumption in the EU. Various effects can be observed:

- The increase in cereal production (+0.02%), as presented above, is accompanied by a marginal increase of hectares for cereals (marginal rate varying between 0.007% and 0.009%) and some intensification of production (yield increasing at the margin by 0.006%).
- Hectares of oilseeds increase through a higher production of sunflower.
- On the negative side, hectares of other arable crops (such as potatoes and pulses) and fallow land decrease.

Table 36 Effects on land use change from marginal shocks on ethanol demand for the EU27 – in % changes

	E2	E4	E6	E8
Cereals	0.015%	0.030%	0.045%	0.062%
Oilseeds	0.005%	0.011%	0.016%	0.021%
Other arable crops	-0.013%	-0.027%	-0.040%	-0.054%
Vegetables and Permanent crops	-0.003%	-0.005%	-0.008%	-0.012%
Fodder activities	-0.002%	-0.003%	-0.005%	-0.007%
Set aside and fallow land	-0.070%	-0.141%	-0.211%	-0.294%

Some non-linearities in the results were observed, especially for cereal and fallow land area, where higher changes are achieved at higher levels of ethanol demand.

5. COMPARISON OF RESULTS FROM ALL MODELS

5.1 Scale of LUC results

To enable comparison of the model results JRC-IE standardised the results reported by the modellers to Mtoe. The marginal changes in area (kHa per Mtoe) for all of the modelled scenarios are shown in Table 37 and Figure 16.

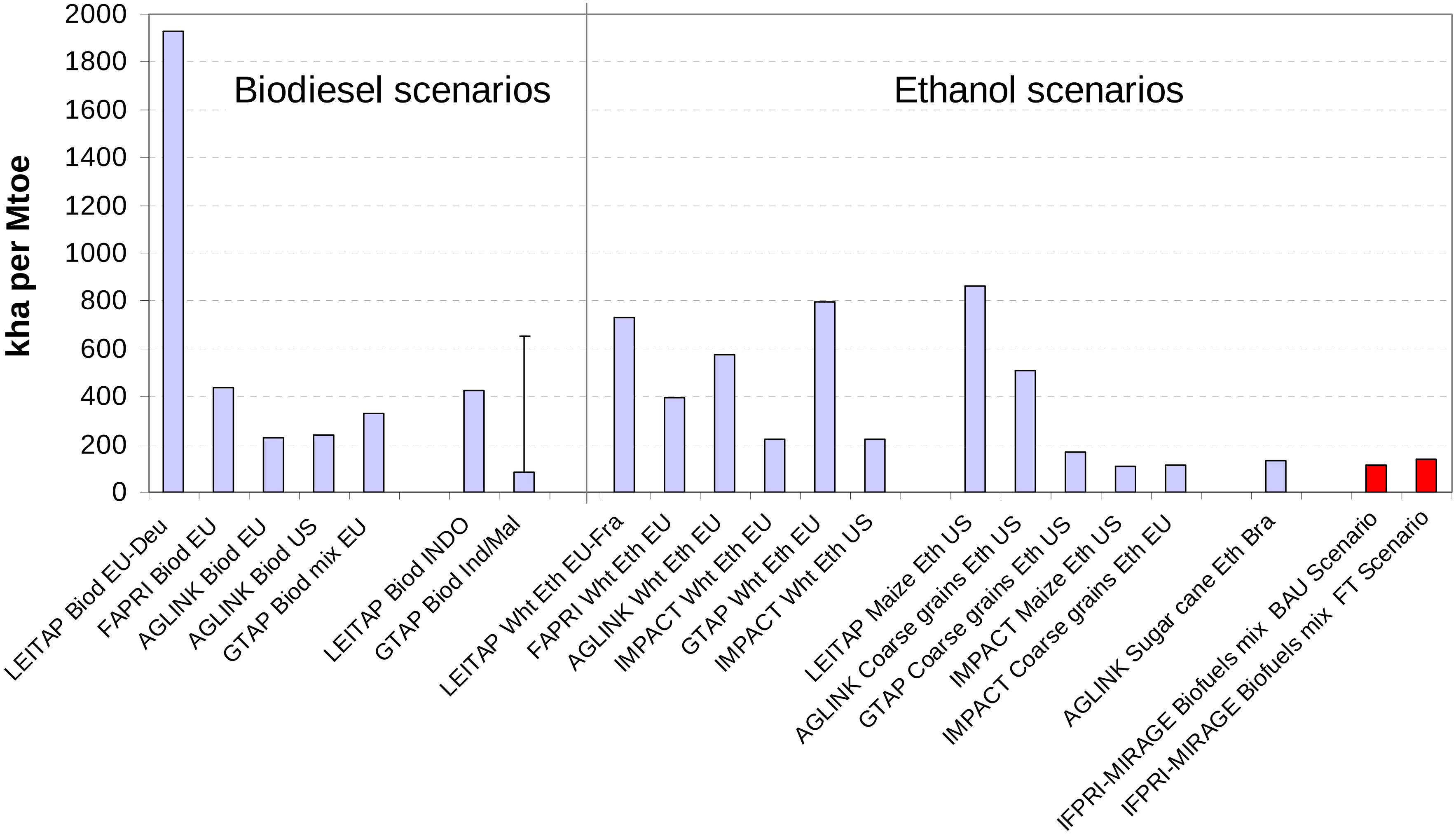
The "GTAP Biodiesel Indonesia/Malaysia" result shown in Figure 16 is shown with an error bar representing the different possible scenario assumptions one can make (see discussions of the workshop in *"The Effects of increased demand for Biofuels feedstocks on the world agricultural markets and areas"*[1].

It should also be noted that the IMPACT results shown in Figure 16 are reported without by-products as the IMPACT model does not take them into account.

Table 37 Summary of modelled LUC results for biodiesel scenarios

Scenarios	Modelled results kha per Mtoe	Modelled results ha per toe
Biodiesel scenarios		
LEITAP Biod EU-Deu	1928	1.93
FAPRI Biod EU	435	0.44
AGLINK Biod EU	230	0.23
AGLINK Biod US	242	0.24
GTAP Biod mix EU	376	0.38
LEITAP Biod INDO	425	0.43
GTAP Biod Ind/Mal	82	0.08
Ethanol scenarios		
LEITAP Wht Eth EU-Fra	731	0.73
FAPRI Wht Eth EU	394	0.39
AGLINK Wht Eth EU	574	0.57
IMPACT Wht Eth EU	223	0.22
GTAP Wht Eth EU	794	0.79
IMPACT Wht Eth US	223	0.22
LEITAP Maize Eth US	863	0.86
AGLINK Coarse grains Eth US	510	0.51
GTAP Coarse grains Eth US	165	0.17
IMPACT Maize Eth US	107	0.11
IMPACT Coarse grains Eth EU	116	0.12
AGLINK Sugar cane Eth Bra	134	0.13

Figure 16 Marginal changes in area per Mtoe for all models and scenarios



For comparison, the graph includes also the results of one of the modelling studies carried out, under request of another Commission's service (DG TRADE), by IFPRI-ATLASS Consortium[26]. This study used the model: MIRAGE.. The study provides the land use change as a consequence of EU biofuels policy assuming first-generation land-using ethanol and biodiesel achieving a 5.6% share of transport fuel consumption in 2020. The model assumes alternative trade policy scenarios: business as usual trade policy (BAU scenario) and full, multilateral trade liberalization in biofuels (FT scenario). The marginal land use change (in Kha per Mtoe) is calculated by JRC-IE considering the marginal biofuel demand in 2020 as the difference between BAU and REF (Baseline) scenarios, and between FT and REF scenarios.

Table 38 shows the share of LUC that is projected by the models within the region of the scenario and the rest of the world. Most of the EU modelled scenarios project that the largest share of LUC occurs outside the EU. Regional results for the IMPACT model are approximate as their regions do not follow national borders.

The models show large variations in the fraction of feedstock which is produced in the "scenario" region where the shock occurs. Sometimes this is due to a difference in the definition of the scenarios. For example, the FAPRI-CARD EU-wheat ethanol scenario cannot be compared directly to the other EU-wheat scenarios because it assumes all the extra wheat is *grown* in EU, whereas the others assume the wheat is *bought* in the EU, allowing more imports. In all of the other EU ethanol scenarios, most LUC is projected to occur outside the EU, with the exception of LEITAP (45% in the rest of the world).

All of the EU biodiesel scenarios project that the greatest share of LUC will occur outside the EU. In the AGLINK-COSIMO and GTAP models the US maize ethanol scenarios project that most of the LUC occurs outside the US. However, the LEITAP model projects that most occurs inside the US.

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[26] "Global trade and Environmental impact study of the EU Biofuels mandate", Final report, March 2010 available online at http://trade.ec.europa.eu/doclib/press/index.cfm?id=542

Table 38 Share of total LUC change, for biodiesel scenarios, within the region of the scenario and the rest of the World (ROW).

Scenarios	**% of total LUC change**	
	Within scenario region	**ROW**
Biodiesel scenarios		
LEITAP Biod EU-Deu	26%	74%
FAPRI Biod EU	8%	92%
AGLINK Biod EU	25%	75%
GTAP Biod mix EU	41%	59%
AGLINK Biod US	1%	99%
LEITAP Biod INDO	124%	-24%
GTAP Biod Ind/Mal	42%	58%
Ethanol scenarios		
LEITAP Wht Eth EU-Fra	55%	45%
FAPRI Wht Eth EU	103%	-3%
AGLINK Wht Eth EU	35%	65%
GTAP Wht Eth EU	44%	56%
LEITAP Maize Eth US	90%	10%
AGLINK Coarse Grain Eth US	9%	91%
GTAP Coarse grains Eth US	41%	59%
AGLINK Sugar cane Eth Bra	123%	-23%

The negative LUC outside EU in FAPRI and LEITAP are due to only considering crop-area effects: increased cereals feed prices shift meat production outside the EU to is shifted outside EU area: concentration of effects on EU is further exaggerated in FAPRI by the comparisons of regional land use change are shown in Figure 17, Figure 18, Figure 19 and Figure 20.

Figure 17 Regional LUC for EU biodiesel scenarios

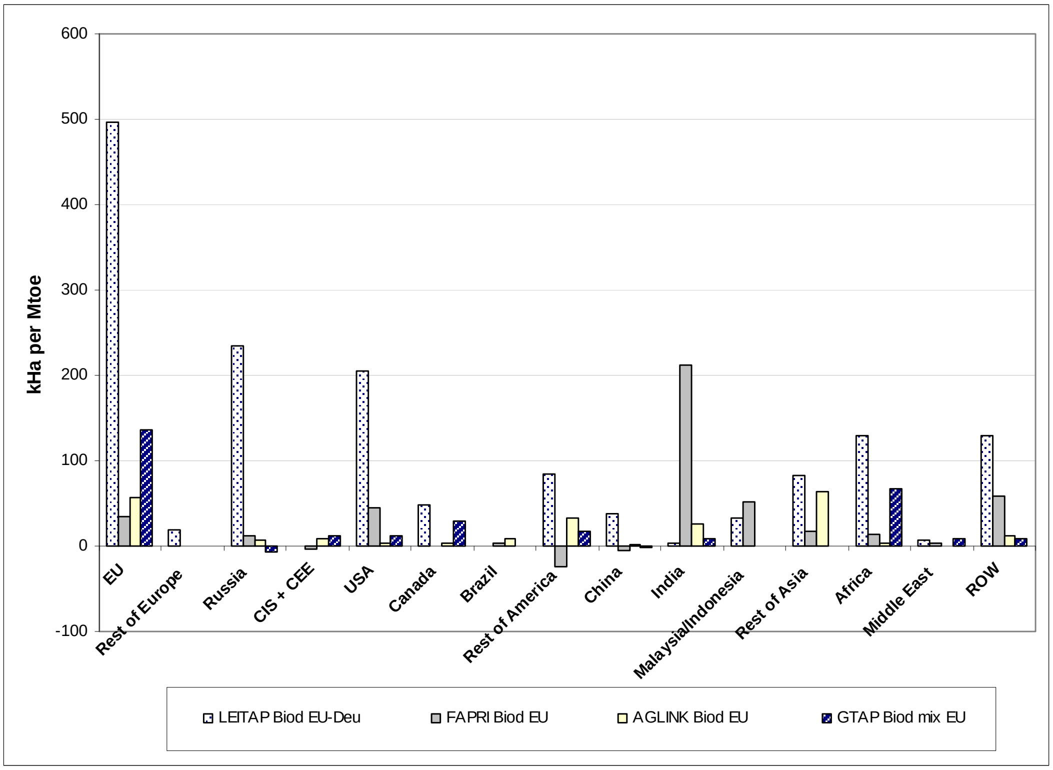
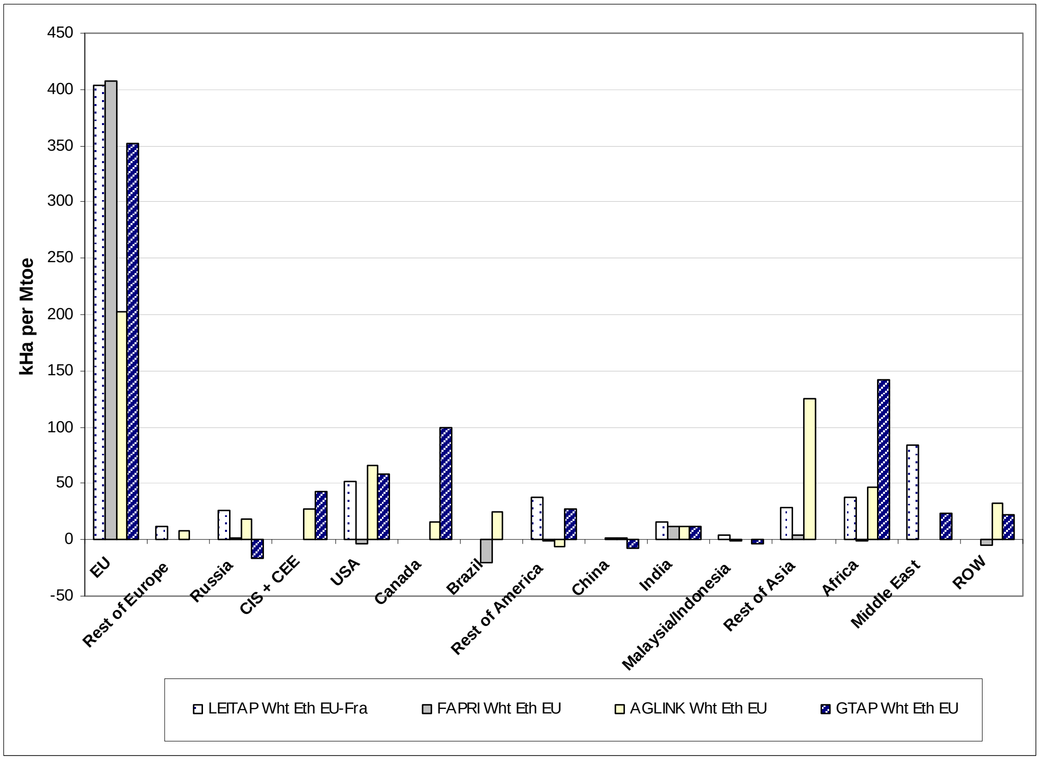


Figure 18 Regional LUC with for EU wheat ethanol scenarios



The FAPRI-CARD results cannot be compared with the others because the scenario froze EU wheat imports to ensure that extra production of ethanol came exclusively from EU wheat (effects outside EU are caused by displacements due to by-products).

Figure 19 Regional LUC for US maize (coarse grain) ethanol scenarios

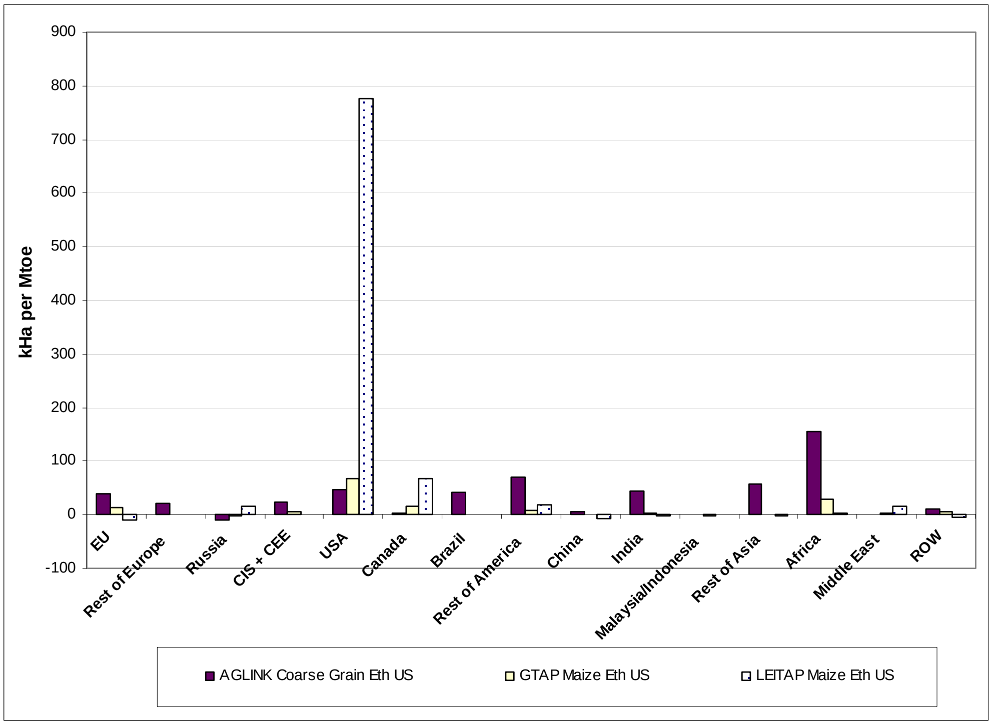


Figure 20 Regional LUC for EU biodiesel demand from Indonesia/Malaysia palm oil scenarios

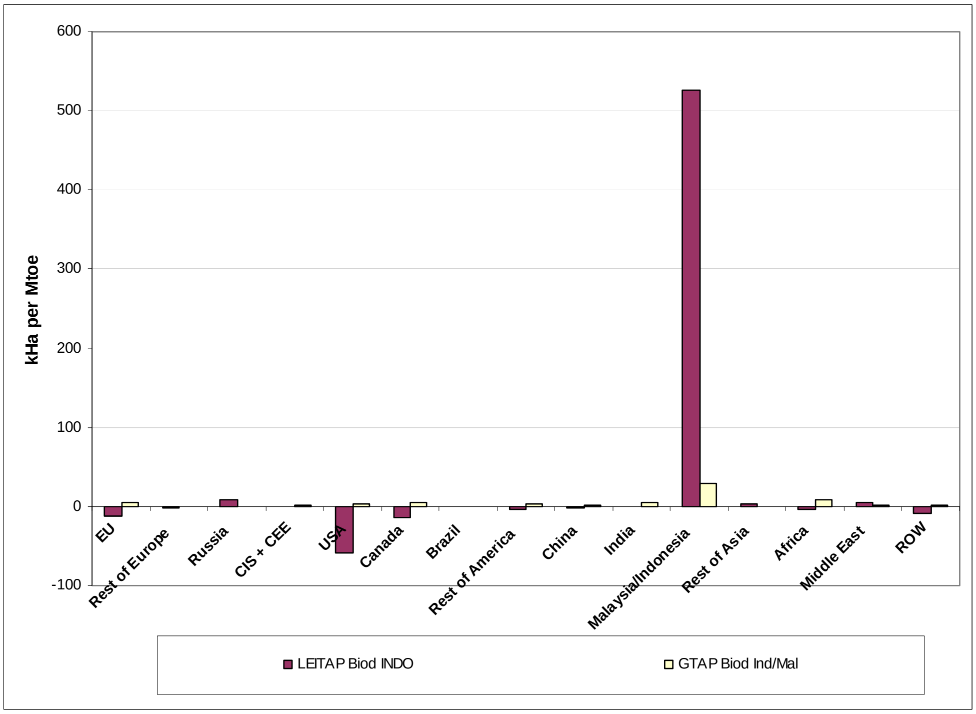


Table 39 shows the parameters which describe the models and the LUC in ha per toe. Section 2.2 of this report describes how to read this table.

Figure 21 also shows the parameters in one chart per parameter for each scenario sorted by feedstock and region.

Table 39 LUC and key model parameters for all models and scenarios

Model and scenario		Feedstock (tonnes)	Feedstock adjustments (%)						Area without yield "savings" (ha)		Area adjustments (ha)					LUC (ha/toe)
				By-products		Food consumption reduction		Average yield				Area "saved" by Yield increase		Area "saved" by crop displacement		
FAPRI-CARD	EU Wheat Ethanol	**5.4**	-	31%	-	34%	÷	3.7	=	**0.66**	-	0.07	-	0.20	=	**0.39**
	EU Rapeseed Biodiesel	**3.0**	-	61%	-	97%	÷	3.7	=	**0.01**	-	0.12	-	-0.51	=	**0.40**
GTAP	EU Wheat Ethanol	**5.2**	-	32%	-	46%	÷	5.5	=	**0.34**	-	0.03	-	-0.48	=	**0.79**
	US Coarse grains Ethanol	**4.6**	-	31%	-	52%	÷	5.5	=	**0.27**	-	0.12	-	-0.01	=	**0.16**
	EU Biodiesel (mix)	**2.4**	-	52%	-	1%	÷	5.5	=	**0.21**	-	0.25	-	-0.42	=	**0.38**
	Malay_Ind Biodiesel	**5.1**	-	22%	-	12%	÷	5.5	=	**0.63**	-	0.23	-	0.32	=	**0.08**
IMPACT	US Maize Ethanol	**4.6**	-	0%	-	36%	÷	5.1	=	**0.58**	-	0.45	-	0.02	=	**0.11**
	US Wheat Ethanol	**4.9**	-	0%	-	47%	÷	5.1	=	**0.51**	-	0.54	-	-0.26	=	**0.22**
	EU Coarse grains Ethanol	**4.8**	-	0%	-	11%	÷	5.1	=	**0.83**	-	0.92	-	-0.21	=	**0.12**
	EU Wheat Ethanol	**4.9**	-	0%	-	47%	÷	5.1	=	**0.51**	-	0.54	-	-0.26	=	**0.22**
LEITAP	Maize Ethanol US	**5.0**	-	7%	-	4%	÷	4.2	=	**1.07**	-	0.02	-	0.18	=	**0.86**
	Wheat Ethanol Fra	**5.5**	-	1%	-	3%	÷	4.2	=	**1.26**	-	0.15	-	0.38	=	**0.73**
	Biodiesel Deu	**3.0**	-	1%	-	9%	÷	4.2	=	**0.64**	-	0.36	-	-1.64	=	**1.93**
	Malay_Ind Biodiesel	**3.0**	-	0%	-	1%	÷	4.2	=	**0.71**	-	0.004	-	0.28	=	**0.43**
Calculations:		Feedstock (tonnes)		fraction of gross feedstock saved by by-products (tonnes)		fraction of net feedstock supplied by reduction in food use (tonnes)		baseline production /baseline area (tonnes/ha)		Would-be extra area without yield changes		baseline area *average of fractional yield increase (per region per crop) weighted by baseline area (ha/toe)		Area saved by total net yield effects - D (ha/toe)		LUC ha/toe

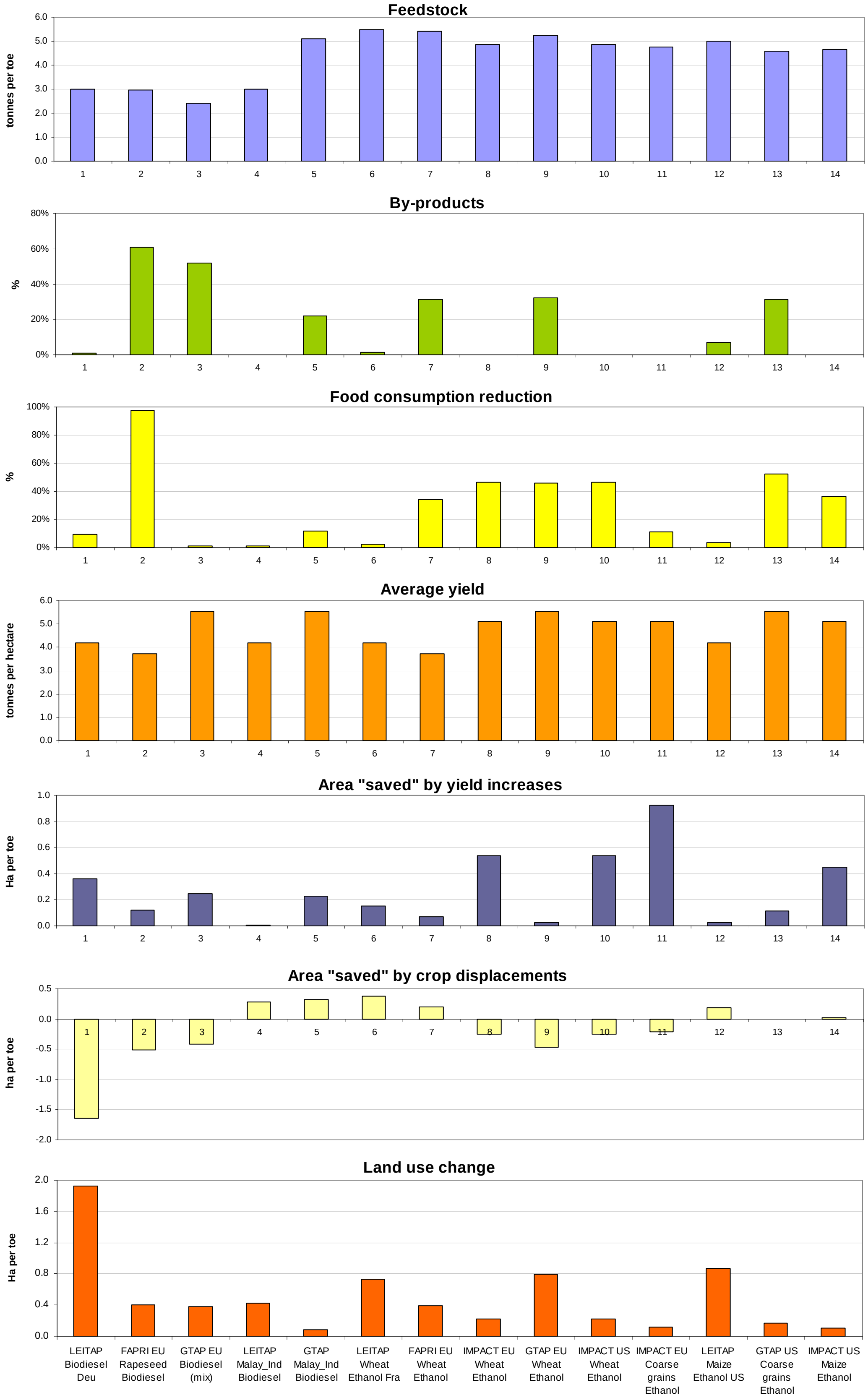


Figure 21 Key model parameters for all models

COMPARISON OF MODEL PARAMETERS

Feedstock per toe biofuel

One should expect the assumed quantity of feedstock required to produce 1 toe of each biofuel to not vary too much from one model to another. The data for IMPACT was inserted by JRC-IE using data from [ENSUS, 2007], which show somewhat lower wheat requirements per toe of ethanol than other data. The figures for oilseeds treat the seeds as the feedstock (rather than vegetable oil). For palm oil that is fresh fruit bunches. The differences are due mostly to different mixes of feedstocks.

A Fraction of extra crops saved by by-products

The modellers could generally only report directly the effect of by-products on the demand of the *principal feedstock*. Those numbers are not comparable with these because they do not include replacement of *other* crops by by-products.

The most striking variations are between models.

LEITAP consistently shows very little impact of by-products. The by-products replace animal feed, including oil-meals and fodder crops. LEITAP calculates replacements in terms of economic value, so we can suppose that they assume a low value for the by-products. Furthermore, LEITAP does not split oilseed production into meal and oil, so the cost of oilseed meal is inflated by the high cost of vegetable oil, reducing the tonnes of crops replaced. However, this effect alone cannot account for the large differences with other models in this parameter. Another effect can be the replacement of fodder-crops like hay, which are not part of the crop area. Although GTAP also uses economic substitution in principle, Purdue have split ‘vegoil’ and oilseed meal production, and introduced some ad-hoc empirical corrections to get realistic figures.

IMPACT does not attempt to include by-products.

For the other models the impact of by-products in terms of tonnes is close to what one could expect from the physical proportion of by-products, which is higher for rapeseed and soybean biodiesel than for bioethanol.

The by-products must have an impact on the yield effects reported below, especially on the effects caused by crop displacements/crop mix changes. However, these cannot be separated out from those of the main feedstock. Experiments conducted by Perdue using GTAP with by-products turned off indicated a reduction in LUC area which is very similar to the reduction in tonnes we estimated. Those figures may however be an underestimate because side-effects in CGE models tend to compensate the effects of switching off the by-products. In general we can expect that the effect of DDGS in area terms would be somewhat higher than their effect in mass terms, because it replaces partly oilseeds which tend to have lower yields than cereals.

B Fraction of extra crops (after correction for by-products) saved by reduced food consumption.

Here food consumption includes crops fed to animal for meat/dairy production. The figures are again for ALL CROPS, not just the principal feedstock. As explained in the methodology, this is calculated by mass balance, and refers to mass of total crops. The main effects are seen in the animal feed sector, rather than in human consumption.

The fraction of tonnes of feedstock coming from reduced consumption of crops for food is low in LEITAP for all their scenarios, and the reason for this is not clear.

Most of the EU biodiesel scenarios show rather small effects on tonnes of food consumption, with the notable exception of FAPRI. However, the anomaly is not actually as large as it appears, because the reduction is expressed as a percentage of the net extra production *after accounting for by-products.* Since by-products already reduced the net feedstock requirements by more than 61% in this scenario, reduction in world food and feed use is only 38% of the *total* feedstock requirement.

This reduction is not mostly from people eating less: it is a shift of meat production from livestock fed on crops (mostly in the EU) to livestock raised on ranches in more extensive countries.

The effects of reduced food/feed consumption are quite consistent for all the wheat scenarios (except LEITAP). And the effects are also not dissimilar for US maize or coarse grains (except LEITAP, as usual). IFPRI-IMPACT shows lower food/feed effects from *EU* coarse grains. This cannot be due to the geographical location of the demand shock, because IFPRI-IMPACT assumes an integrated world market. It must be due to the difference in the type of coarse grain: barley, oats, rye etc in the EU instead of maize in US. The market in these grains is smaller than in maize, reducing the tonnes of crop saved by a given fractional reduction in food demand. Furthermore, many "other coarse grains" are grown for local consumption and not traded, so the market is less liquid.

C Average Crop Yield

This is only in the table for comparison. It depends on the dataset used for yields, the year which is modelled and which crops which are included in the models. For all the scenarios the average yields were calculated form the output data after correcting the sugar-crop yields to sugar equivalents (otherwise their high water content skews the results).

D *Area saved by 'real' yield increase*

This is the increase in average yield for all the crops in all regions, weighted by the baseline area-distribution of the crops. It incorporates the effects of price increases compared to baseline, as well as the small adjustments to average yield made by some models as a function of the change in area of a crop. For GTAP it also incorporates the effect on the world-average yield of the lower yields assumed for crops at the margin of cultivation[27].

It does not include 'virtual' changes in average world crop yield caused by changes in crop mix and regional distribution of crops compared to the baseline (which would occur even if the yield of each individual crop in each region was unchanged).

The averaged real yield increases in all scenarios, saving ILUC area.

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[27] Not immediately obvious; but think about it...the reduced yield on the new land reduces the average yield for the crops expanding in that region. For marginal changes, the effect of area expansion on the area weighting in the "real" yield calculation is negligible.

IFPRI-IMPACT model has consistently the highest area saved by ‘real’ yield increases, indicating the highest ratio of yield elasticity / supply elasticity. In the case of their EU coarse-grains scenario it accounts for about 90% of the production increase.

GTAP has lower ‘real’ yield changes than IFPRI-IMPACT, but we should bear in mind the effect of the 0.66 factor they apply to the yield of crops on new land. If this was not present, the ‘real’ yield increase would be greater. It is unexpected that the contribution of yield increase compared to area in the Malaysia/Indonesia biodiesel scenario is higher than in other GTAP scenarios, because historically palm oil production has increased very largely by increase in area rather than yield; and this is not true for most crops in developed countries.

FAPRI-CARD has moderate yield increases, which reduce ILUC by 16-24%.

E Area saved by crop displacements

If there was only one crop in the world, one could estimate the average yield on new land from the output data of models. But when there is a mix of crops, that mix can change even on the existing land (as for example, oilseeds displace cereals in a biodiesel scenario). This gives a change in overall yield which interferes with the determination of the yield on the extra land. There is another effect too: area of a particular crop may diminish in one country and rise in another one which has a different yield, also affecting the average yield. These are the ‘virtual’ yield changes due to crop displacements which we calculate here as a percentage of the baseline yield, and convert to area terms by multiplying by baseline area.

Looking at the results we see that the area ‘saved’ by virtual yield changes can be positive or negative. They are generally positive when the feedstock has a higher yield than the crops it displaces, and negative when the feedstock has a lower yield.

Thus all EU biodiesel scenarios show that LUC increases because of crop displacements, (there is a negative “saving”), whilst for biodiesel scenarios based on palm-oil LUC decreases because palm fruit yield is higher than most other tropical crops in the region.

On this basis one expects a LUC saving also for wheat and maize as feedstock crops, and indeed this is seen in LEITAP and FAPRI-CARD. But there is also the other displacement effect to think about: in some models there is a lot of cereals area expansion in countries with relatively low yields (India, Canada etc.). This causes a decrease in average yield and an increase in LUC; a negative “saving” of area. This is a stronger effect in GTAP and IFPRI-IMPACT, which is easy to understand in the second case because it assumes an integrated world market where production spreads across borders more easily than in the other models.

6. INDICATIVE CO_2 EMISSIONS FROM LUC

Many readers may be unfamiliar with the order of magnitude of ILUC effects in terms of land, but want to know what the effects are on the emissions from biofuels. Although it is not the main objective of this study, considering the policy context, it is very important to give indications about the CO_2 implications of ILUC resulting from this modelling exercise. However, only one model (FAPRI-CARD) provided a detailed calculation of marginal emissions, and another one (GTAP) reported only emission factors for regional land use changes.

Being aware that a simple estimation using a fixed emission factor would not account for the large variations of soil properties and climate around the world, for the purpose of this study JRC-IE applied in any case this simplified approach to provide a very rough estimation of the emissions resulting from the area increase calculated by all of the models. A detailed methodology to assess GHG emissions (soil C and N_2O) from ILUC has been developed by the JRC and is reported in a separate JRC report.[28]

An average value of 40 tC/ha for soil C emissions was used (IPCC default values report 38 to 95 tC/ha following land cover conversion for EU and agricultural areas in North America). Results of this rough estimate are shown in Fig 22. The error bars represent the maximum range using 95 tC/ha (value also used in Searchinger et al, 2008), and the minimum derived from an emission factor of 10 tC/ha (used in FAPRI-CARD calculations with GREEN-AGSIM reported to the JRC).

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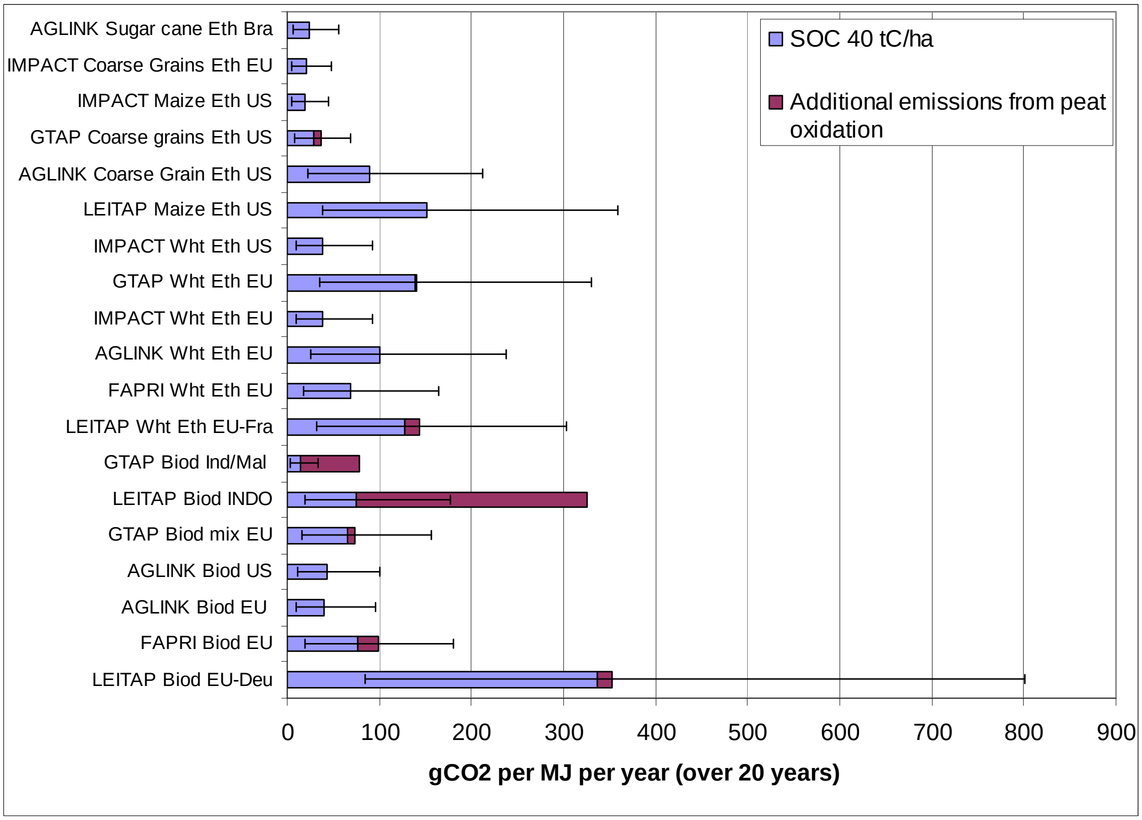
[28] "Biofuels: a New Methodology to Estimate GHG Emissions Due to Global Land Use Change. A methodology involving spatial allocation of agricultural land demand, calculation of carbon stocks and estimation of N_2O emissions". R. Hiederer, F. Ramos, C. Capitani, , R. Koeble, V. Blujdea, O. Gomez, D. Mulligan and L. Marelli. EU Report 24483, 2010, available on line at http://re.jrc.ec.europa.eu/bf-tp/

Fig 22: **Rough indication of emissions <u>assuming</u> 40 tonne of C per hectare over 20 years**



Where the models reported palm oil area expansion (mainly in Malaysia and Indonesia) JRC-IE estimated additional CO_2 emissions from peat oxidation using an average value for palm oil of 19 tCO_2 per ha per year (See Table 40). This emission factor is based on 33% oil palm expansion taking place onto peatland, and peat oxidation emissions conservatively estimated to be 57 tonnes of CO_2 per ha per year (which does not include changes in carbon sequestrated in living biomass, or emissions from peat fires), as explained in details in Appendix III.

Emissions from this source are significant for all biofuel pathways. In the EU biodiesel scenarios the peat oxidation emissions range from 7 to 23 tCO_2 per ha per year. In contrast, the peat oxidation emissions from the Malaysia/Indonesia scenarios range from 64 to 252 g CO_2/MJ biodiesel. Emissions from peat oxidation in the ethanol scenarios range from 1 to 15 g CO_2/MJ.

Extracting the data on palm oil production for AGLINK-COSIMO model is a subject of further work.

Table 40: JRC-IE estimate of CO_2 emissions (tonne per ha) from peat oxidation only, at 19 tCO_2/ha/y average for palm oil. These emissions are in addition to the land use change emissions shown in Figure 20.

Oil palm area change	kHa per Mtoe	t CO_2/toe	g CO_2/MJ
Biodiesel scenarios			
LEITAP Biod EU-Deu	33	1	15
FAPRI Biod EU	51	1	23
GTAP Biod mix EU	16	0	7
LEITAP Biod INDO	561	11	252
GTAP Biod Ind/Mal	143	3	64
Ethanol scenarios			
LEITAP Wht Eth EU-Fra	1.7	1	15
GTAP Wht Eth EU	0.1	0.1	1
GTAP Maize Eth US	0.9	0.3	8

6.1 CO_2 emissions from FAPRI-CARD model

In the present study, only one model (FAPRI-CARD) could report to JRC-IE calculations of CO_2 emissions from the two scenarios simulated. The Greenhouse Gases from the Agricultural Simulation Model (GreenAgSiM) model developed within FAPRI-CARD (Dumortier et al, 2009) was used for this purpose.

The calculation of land-use change related emissions is done in two steps. First, the land-use dynamics need to be calculated based on output from the CARD Model. In a second step, carbon emissions based on land-dynamics and bio-physical conditions are computed. The two sources/sinks of carbon in GreenAgSiM are biomass and soil. A default factor of 0.47 tonnes of carbon per tonne of dry matter is used to calculate the biomass in CO_2-equivalent. The change in the amount of soil organic carbon (SOC) depends on factors such as climate region, native soil type, management system after conversion, and input use. The FAO Soil Map was used (which subdivides soil into three large categories with emission factors of 20 t/ha, 40 t/ha, and 80 t/ha), considering medium input, full tillage and the top 30 cm of soil carbon. The conversion is assumed to be from forest, shrub-land, grassland, and set-aside to agricultural land i.e. cropland and pasture.

Results from GreenAgSiM model calculations are reported in Table 41.

Table 41: CO_2 marginal emissions calculated from FAPRI-CARD LUC results

	EU Wheat Ethanol	**EU Rapeseed Biodiesel**
Ethanol/biodiesel increase in million liters	254	288
Ethanol/biodiesel increase in Mtoe	0.130	0.230
Difference in Area Harvested (ha)	44191	83966
Difference in Emissions (in million tons of CO2 -equivalents)	1.67	41.70
CO_2 tonnes per ha	38	497
tC/ha	10	135
CO_2 produced per liter of ethanol (in kg)	6.6	145.0
Energy Content (MJ/liter)	21.2	32.7
Emissions in grams of CO_2 per MJ	310.6	4432.7
Emissions in grams of CO_2 per MJ (over 30 years)	10.4	147.8
Emissions in grams of CO_2 per MJ (over 20 years)	**15.5**	**221.6**

In calculating the emissions, the different assumptions of the models play a crucial role. For this specific exercise, FAPRI-CARD assumed (as explained in section 4.2) that all the increase in ethanol consumption comes from wheat *grown* in the EU (rather than just bought there). The model decides that (after allowing for the use of DDGS in animal feed) most of this wheat is diverted from animal feed, partly because it is replaced by DDGS by-product and partly by imported meat, compensating a decline in meat production in the EU. Those meat imports come principally from extensive meat producing regions which do not use much crops to feed the livestock, which lives on ranch land. There is probably an extension of pasture onto nature land as a result, but this does not consider this in the results for cropland.

Accordingly FAPRI-CARD tells GreenAgSiM that all the land use change for EU wheat-ethanol occurs inside the EU. That is 0.39 hectares extra cropland in the EU per toe bioethanol. However, the marginal shock in FAPRI was only about 1/10 Mtoe, so the GreenAgSiM only had to allocate about 40 kha, calculated on the basis of the average EU wheat yield with a small correction (~3%) for the difference in yield between average EU wheat and the yield on the extra cropland area.

FAPRI-CARD preferentially assigns increasing crop area in the extra-biofuel scenario to idle cropland. In GreenAgSiM, idle cropland is any cropland abandoned since 1990. The abandoned land persisted into the baseline FAPRI-CARD projection, and so the 40 kha was accommodated on that land.

It is quite logical to think that land which is temporarily abandoned because the market economy makes it not quite profitable to farm ("buffer land") would be the first land brought back into production if prices increase. But this assumption is questionable *for assigning small but sustained increases in crop area*: the argument goes that there will always be a limited area buffer of land coming in and out of production in response to market fluctuations, and this should not be assigned meeting to a sustained change in demand. In that case the next time crop prices fluctuate upwards, more land will be converted to cropland to form a new buffer.

But since 1990 most cropland abandoned in EU27 was because of the withdrawal of state subsidies and break-up of state farms to smallholdings in new member states. This is not buffer land; it was not abandoned because of marginal changes in crop price: it was abandoned for structural reasons which are hardly reversible. So not much of this land will come back into cultivation because of a marginal increase in crop price. In as much as it does, it will have a much lower yield than the EU average (see section 7).

In GreenAgSiM idle land is assumed to sequester carbon at an annual rate which is equal to the (soil stock as idle cropland - soil stock under cropland)/20, using the IPCC carbon stock values of idle and productive cropland, until it reaches the maximum. When the abandoned land in the baseline is converted to cropland in the scenario, this carbon sequestration is lost and becomes an annual source of CO_2.

The IPCC default value for the carbon stock of idle land is for land that has become re-vegetated only with perennial grasses. This represents *the lowest possible sequestration of carbon*, because it assumes that none of the land becomes invaded or planted with forest and that even after 30 years the natural succession to shrub-land remains suppressed. In fact LULUCF declarations in EU27 (EEA, 2010) indicate that about 20% of the abandoned cropland from 1997-2007 went straight to reforestation, the rest initially to pasture. In addition, some of the cropland which initially became pasture may have subsequently become scrub or forest, but that does not show up in the statistics on the conversion of cropland. Forest and scrub show higher total carbon stock gains than pasture, so the actual foregone carbon sequestration is higher than estimated by GreenAgSiM for the EU-wheat scenario.

For the rapeseed-Biodiesel scenario the FAPRI-CARD results tell GreenAgSiM that the majority of cropland increase occurs outside the EU, mostly in India and the “Rest of the World”. This happens on land with lower yields, and GreenAgSiM places that extra cropland on a mixture of forest and pasture. This explains the much higher emissions in this scenario compared to the EU-wheat ethanol scenario.

6.2 CO_2 emissions calculated from GTAP emissions factors

In responding to the JRC-IE request of “reporting the assumptions on carbon release or foregone carbon sequestration made in deducing LUC emissions from conversion of different land use types”, GTAP modellers included a table (from Hertel et al., 2009) with emission factors (EF) used to calculate LUC emissions over 30 years (see Table 42).

Table 42: GTAP Emission Factors (in Tons CO_2 / Ha)

Region	Forest to Crop	Pasture to Forest	Aboveground Biomass	Pasture to crop
1 USA	760	219	18	106
2 EU27	297	362	18	156
3 BRAZIL	388	164	18	72
4 CAN	705	434	18	196
5 JAPAN	574	223	18	85
6 CHIHKG	574	223	18	196
7 INDIA	574	223	18	196
8 C_C_Amer	388	164	18	72
9 S_o_Amer	388	164	18	72
10 E_Asia 5	574	223	18	85
11 Mala_Indo	937	337	18	85
12 R_SE_Asia	937	337	18	85
13 R_S_Asia	937	337	18	85
14 Russia	311	392	18	156
15 Oth_CEE_CIS 2	297	362	18	156
16 Oth_Europe	297	362	18	156
17 MEAS_NAfr	152	59	18	82
18 S_S_AFR	305	129	18	43
19 Oceania	388	198	18	98

Region specific EFs (where data are available) are developed for each type of land conversion:
1) Forests to crops
2) Pasture to crops
3) Pasture to forests

The small amount of aboveground biomass in annual crops that results in carbon sequestration is also taken into account (third column of the table)

JRC-IE calculated the corresponding marginal CO_2 emissions per year for the four GTAP scenarios multiplying the regionally disaggregated LUC data (in ha/Mtoe) by the emission factors in the above table. Carbon release and foregone carbon sequestration were calculated (using table 42) and considering:

1. Emissions from forest loss (from column 1)
2. Sequestration from forest gain (from column 2)
3. Sequestration from gain in crop area (from column 3)
4. Emissions from loss of Pasture area (from column 4)

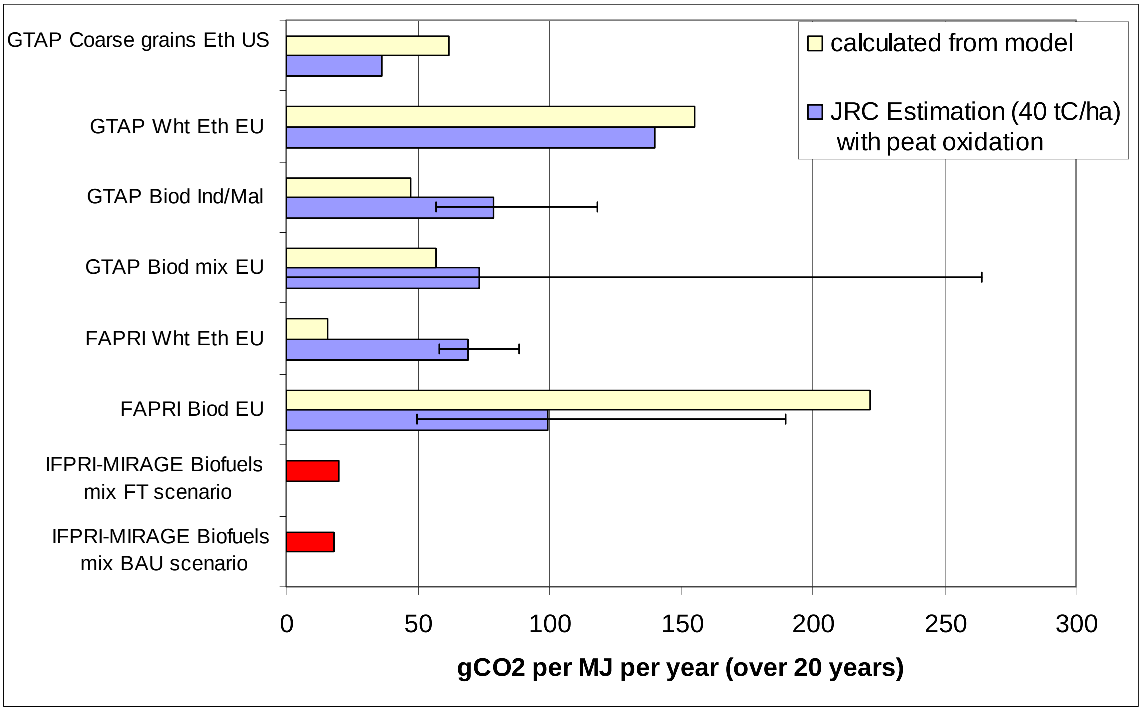
Total CO_2 emissions calculated by JRC-IE for the four scenarios are reported in Table 43. Detailed tables with results of JRC-IE calculations are reported in Appendix II.

Table 43: CO_2 marginal emissions calculated by the JRC-IE from GTAP LUC data and emission factors

	EU Wheat ethanol	US Coarse Grain Ethanol	EU Biodiesel (mix)	Mala-Indo Biodiesel
Total g CO2/MJ	3092	1245	1134	931
g CO2 / MJ per year (over 20 years)	**155**	**62**	**57**	**47**

A comparison with the values estimated by JRC-IE as explained above is shown in Figure 23.

Figure 23: Comparison between JRC-IE indicative estimates of CO_2 emissions (including additional estimation for peat oxidation) and precise values calculated from FAPRI-CARD and GTAP data



The CO_2 emissions calculated using the EFs reported by GTAP for the US-coarse grains scenario fall within the upper range estimated by JRC-IE. In fact, most of the land use change for this scenario occurs within the US, where, according to IPCC indications, EF is closer to the higher limit considered by JRC-IE (> 40 tC/ha).

The same consideration is valid for GTAP-EU wheat (and biodiesel mix) scenario: the largest increase in cropland area occurs within the EU, for which the average EF used for JRC-IE estimation is realistic. Thus, CO_2 emissions estimated by the JRC-IE are close to the values calculated from GTAP data.

Emissions calculated with GTAP EFs for Biodiesel-Mala-Indo scenario do not account for additional emissions due to peat oxidation, and in fact this value falls below the minimum range estimated by JRC-IE.

As reported in Table 42 above, the emission factor used in GreenAgSIM to estimate CO_2 emissions for EU-Wheat-Ethanol scenario is approximately 10 tC/ha, which in fact corresponds to the lowest JRC-IE estimation, but as indicated in section 6.1, the assumptions made in GreenAgSIM mean that it is estimating the lower limit of the actual emissions in this case. In contrast to this low EF value, GreenAgSIM used an emission factor of 135 tC/ha for the EU Biodiesel scenario, well above the JRC-IE maximum value.

For comparison, Figure 23 also includes the marginal CO_2 emissions amortized over 20 years calculated in the IFPRI-MIRAGE study previously mentioned (in section 5.1) for the two scenarios, BAU (Business as Usual) and FT (Full Trade).

7. DISCUSSION

Some of the most relevant issues discussed during the workshop on "*The Effects of increased demand for Biofuels feedstocks on the world agricultural markets and areas*" organised in Ispra[1] between the experts involved in this comparison exercise need also to be mentioned in this section.

7.1. How different models calculate area change per crop

The economic models project the average yield and the change in crop production, both for each region and crop. How do they work out the crop area change per region?

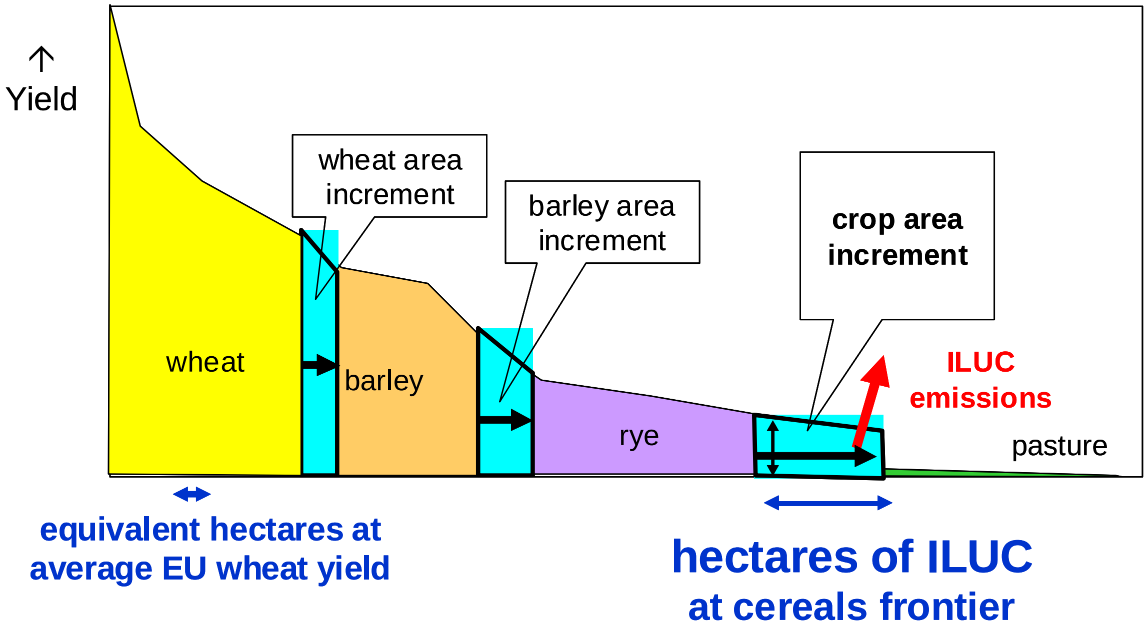
All the models except GTAP take the extra tonnes of each crop and divide by the yield *of the same crop*. Then they sum the area changes for each crop. The result of this 'per-crop' approach is that the area of crop expansion depends strongly on the crop chosen as the feedstock: for example, ethanol from EU rye (average yield ~3.4 tonnes/ha) would show much more land use change than ethanol from EU-wheat (average yield ~5.7 tonnes/ha). By contrast, GTAP (see below) would show almost the same LUC for both.

FAPRI-CARD, AGLINK-COSIMO and LEITAP adjust the average yield according to the price and the extension onto other crops. For example, in FAPRI-CARD, the EU wheat yield increases by 0.52% for each 1% increase in (revenue-costs), and decreases by 0.0256% for every 1% increase in wheat area. That correction is made on the basis of statistics which reflect the fact that wheat usually expands onto poorer land. It corresponds to assuming the yield at the margin of cultivation is 97.4 % of the average yield. Conversely, crops like soybeans which can compete for land with higher-yielding crops like maize may show a slight increase in average yield with increasing area.

GTAP takes into account an additional consideration when estimating the overall extension of cropland in ILUC. As well as adjusting the average yield per crop for price and area changes, it includes a factor which estimates the yield at the frontier of crop production, where the marginal increase in area is actually occurring.

Figure 24 shows an example where wheat production increases, *but production of other cereals remains fixed* for the sake of argument, yield increases caused by crop price are ignored in this diagram.

Figure 24: EU cereals displacement due to increased demand



The yield of different cereal fields is ranked by suitability as a function of cumulative area. The areas under the graph represent tonnes of cereals production. Wheat supply must increase by “W” tonnes, represented by the green trapezoid at the right of the wheat area. As wheat and barley have about the same price and take similar inputs per tonne at the wheat/barley frontier, the yield of wheat is similar to that of barley at that point. So about “W” tonnes of barley production is displaced, but at lower yield. That barley production is recovered from rye production at an even lower yield. If rye is the frontier crop bordering pasture-land, the increment in crop area depends on the rye yield. It does not matter if it is “W” tonnes of wheat, “W” tonnes of barley or “W” tonnes of rye which is required, as it is always the yield at the frontier of cropland which matters.

Therefore, GTAP calculates incremental area for all crops on the basis of an estimated marginal yield for a region, found from the average yield of all crops in that region and a factor assumed for the marginal/average yield ratio. In the version of GTAP used in this comparison, this ratio is set at 0.66 for all GTAP regions. Thus the crop area change for a tonne of extra EU wheat in GTAP is 1/(0.66*average EU cereals yield), whereas in the other models it is close to 1/(average EU wheat yield). Using EUROSTAT data from 2008, 1 tonne of wheat on new crop area in EU would require 0.29 ha according to the GTAP method, but only about 0.18 ha according to the other models.

JRC-IE made an estimate for the ratio of marginal/average cereals yield in EU from EUROSTAT statistics. We can calculate the average of national-average cereals yield weighted by the actual magnitude changes in national arable area which occurred between 1997 and 2007. The result is 0.65 times the average EU cereals yield (based on average yields over the same period). That value agrees fortuitously well with that assumed in GTAP. But it does not yet take into account the yield variations within each country or on a particular farm. The farms which are least profitable are unlikely to be able to grow wheat: more likely the marginal crop is a hardier cereal like rye. The average national rye yield weighted by arable-area-change is on those countries is 0.41 times the average EU cereals yield in the same time period, and the worst-performing farms would presumably have even lower yields than that.

And the least-profitable fields on a single farm are also likely to have lower yield than the average yield on that farm. DEFRA (1998)[29], showed statistically that in the early 1990s, when the imposed CAP set-aside percentage went up and down unpredictably from year to year (making it difficult for farmers to plan incorporation of set-aside into crop/fallow rotations), 14% of set-aside would generate 10% loss of production. That implies the yield of the set-aside fields was roughly 0.71 times the average yield on a particular farm. A similar study of US farm programs (Love and Foster, 1990) indicates an even lower ratio, ascribed principally to differences in yield on set-aside fields.

So our rough estimate shows that the marginal yield of cereals in EU is <0.41*0.7= 0.29 of the average cereals yield. The conclusion is that in the case of EU cereals, GTAP still significantly overestimates the marginal yield with its factor of 0.66 of the *average yield*, whilst all the other models overestimate it even more, especially when the main crop expanding is EU wheat.

The value of the marginal/average yield depends on the size of the region. The larger and more diverse the region, the larger the likely difference in yields. Recently, (Tyner et al,) attempted to estimate the ratio more accurately for almost 200 different regions comprising the intersections of the GTAP regions and different Agro-environmetal zones. As the regions are smaller and less diverse than the original GTAP regions, it is not surprising that most of the marginal/average yield ratios were found to be smaller. But they need to be applied to average yields *per region and AEZ*, which would be more diverse than average yields per existing GTAP region.

The methodology of (Tyner, 2010) is based on a theoretical estimate yields based on a crop growth model with localized input data. Average yields for C4 cereals crops were calculated for 0.5 degree (~2500 km^2) grid-squares, and the distribution of new land between these grid-squares was considered. No account could be taken of yield variations within a grid square.

7.2 Yield responses

7.2.1 Defining what we are talking about

Year-on year yield increases applied to both extra-biofuels and baseline scenarios have little effect on marginal LUC results. What matters in the context of Indirect Land Use Change is if the aggregate yield of all crops changes between the scenarios. That does not depend only on the crop which is being used to make the biofuel. Average yields can change in the biofuels scenarios (compared to baseline) due to:-

- change in the mix of crops (e.g. cereals vs. oilseeds)
- change in the geographical distribution of crops (e.g. coarse grains in US and Argentina).
- change in the crop area of particular crops, as described above.
- changes in crop price

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[29] [DEFRA 1998],, http://www.defra.gov.uk/evidence/economics/foodfarm/evaluation/setaside/FullRep.pdf

The aggregate effect of these changes can be an increase or decrease in overall yield.

The effect of crop price was discussed at length at the model comparison workshop organized by JRC-IE. Two different yield-on-price effects need to be distinguished:

(A) Reversible yield increases due to crop price increase.

(B) Increase in the rate of year-on-year yield improvement, due to increased rate of technology development.

These may have different emissions consequences, and need to be discussed separately.

7.2.2. Reversible yield increases due to crop price increase

If the crop price goes up, simple economics means that the economically-optimum level of inputs per tonne of crop also increases, and this increases yield on a given patch of land, starting already at the following harvest. This is a reversible effect, but of course if the higher price is sustained, the higher yield is sustained. All of the models in the JRC-IE model comparison exercise took into account this effect in some way.

It is the ratio of yield to area elasticity which is important in ILUC modelling

The elasticity of yield on price has been extensively investigated by economists, but generally for a rather limited range of crops and countries (due to lack of data elsewhere). (Keeney and Hertel, 2008) provide an excellent review. Thus values for a few US crops tend to be applied to the whole world. In fact, one can expect that yields respond to prices more in developing countries where yields are further from the technological limits (and there are good returns for applying more fertilizer, for example). However, it is exactly these countries which tend also to have the cheapest resources of unused fertile land. So they also have the highest crop-area-response to price increases. What is critical to ILUC estimates is the *ratio* of yield and area elasticity on price: this determines which proportion of increased production comes from increased crop area.

Figure 25: Rate of increase of yield vs. area for EU cereals (from ENSUS)

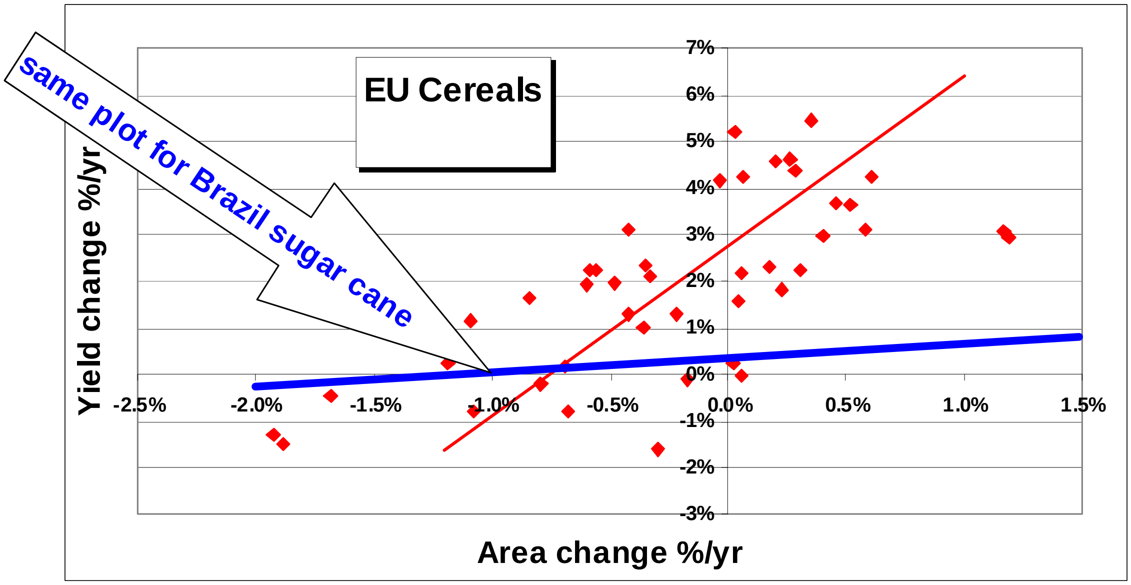

Figure 25 above shows a plot made by ENSUS of the rate of increase of area and yield (averaged over 4years) for EU cereals[30]., plotted one against the other. It shows that for cereals in the EU, most production increase came from increased yields whereas for Brazilian sugar cane most came from increased area. The same trend applies to other crops from developed vs. developing countries: for example, historically, almost all the increase in palm oil production has come from increased area. By contrast, area change of cereals in the EU is constrained by the Common Agricultural Policy, particularly by the area payment scheme, which restricts subsidies to keep only production on the existing cereals area profitable. So the relatively small ratio of area/yield elasticity in EU and other developed regions indicates *lower area elasticity*, rather than higher yield elasticity, compared to developing countries.

Emissions from yield increases

GHG emissions from farm inputs are dominated by emissions for the production of nitrogen fertilizer and the emissions of N_2O from the soil provoked by the use of nitrogen fertilizer. Traditionally, agricultural economists have focused on extra nitrogen fertilizer applications as the main way farmers to increase yields: one can find many statements to the effect that "the main way farmers can increase yields in the short term is to increase fertilizer use". If price-induced yield increases would be made *entirely* through increases in fertilizer spending, then the marginal emissions per tonne of extra production through yield increase are much greater than the average emissions per tonne of wheat. It is instructive to look at *how much* greater:

When crop prices go up, the economically optimum spending on farm inputs increases, and this (other factors being equal) leads to higher yields. There is a limit to the extra spending on inputs, because as the extra spending increases, the returns in terms of extra yield per euro decreases. The economic optimum is reached when the value of the marginal extra crop comes to equal the value of the marginal extra spending on inputs.

Figure 26: Rate of yield increase vs. amount of N application

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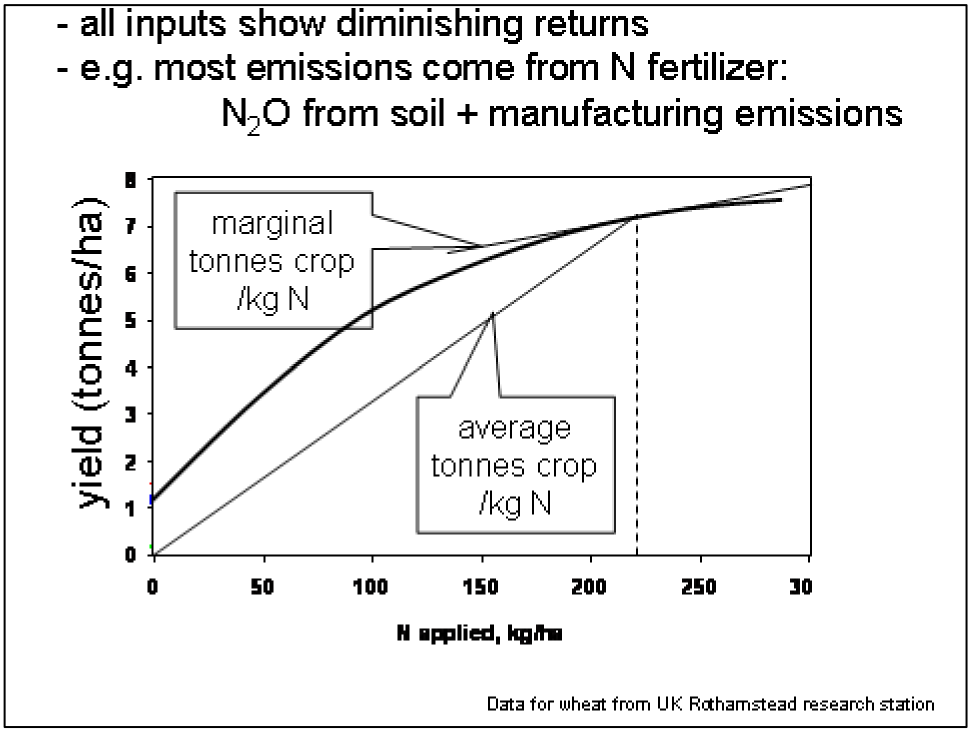
[30] Unlike some other correlations from this source, this plot does not ignore other explanatory variables: production change must come from either yield change or area change.



- all inputs show diminishing returns
- e.g. most emissions come from N fertilizer: N_2O from soil + manufacturing emissions

Data for wheat from UK Rothamstead research station

So at the economic optimum, the marginal tonnes of wheat per marginal tonne of N fertilizer are given approximately by the price ratio of nitrogen fertilizer to wheat. In the UK, Sept 2009, wheat price was about 100 UKP/tonne and ammonium nitrate cost 522 UKP/tonne N. So the marginal use of N per tonne wheat was roughly 0.2 tonnes N per tonne of wheat, compared to an average figure of about 0.024 tonnes N/tonne wheat; about a factor of 12 higher.

Putting in the values for maize and nitrogen prices in Iowa produces a factor of 8. This agrees with the results of field trials where the rate of fertilizer was varied around the average value. Putting in historical data on farm-gate fertilizer prices and producer crop prices for different counties, crops and times (from FAO database of fertilizer prices) shows this factor is consistently higher than 5, even allowing for a risk-premium on investing in fertilizer in unstable regions.

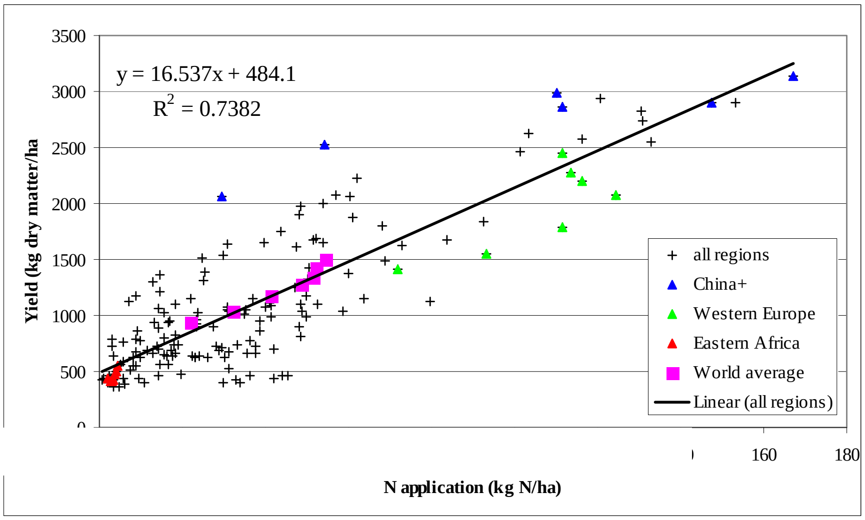
Not all extra yield will come from extra nitrogen fertilizer: there will be additional extra yield from other marginal spending (pesticides, herbicides, more expensive seed, other fertilizers, diesel for more tractor-passes, new machinery, labour etc.), which will not have such high emissions (per Euro spent) as N fertilizer. However, the factor 5 to 12 means that *even if the other inputs had zero emissions* associated with them, the marginal emissions per tonne of crop would be higher than average ones for any scenario where more than 8-20% of the marginal spending is on nitrogen fertilizer.

However, some of the alternative inputs (diesel, other fertilizers etc.) have significant emissions themselves, and farmers will always need more of them per marginal tonne of wheat than per average tonne. So in practice the marginal spending on fertilizer would have to be near zero if the marginal farming emissions per tonne of production due to price-induced yield increase are to be less than the average emissions.

At the JRC-IE model comparison workshop, Elke Stehfest (PBL, Planbureau voor de Leefomgeving) showed a correlation of 5-year averaged yields against nitrogen fertilizer use in different regions and time (1970-2000) (Figure 27). The slope gives a very low apparent ratio of marginal nitrogen use to extra tonne of production. But (as she pointed out) other explanatory variables are not considered in this plot: as N application increases with water availability per region, state of agricultural development and time. The yield increases due to these three powerful factors are all ascribed to N fertilizer increase in this plot, so that an exaggerated number of extra tonnes are ascribed to a certain increase in nitrogen fertilizer and nitrogen use per tonne is very much underestimated. Similar misleading conclusions are drawn from other analyses which make regressions or correlations which miss other explanatory variables of yield.

The main problem is the confusing influence of time. Until the 1990s fertilizer use per tonne of crop was increasing everywhere in the world, but since then it has stopped increasing and even declined in developing countries (due to environmental legislation and increases in fertilizer price). That says nothing directly about what happens to fertilizer as a result of crop-price increase, because in that period the price of crops was generally falling.

Figure 27: Average agricultural production [t/ha] vs. average N fertiliser input [kg/ha] in 5 year time steps between 1970 and 2000 (PBL).



Average agricultural production [t/ha] versus average N fertiliser input [kg/ha], in 5 year time steps between 1970 and 2000.

Professional agricultural economists have devoted a large amount of work to estimating the response of yield to crop price. One of the more recent studies is (Keeney and Hertel, 2008). This study reviews previous work, and then goes on to develop new estimates for yield elasticities on price which are used in a database for GTAP economic model. There are various statistical approaches, but they generally start off with correlating statistical data on yields against several explanatory variables, including fertilizer (or its proxy, the ratio of crop price to fertilizer price), and other inputs.

The economists who made these investigations have data which could be used to estimate the amount of increased fertilizer which would be used per tonne of extra crops from yield increase. However, it is not easy to extract this information in retrospect from the data reported in the papers.

7.2.3 Response of RATE-of-yield-improvement to crop price

Yield response to long-term sustained prices involves *irreversible* increases due to developments in mechanization, plant breeding etc. These long-term changes are not automatically linked to an increase in N input, but they happen with a time lag. The lag for research and development in terms of their effect of yields is thought to be about 20 years, maybe longer, so any effect on research spending will only be seen beyond the time-frame of most ILUC modelling. IFPRI for example found the time-lag between research developments and practical results to be at least 17 years.

This effect is modelled in FAPRI-CARD without a time-lag, but GTAP has an exogenous rate of yield increase with time.

General technological improvement and research has been going on for many years against the background of falling real product prices. Thus, research has concentrated on how to achieve acceptable yields with less input (an example is GM (genetically modified) crops, which save on pesticide or herbicide costs but have not so far contributed much to yield increases). However, if the prices are seen to be increasing, the direction of research will turn towards intensification i.e. getting a higher yield even if this means more inputs. Therefore it is not clear whether this research-spending-effect will increase or decrease emissions per tonne of production.

In 2007 and 2008 there was seen to be a significant increase of capital directed into research and development of new seeds and technology, mainly related to speculation of food shortages and an increase in biofuels. At the same time many developing countries have increased their spending on agriculture. It has been shown that there is a significant correlation between long term yield increases and factors such as policy and public or private expenditure.

How big could the research spending effect be?

The driver for research improving farmers’ net return per ha is the expected net-return/ha. But the driver for higher *yield* (rather than lower input costs) is crop price. Let us suppose there is a sustained 10% increase in crop price in a biofuels scenario compared to baseline. The driver for research on increased yields is 10% higher, so we can estimate that research spending in the direction of increased yields (rather than reduced farm costs) would increase about 10% as a result. The resulting increase in research spending in the direction of yield increase can be expected to be less than 10% because of the law of diminishing returns, but let us suppose it is linear to find the maximum size of the effect; then the rate of yield increase should go up 10%. From 1998-2008 the average rate of world cereals yield increase according to FAOSTAT was 1.0% per year. The extra research spending due to a 10% cereals price increase can be expected to raise this by up to a tenth, to about 1.1% per year. Over ten years the yield then goes up 11.6% instead of 10.4%. So up to 1.2% yield increase has resulted from a 10% price increase sustained over 10 years. This represents a contribution of up to 0.12 to the effective long-term elasticity of yield on price.

The direct yield elasticity on price assumed by GTAP for US-maize ethanol scenarios is ~0.65. So the research spending effect can moderately affect the long-term elasticity of yield on price.

7.3 Armington vs. integrated world market model

The results of GE models like GTAP and LEITAP show a strong correlation between the regions where ILUC occurs and the regions where extra biofuel production takes place. This is a result of the Armington elasticities used in GTAP and LEITAP: the lower the elasticity, the more the ILUC effects are concentrated on the areas where the increase in biofuel production takes place. Armington elasticities are supposed to allow for transport costs, import tariffs and regulations, and imperfect information flows.

With the Armington approach, the composition of trade (that determines land use change patterns) is not fixed, but sticky, depending on existing trade flows. The stickiness of the composition of trade and stickiness of the mix of imported and domestic goods depends on the elasticities of substitution among imports from different sources (regions in the model), and elasticities between imported and domestic goods, respectively (Hertel et al., 2007). These elasticities are derived from statistics of market price correlations, which typically vary with a time-constant of about a year.

The IFPRI model assumes a single world market without allowing for transport costs or import tariffs and restrictions. FAPRI-CARD and AGLINK-COSIMO models take these effects into account; the only aspect missing is imperfect information flow. However, one would expect that in the decade or so required for biofuels production to ramp up, there would be plenty of time for the information to reach all parts of the world, so in principle one would not expect these models to differ much from GTAP or other general equilibrium models.

However, there is always the problem of calibrating the Armington elasticities against real data. The available data is mostly annual time-series changes in yields, areas and prices. The main source of variability is the effect of weather on harvests. On that short time-scale elasticities are likely to be lower than over the time-scale of decades. A temporary shortage of, say, rapeseed oil in the EU after a bad EU harvest, will be mostly compensated by increased EU rapeseed planting in the following season (to replace stocks), as well as imports of rapeseed oil as a direct replacement. But a rapeseed oil “shortage” which lasts a decade because of an increase in demand due to biofuels will result in much more widespread effects, as manufacturers and consumers learn to use substitute oils, and as production area expands in regions with more available land.

Economists recognize that long-term elasticities of all types are higher than short-term ones, but there is very little long-term data available to fit. Furthermore, there is a lot of noise in the data, which makes small cross-elasticity terms not statistically significant, and therefore they may be ignored, even though as a whole they could have an appreciable effect. That means that crop substitution effects may be underestimated even in the short-term.

All this can be expected to result in a tendency for economic models to over-concentrate their results both in a geographical sense and in a crop-specific sense, when applied to long-term changes.

JRC-IE investigated to what extent changes in crop demand correlated to changes in production over the period of a decade. Figure 28 shows the correlation for wheat, and Figure 29 for vegetable oil. The low correlation factors, especially for vegetable oil, indicate that, at least for these commodities, the world market behaves rather like an integrated world market over this time scale.

On the other hand, Villoria and Hertel (2009) at Purdue formulated an econometric model which permits them to test two competing hypotheses: Armington and the integrated world model for international trade in coarse grains. They showed that there is a statistically valid deviation from the behaviour one would expect from an integrated world model. Because the composition of coarse grains may play a role in the result, further analysis should look at more disaggregated commodities, like maize, on crop distribution.

Whether the Armington structure increases or decreases net global land requirement relative to the integrated world market assumption depends on relative yields. As an example, the case of US coarse grains can be considered: US coarse grains yields are the highest in the world. When one hectare of maize grown for food is displaced by one hectare of maize for fuel in US, more than one hectare in the rest of the world will be needed to cover the shortage of maize for food. In the integrated world market assumption, the shock originated in US is more easily transmitted through the global economy than it is using the Armington approach. Because US maize yields are higher than maize yields in other regions of the world, the net global land requirement under an integrated world market will be higher than under an Armington assumption.

This can be seen by comparing the marginal yields from these models with the average world yields according to FAO (the source of yield information for all the GTAP-based models), which is only 3.4 tonnes/ha for cereals and 0.6 tonnes/ha for oilseeds in 2007. The McGill-M3 database (McGill and Wisconsin University[31]) indicates significantly lower median world yields, for example 2.6 t/ha for wheat (2001). The situation is the opposite with EU biodiesel, according to GTAP modelling with Armington elasticities switched on or off.

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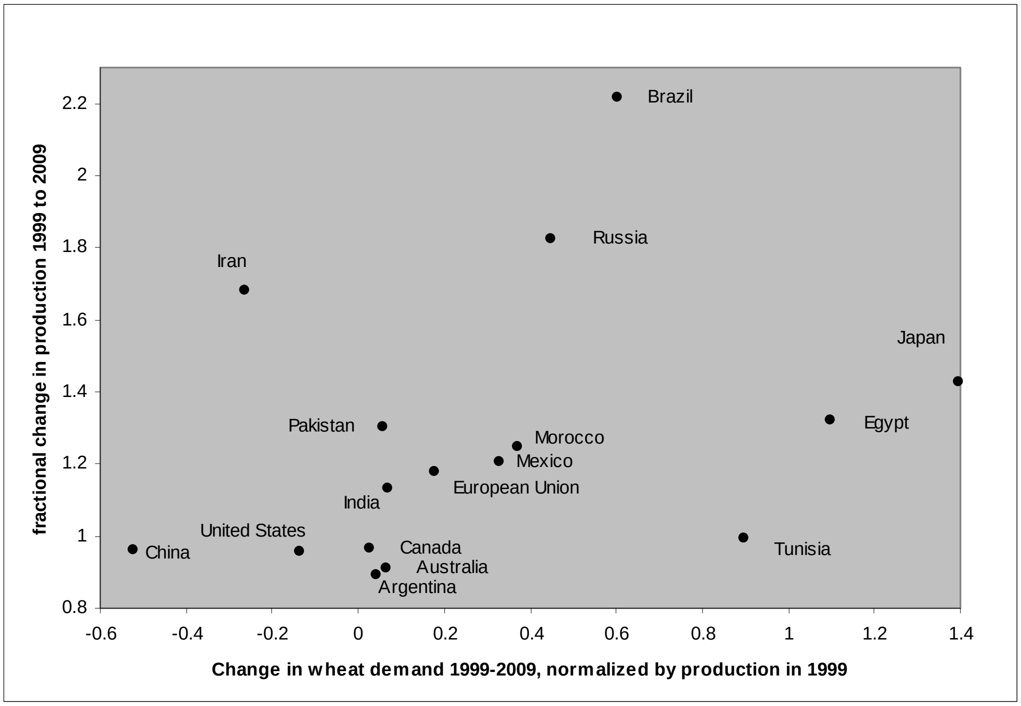
[31] The M3 database is described in more detail in the JRC report “Biofuels: a New Methodology to Estimate GHG Emissions Due to Global Land Use Change. A methodology involving spatial allocation of agricultural land demand, calculation of carbon stocks and estimation of N_2O emissions”

Figure 28 Correlation between change in wheat production and change in wheat demand (1999 to 2009) for the main wheat-trading nations [Data from FAPRI-CARD database]. The data is normalized by dividing by the production per country (otherwise you get an autocorrelation determined by the size of the country[32]). **The correlation coefficient is low: 0.15**



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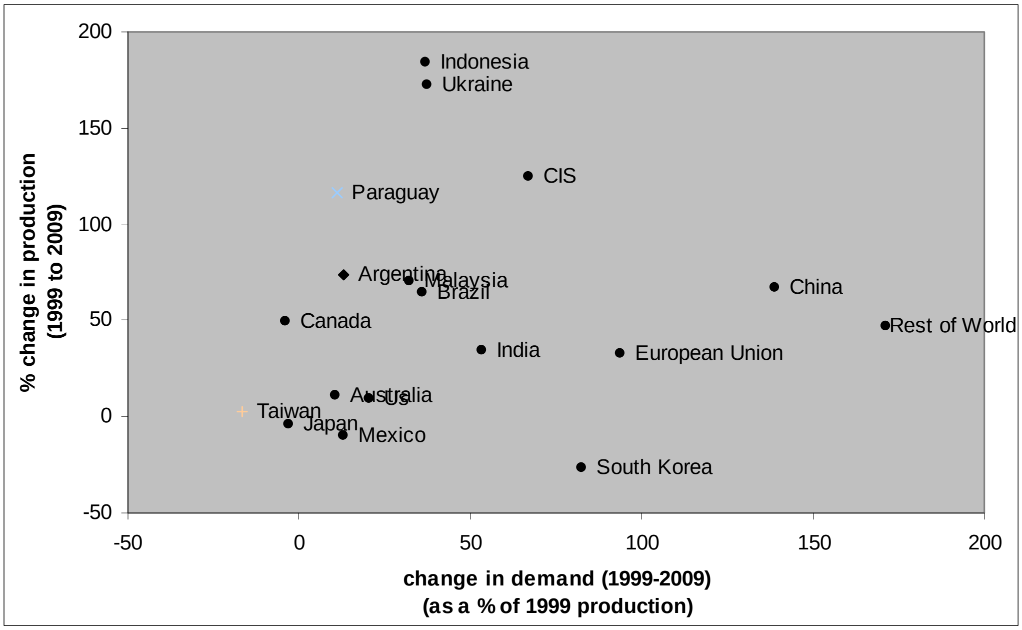
[32] At first glance, it would seem preferable to normalize change in demand by the initial *demand*. However, look what happens in the case of a country with high production but low demand: a 50% increase in demand could be insignificant in actual tonnes, whilst giving the impression of "causing" a 50% increase in production, which might be many times greater in terms of actual tonnes.

Figure 29 Correlation between change in vegetable oil production and change in total vegetable oil demand (1999 to 2009) for the main wheat-trading nations (Data from the FAPRI-CARD database). The data is normalized by dividing by the production per country (otherwise you get an autocorrelation determined by the size of the country)**. Correlation coefficient is very low, 0.07**



8. CONCLUSIONS

- The distinction between direct and indirect land use change only makes sense for a particular batch of biofuels: at a policy or aggregated level in models there is only total land use change (LUC)
- We compare the results of five different models for marginal changes in biofuels demand from different feedstocks. This makes sense because all these models appear to be either linear or close to it, for a given mix of biofuels.
- All biofuels in all models showed significant increases in land use for crops
- All the results from JRC-IE compared models are higher in terms of extra hectares of crop per Mtoe than results in the mixed biofuel scenario in the IFPRI-MIRAGE study for DG-TRADE. The two models which incorporate GHG emissions also showed higher GHG emissions per toe biofuel than the average for IFPRI-MIRAGE, and our rough estimates of the GHG emissions for all the other models show these are likely to be higher too. (However, we should bear in mind that the IFPRI-MIRAGE scenario has a high proportion of Brazilian ethanol, which AGLINK-COSIMO indicates to have the lowest LUC effect).
- All models in this study do not include emissions from tropical peat oxidation following drainage for oil-palm. But even a conservative estimate of these emissions from this source show they are significant for biofuels scenarios. The provision for these emissions in IFPRI-MIRAGE is much too low.
- All models except GTAP calculate the extra area for an extra tonne of a particular crop by dividing by a yield within a few percentage of the average yield for that crop in the same region. Thus the extra crop area for a tonne of EU rye would be apparently much greater than for a tonne of EU wheat. By contrast GTAP uses 0.66 times the average EU crop yield in both cases. We think this approach is correct in principle, although more research is needed on the actual yields on marginal land.
- For the case of EU wheat, the average yield of crops at the margin of cultivation is clearly less than 0.66 of the average EU wheat yield, so all models underestimate the area of LUC in this case at least.
- The major factors causing dispersion of model results are: by-product effects (mostly affecting LEITAP), how much yields increase with price, and how much crop production is shifted to developing countries.
- How much price affects yields is still uncertain. The proposed “research spending effect” on the rate of yield increase can only have a moderate effect by comparison.
- Apart from emissions from LUC, one should consider at least two other “indirect emissions”: the emissions from yield intensification due to crop price rises, and the extra emissions from growing crops on marginal land rather than the ‘direct’ emissions from existing cropland.

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APPENDIX I: COUNTRY AND CROP RESULTS

Crop by country tables are provided here for the models that reported data to this level. GTAP, FAPRI and LEITAP.

1. GTAP

Region in the model	**Description**
USA	United States
EU27	European Union 27
BRAZIL	Brazil
CAN	Canada
JAPAN	Japan
CHIHKG	China, Hong Kong
INDIA	India
C_C_Amer	Central and Caribbean Americas
S_o_Amer	South and Other Americas
E_Asia	East Asia
Mala_Indo	Malaysia and Indonesia
R_SE_Asia	Rest of South East Asia
R_S_Asia	Rest of South Asia
Russia	Russia
Oth_CEE_CIS	Other East Europe and Rest of Former Soviet Union
Oth_Europe	Rest of European Countries
MEAS_NAfr	Middle Eastern and North Africa
S_S_AFR	Sub Saharan Africa
Oceania	Oceania countries

Crop commodities in the model	**Description**[33]
Paddy_Rice	Paddy Rice
Wheat	Wheat
CrGrains	Coarse grains
Oilseeds	Oil seeds
Sugar_Crop	Sugar cane, sugar beet
OthAgri	Other agriculture goods (plant fibre other crops)

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[33] There are total 33 traded commodities in this version of the GTAP model, 6 of which are crops.

Table 44 EU wheat-ethanol: Marginal change in area – region and crop (kha per Mtoe)

	Paddy_Rice	Wheat	Coarse Grains	Oilseeds	Sugar_Crop	Other Agri	Total
World	**-28.06**	**1,107.63**	**-333.79**	**12.50**	**-0.52**	**36.70**	**794.45**
EU27	-0.20	797.78	-442.71	-1.82	3.91	-4.70	352.26
SS Africa	-1.09	12.22	25.23	12.18	0.33	92.67	141.55
Canada	0.00	75.95	9.70	9.65	0.01	3.68	98.99
Brazil	0.21	2.81	1.57	22.02	-0.06	13.39	39.93
USA	-1.59	38.54	88.10	-29.63	-0.73	-37.00	57.69
Other CIS+CEE	-0.19	51.97	-0.59	-1.15	-0.72	-6.14	43.19
Rest of America	-0.34	13.91	1.33	-0.65	-0.17	3.46	17.54
Malays Indone	-4.47	0.00	-0.47	0.13	-0.09	0.99	-3.91
MidEast N Africa	-1.50	38.09	-4.48	-1.88	-0.23	-6.69	23.31
Oceania	-0.02	27.46	-0.72	-0.12	-0.04	-4.99	21.57
India	-2.22	12.50	-3.23	-0.84	-0.60	6.74	12.35
Russia	-0.15	21.92	-12.31	-1.45	-0.42	-24.07	-16.48
C.Amer +Carib	0.04	2.15	4.87	0.16	-0.57	2.66	9.31
China	-6.85	2.52	0.45	3.62	-0.31	-6.30	-6.88

Table 45 Percentage change in yield - EU wheat ethanol

	Paddy_Rice	Wheat	CrGrains	Oilseeds	Sugar_Crop	OthAgri
USA	0.019	0.088	0.063	0.039	0.068	0.047
EU27	-0.128	-0.071	-0.322	-0.222	-0.180	-0.209
BRAZIL	-0.009	0.008	-0.007	-0.002	-0.015	-0.011
CAN		-0.045	-0.040	-0.068	-0.048	-0.032
JAPAN	0.016	0.034	0.019	0.018	0.015	0.017
CHIHKG	0.020	0.023	0.022	0.028	0.017	0.025
INDIA	0.012	0.011	0.010	0.010	0.010	0.013
C_C_Amer	0.008	0.089	0.028	0.028	0.008	0.024
S_o_Amer	0.010	0.041	0.025	0.025	0.007	0.035
E_Asia	0.024	0.052	0.033	0.037	0.063	0.028
Mala_Indo	0.020		0.023	0.019	0.021	0.026
R_SE_Asia	0.012	0.025	0.017	0.021	0.014	0.025
R_S_Asia	0.014	0.044	0.032	0.021	0.032	0.033
Russia	0.068	0.077	0.054	0.051	0.048	0.062
Oth_CEE_CIS	0.047	0.043	0.037	0.057	0.040	0.048
Oth_Europe	-0.070	0.020	-0.026	-0.026	-0.029	-0.035
MEAS_NAfr	0.095	0.083	0.079	0.096	0.046	0.083
S_S_AFR	-0.026	-0.016	-0.029	-0.021	-0.042	-0.022
Oceania	0.027	0.064	0.036	0.037	0.026	0.058

Table 46 US maize ethanol: Marginal changes in area (kha per Mtoe)

	Paddy_Rice	Wheat	Coarse Grains	Oilseeds	Sugar_Crop	Other Agri	Total
World	**-10.69**	**-37.62**	**273.18**	**-18.35**	**-3.44**	**-38.50**	**164.61**
EU27	0.22	3.88	-2.86	6.52	0.01	5.22	12.99
SS Africa	0.29	1.65	1.91	7.91	0.05	18.32	30.13
Canada	0.00	3.92	1.64	7.97	0.00	3.62	17.16
Brazil	-0.26	0.00	5.69	6.82	-1.63	0.63	11.25
USA	-2.50	-56.77	252.30	-61.93	-0.76	-62.39	67.95
Other CIS+CEE	-0.01	2.83	2.07	0.98	-0.03	1.00	6.84
Rest of America	0.08	0.63	0.56	4.39	-0.08	0.70	6.28
Malays Indone	-1.73	0.00	0.01	0.87	-0.04	0.00	-0.89
MidEast N Africa	-0.40	2.57	2.57	0.21	-0.07	-1.73	3.15
Oceania	0.02	0.86	3.09	0.67	-0.00	0.24	4.89
India	-0.58	1.34	-0.49	0.27	-0.11	1.54	1.98
Russia	0.01	-0.55	0.12	0.91	-0.09	-3.58	-3.19
C.Amer +Carib	0.28	0.17	1.75	0.35	-0.34	0.81	3.03
China	-2.48	0.33	4.30	3.00	-0.13	-3.27	1.74

Table 47. Percentage change in yield due to the expansion of US maize ethanol

	Paddy_Rice	Wheat	CrGrains	Oilseeds	Sugar_Crop	OthAgri
USA	0.000	0.022	0.083	0.019	0.064	0.032
EU27	0.000	0.002	0.001	0.004	0.001	0.002
BRAZIL	0.009	0.016	0.013	0.012	0.005	0.006
CAN		-0.006	-0.007	-0.004	-0.007	-0.003
JAPAN	0.007	0.009	0.014	0.008	0.006	0.007
CHIHKG	0.009	0.011	0.012	0.013	0.008	0.011
INDIA	0.003	0.002	0.003	0.003	0.003	0.003
C_C_Amer	0.008	0.013	0.011	0.013	0.004	0.010
S_o_Amer	0.007	0.012	0.011	0.015	0.005	0.013
E_Asia	0.012	0.011	0.015	0.022	0.005	0.013
Mala_Indo	0.009		0.011	0.011	0.009	0.010
R_SE_Asia	0.006	0.007	0.010	0.015	0.007	0.010
R_S_Asia	0.003	0.008	0.007	0.005	0.006	0.006
Russia	0.013	0.011	0.010	0.011	0.007	0.010
Oth_CEE_CIS	0.004	0.002	0.002	0.006	0.003	0.004
Oth_Europe	-0.002	0.002	0.002	0.001	-0.002	-0.002
MEAS_NAfr	0.018	0.016	0.018	0.020	0.010	0.017
S_S_AFR	-0.005	-0.006	-0.007	-0.003	-0.009	-0.005
Oceania	0.007	0.009	0.013	0.017	0.006	0.012

Table 48 EU biodiesel mix: Change in harvested area, kha/Mtonne biofuel

	Paddy_Rice	Wheat	Coarse Grains	Oilseeds	Sugar_Crop	Other Agri	Total
World	**-20.82**	**-46.11**	**-20.67**	**466.43**	**-1.51**	**-46.40**	**330.88**
EU27	-0.12	-53.82	1.45	237.10	0.53	-49.77	135.37
SS Africa	-1.22	1.38	3.79	34.52	0.66	28.74	67.87
Canada	0.00	7.49	2.30	17.71	0.00	1.80	29.30
Brazil	-0.92	-1.27	-4.29	46.07	-0.89	-2.34	36.37
USA	-0.49	-2.09	-12.41	39.11	-0.89	-11.13	12.62
Other CIS+CEE	-0.03	4.58	1.00	6.11	-0.13	1.39	12.93
Rest of America	-0.11	-5.04	-3.39	29.79	-0.17	-7.73	13.35
Malays Indone	-9.60	0.00	-2.07	16.47	-0.29	-3.82	0.69
MidEast N Africa	-0.33	3.16	-0.19	5.29	0.01	1.03	8.97
Oceania	0.03	1.35	1.84	2.41	0.00	2.85	8.49
India	-0.74	0.56	-1.82	8.35	-0.27	3.11	9.20
Russia	-0.05	-3.29	-3.69	9.23	-0.19	-9.48	-7.46
C.Amer +Carib	0.16	0.24	-0.18	1.24	0.00	1.79	3.25
China	-4.07	-0.62	-2.33	10.15	-0.18	-4.41	-1.46

Table 49 Percentage change in yield due to the expansion of EU biodiesel

	Paddy_Rice	Wheat	CrGrains	Oilseeds	Sugar_Crop	OthAgri
USA	0.039	0.026	0.034	0.054	0.035	0.034
EU27	0.016	0.039	0.050	0.136	0.026	0.034
BRAZIL	0.019	0.039	0.017	0.035	0.003	-0.002
CAN	-0.435	-0.014	-0.013	-0.008	-0.012	-0.010
JAPAN	0.004	0.006	0.004	0.004	0.003	0.004
CHIHKG	0.012	0.011	0.010	0.019	0.010	0.013
INDIA	0.005	0.002	0.004	0.010	0.004	0.005
C_C_Amer	-0.001	0.010	0.000	0.014	-0.002	0.003
S_o_Amer	0.035	0.056	0.052	0.081	0.039	0.059
E_Asia	0.005	0.014	0.005	0.005	0.006	0.006
Mala_Indo	0.066	-4.218	0.055	0.112	0.071	0.067
R_SE_Asia	0.007	0.005	0.008	0.014	0.007	0.011
R_S_Asia	0.003	0.003	0.003	0.010	0.004	0.006
Russia	0.026	0.026	0.024	0.051	0.020	0.025
Oth_CEE_CIS	0.008	0.004	0.005	0.018	0.007	0.009
Oth_Europe	0.003	0.006	0.005	0.014	-0.005	0.001
MEAS_NAfr	0.017	0.011	0.014	0.029	0.005	0.015
S_S_AFR	0.002	-0.002	0.001	0.014	-0.004	0.004
Oceania	0.002	0.006	0.007	0.039	0.002	0.011

Table 50 Biodiesel from Malay/Indonesian palm oil, kha/0.95 Mtonne biofuel (

	Paddy_Rice	Wheat	Coarse Grains	Oilseeds	Sugar_Crop	Other Agri	Total
World	**-69.104**	**-4.752**	**-17.056**	**199.520**	**-2.738**	**-37.472**	**68.352**
EU27	0.080	-0.556	-0.692	6.238	-0.060	0.324	5.328
SS Africa	0.059	0.190	-0.048	4.968	0.068	2.736	7.968
Canada	0.000	-0.108	0.276	4.545	0.000	0.179	4.892
Brazil	-0.056	-0.018	-0.120	4.318	-0.203	-0.202	3.716
USA	-0.159	-2.448	-3.788	12.956	-0.096	-3.612	2.848
Other CIS+CEE	-0.002	0.420	0.280	0.528	-0.002	0.314	1.536
Rest of America	-0.051	-1.441	-0.462	7.345	-0.032	-2.442	2.916
Malays Indone	-65.545	0.000	-13.459	143.262	-2.114	-33.109	29.036
MidEast N Africa	-0.062	0.238	-0.087	0.776	-0.005	-0.007	0.852
Oceania	0.009	-0.110	0.200	0.634	0.015	0.986	1.734
India	-0.472	-0.350	-0.542	5.908	-0.082	0.264	4.736
Russia	0.007	-0.178	-0.332	1.037	-0.024	-0.622	-0.112
C.Amer +Carib	0.028	0.009	-0.020	0.234	-0.018	0.166	0.398
China	-1.200	-0.522	1.706	3.262	-0.059	-2.032	1.152

Table 51 Percentage change in yield due to the expansion of palm oil biodiesel

	Paddy_Rice	Wheat	CrGrains	Oilseeds	Sugar_Crop	OthAgri
USA	0.011	0.005	0.009	0.016	0.009	0.009
EU27	0.000	0.001	0.001	0.003	0.000	0.001
BRAZIL	0.002	0.005	0.002	0.004	0.001	0.000
CAN		-0.003	-0.002	0.000	-0.002	-0.002
JAPAN	0.000	0.000	0.000	0.000	0.000	0.000
CHIHKG	0.004	0.005	0.005	0.007	0.004	0.005
INDIA	0.000	-0.001	0.000	0.004	0.000	0.000
C_C_Amer	0.000	0.001	0.000	0.003	0.000	0.000
S_o_Amer	0.009	0.014	0.013	0.020	0.010	0.014
E_Asia	0.001	0.000	0.001	0.002	0.000	0.001
Mala_Indo	0.475		0.403	0.871	0.516	0.470
R_SE_Asia	0.007	0.004	0.010	0.016	0.007	0.007
R_S_Asia	-0.001	-0.003	-0.002	0.005	-0.002	0.000
Russia	0.003	0.002	0.002	0.005	0.002	0.002
Oth_CEE_CIS	0.001	0.000	0.000	0.001	0.000	0.001
Oth_Europe	0.000	0.000	0.000	0.001	-0.001	-0.001
MEAS_NAfr	0.002	0.002	0.002	0.004	0.001	0.002
S_S_AFR	0.000	0.000	0.000	0.002	-0.001	0.000
Oceania	-0.001	-0.001	-0.001	0.008	-0.001	0.001

2. FAPRI-CARD

Country coverage and commodity codes:

Area, production and yield tables include results for the major countries and regions reported in FAPRI report.

Code	**Country Coverage**
A7_	Latin America, Other
AG_	Algeria
AR_	Argentina
AU_	Australia
BR_	Brazil
CA_	Canada
CN_	China
E7_	Eastern Europe, Other
EG_	Egypt
EU_	EU
F0_	Africa, Other
IN_	India
JP_	Japan
KR_	South Korea
M0_	Middle East, Other
ML_	Malaysia
MX_	Mexico
PH_	Philippines
PK_	Pakistan
R2_	Commonwealth of Independent States
RU_	Russia
S0_	Asia, Other
SF_	South Africa
TA_	Taiwan
TH_	Thailand
U9_	United States, Metric Units
UK_	Ukraine
VN_	Vietnam
W0_	Rest of World
W1_	World

Code	**Commodity**
BA	Barley
CO	Corn (maize)
KS	Palm Kernel
ML	Palm Oil
OA	Oats
PE	Peanut
RI	Rice, All
RS	Rapeseed
RY	Rye
SB	Soybeans
SG	Sorghum
SJ	Sugar Cane
SK	Sugar Beet
TC	Total Crops
US	Sunflower Seed
WH	Wheat, All

Table 52 FAPRI-CARD - EU wheat ethanol scenario - Area changes (average 2017 to 2023) in Kha per Mtoe extra biofuel.

	BA	CO	KS	OA	PE	RI	RS	RY	SB	SG	SJ	SK	US	WH
A7_	-0.077	-0.092		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.404
AG_	-0.176	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.454
AR_	-0.124	-0.575		0.000	0.000	0.004	0.000	0.000	-3.127	-0.626	0.061	0.000	0.291	2.986
AU_	-0.380	-0.010		0.000	0.000	0.018	0.388	0.000	0.000	-0.419	0.090	0.000	0.000	3.140
BR_	-0.050	-6.334		0.000	0.000	-0.230	0.000	0.000	-23.300	0.000	4.053	0.000	0.000	0.112
CA_	-1.487	-0.271		0.004	0.000	0.000	1.740	0.000	-0.179	0.000	0.000	0.000	0.000	4.393
CN_	-0.213	-1.440		0.000	-0.247	-1.401	2.156	0.000	-1.150	0.000	0.096	0.020	-0.028	6.747
E7_	-0.034	-0.174		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.229
EG_	0.000	-0.207		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.029	0.011	0.000	0.182
EU_	35.037	51.293		23.746	0.000	0.005	-27.311	1.515	-1.058	0.000	0.000	-7.552	-6.165	338.434
F0_	-0.192	-1.410		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ID_	0.000	-0.436	0.000	0.039	0.000	0.000	0.151	0.000	0.000	0.000	0.000	0.017	0.000	0.000
IN_	0.000	2.171	0.000	0.000	-0.212	-1.689	2.628	0.000	-1.821	-7.448	0.524	0.000	0.000	17.799
JP_	-0.039	0.000		0.000	0.000	0.060	0.001	0.000	-0.029	0.000	0.002	0.004	0.000	0.048
KR_	0.000	0.000		0.000	0.000	0.039	0.000	0.000	-0.018	0.000	0.000	0.000	0.000	0.000
M0_	-0.301	-0.024		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML_	0.000	-0.006	0.060	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.000
MX_	-0.117	2.624		0.000	0.018	0.003	0.000	0.000	-0.009	-2.811	0.004	0.000	0.000	0.481
PH_	0.000	-0.279		0.000	0.000	0.257	0.000	0.000	0.000	0.000	0.104	0.000	0.000	0.000
PK_	-0.033	0.019		0.000	0.000	0.155	0.000	0.000	0.000	-0.232	0.154	0.001	0.000	3.423
R2_	0.000	0.000		0.000	0.000	0.000	0.075	0.000	-0.078	0.000	0.000	0.000	0.172	0.000
RU_	-1.896	-0.093		-0.586	0.000	0.000	0.000	0.991	0.000	0.000	0.000	0.036	0.000	3.448
S0_	-0.336	-0.207		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.848
SF_	0.011	0.896		0.000	0.000	0.000	0.000	0.000	0.000	-0.115	0.051	0.000	0.000	0.000
TA_	0.000	-0.003		0.000	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TH_	0.000	-0.094		0.000	0.000	0.124	0.000	0.000	0.000	0.000	0.059	0.000	0.000	0.000
U9_	-0.397	-5.578		0.007	0.003	-0.174	-0.243	0.000	-4.642	-8.043	0.014	-0.004	-0.031	12.037
UK_	-0.366	-0.153		-0.050	0.000	0.000	0.042	0.172	0.000	0.000	0.000	0.011	0.082	0.856
VN_	0.000	-0.084		0.000	0.000	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
W0_	-0.016	0.149	0.013	-0.558	0.136	0.399	0.241	0.528	-0.619	-9.840	0.389	0.065	0.978	0.469
W1_	**28.645**	**39.652**	**0.112**	**22.532**	**-0.302**	**-2.048**	**-20.283**	**3.265**	**-36.487**	**-35.270**	**0.006**	**-0.007**	**-4.701**	**399.251**

Table 53 FAPRI-CARD - EU rapeseed biodiesel scenario Area changes (average 2017 to 2023) in Kha per Mtoe extra biofuel

Crop	BA	CO	OA	PE	RI	RS	RY	SB	SG	SJ	SK	US	WH
A7_	0.737	-0.917	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.792
AG_	0.121	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.672
AR_	0.783	-2.564	0.000	-0.000	0.011	0.000	0.000	-33.263	-0.113	0.030	0.000	12.873	-0.596
AU_	3.817	-0.017	0.000	0.000	0.034	31.328	0.000	0.000	-0.224	0.069	0.000	0.000	-37.167
BR_	0.335	22.708	0.000	*0.000*	-1.549	0.000	0.000	-19.608	0.000	0.344	0.000	0.000	-0.758
CA_	-13.374	-6.964	-0.598	0.000	0.000	183.405	0.000	-1.453	0.000	0.000	-0.184	0.000	-140.601
CN_	0.486	-142.531	0.000	7.557	-11.536	262.269	0.000	-8.147	0.000	-0.008	0.003	-4.386	-107.854
E7_	0.311	-0.408	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.584
EG_	0.000	-0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.022	-0.006	0.000	0.727
EU_	-49.328	-35.104	-12.518	0.000	0.015	209.683	-6.854	-0.894	0.000	0.000	-2.681	32.281	-99.983
F0_	1.928	9.339	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ID_	0.000	1.489	0.000	0.000	0.543	0.000	0.000	0.000	0.000	-0.006	0.000	0	0.000
IN_	1.489	3.682	0.000	-27.099	-6.234	252.733	0.000	-53.653	-3.868	-0.033	0.000	0.000	44.959
JP_	0.000	0.000	0.000	0.000	0.141	0.069	0.000	-0.007	0.000	0.001	0.003	0.000	0.312
KR_	0.000	0.000	0.000	0.000	0.074	0.000	0.000	-0.002	0.000	0.000	0.000	0.000	0.000
M0_	0.543	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
ML_	0.000	0.018	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000
MX_	0.000	-3.760	0.000	0.129	-0.012	0.000	0.000	-0.027	-0.913	0.007	0.000	0.000	1.045
PH_	0.000	0.830	0.000	0.000	0.663	0.000	0.000	0.000	0.000	0.063	0.000	0.000	0.000
PK_	0.000	-0.605	0.000	0.000	0.453	0.000	0.000	0.000	-0.584	0.041	0.001	0.000	8.677
R2_	-0.006	0.000	0.000	0.000	0.000	7.324	0.000	-0.799	0.000	0.000	0.000	-8.077	0.000
RU_	0.000	-0.144	-3.187	0.000	0.000	0.000	1.007	0.000	0.000	0.000	-0.049	0.000	13.145
S0_	4.053	-1.199	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	3.442
SF_	0.000	-1.069	0.000	0.000	0.000	0.000	0.000	0.000	-0.158	0.039	0.000	0.000	0.000
TA_	0.000	0.013	0.000	0.000	-0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
TH_	0.000	0.270	0.000	0.000	0.354	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000
U9_	-0.792	27.290	-0.646	1.539	-0.045	3.781	0.000	-36.049	-4.637	0.105	-0.456	10.867	42.987
UK_	0.853	-0.395	-0.226	0.000	0.000	5.622	0.248	0.000	0.000	0.000	-0.036	-9.651	1.966
VN_	0.000	0.302	0.000	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
W0_	0.827	0.212	-5.696	0.538	1.632	26.614	0.722	-2.829	-7.402	0.297	0.049	44.166	0.901
W1_	**-43.915**	**-129.593**	**-22.972**	**-17.336**	**-14.782**	**982.828**	**-4.777**	**-157.910**	**-17.768**	**0.001**	**-0.003**	**78.073**	**-251.990**

Table 54 FAPRI-CARD EU- Wheat Ethanol scenario - production changes (2017 to 2023) in tonnes per Mtoe extra biofuel

Crop	BA	CO	KL	KS	ML	OA	PE	RI	RS	RY	SB	SG	SJ	SK	US	WH
A7_	-0.15	-0.31	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36
AG_	-0.20	-0.00	0.00		*0.00*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92
AR_	-0.49	-5.11	0.00		0.00	0.00	0.00	0.02	0.00	0.00	-9.93	-4.00	5.04	0.00	0.56	9.31
AU_	-0.68	-0.15	0.00		0.00	0.00	0.00	0.14	0.49	0.00	0.00	-2.17	8.41	0.00	0.00	2.66
BR_	-0.18	-47.95	0.00		0.00	0.00	0.00	-1.01	0.00	0.00	-84.06	0.00	434.63	0.00	0.00	0.82
CA_	-5.30	-2.96	0.00		0.00	0.01	0.00	0.00	3.46	0.00	-0.54	0.00	0.00	0.03	0.00	13.29
CN_	-0.91	77.77	0.00		0.00	0.00	-0.89	-5.44	4.59	0.00	-2.70	0.00	7.43	0.91	-0.05	87.67
E7_	-0.11	-0.97	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83
EG_	0.00	-2.09	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.13	0.59	0.00	1.39
EU_	157.56	310.22	-0.01		0.00	74.22	0.00	0.02	-89.44	5.55	-3.11	0.00	0.00	-576.48	-11.80	2118.05
F0_	-0.21	-3.03	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ID_	0.00	-1.53	0.02	0.05	0.19	0.00	0.00	0.49	0.00	0.00	0.00	0.00	1.33	0.00	0.00	0.00
IN_	0.00	22.76	0.00	0.00	0.00	0.00	-0.24	-4.15	2.71	0.00	-2.40	-1.79	38.05	0.00	0.00	140.50
JP_	-0.14	*-0.00*	0.00		0.00	0.00	0.00	0.44	0.00	0.00	-0.05	0.00	0.08	0.27	0.00	0.23
KR_	0.00	-0.00	0.00		0.00	0.00	0.00	0.20	0.00	0.00	-0.03	0.00	*0.00*	0.00	0.00	0.00
M0_	-0.47	-0.21	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ML_	0.00	-0.02	0.04	0.07	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.00	0.00	0.00
MX_	-0.36	8.18	0.00		0.00	0.00	0.03	0.04	0.00	0.00	-0.02	-11.57	0.29	0.00	0.00	2.86
PH_	0.00	-1.37	0.00		0.00	0.00	0.00	1.13	0.00	0.00	0.00	0.00	6.60	0.00	0.00	0.00
PK_	-0.06	-0.15	0.00		0.00	0.00	0.00	0.37	0.00	0.00	0.00	-0.26	9.43	0.04	0.00	12.21
R2_	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.10	0.00	-0.13	0.00	0.00	0.00	0.22	0.00
RU_	-4.06	-0.94	0.00		0.00	-0.98	0.00	0.00	0.00	2.15	0.00	0.00	0.00	1.22	0.00	10.25
S0_	-0.66	-0.77	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.56
SF_	0.04	2.90	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.43	3.25	0.00	0.00	0.00
TA_	0.00	-0.02	0.00		0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TH_	0.00	-0.51	0.00		0.00	0.00	0.00	0.25	0.00	0.00	0.00	0.00	5.50	0.00	0.00	0.00
U9_	-1.48	-67.63	0.00		0.00	0.02	-0.00	-1.07	-0.45	0.00	-17.35	-36.22	0.86	-0.57	-0.06	39.63
UK_	-0.87	-1.22	0.00		0.00	-0.09	0.00	0.00	0.09	0.37	0.00	0.00	0.00	0.42	0.13	2.94
VN_	0.00	-0.68	0.00		0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W0_	-0.07	0.29	0.00	0.01	0.02	-0.86	0.15	0.95	0.29	0.96	-1.32	-16.41	31.86	2.99	1.03	2.01
W1_	140.88	284.48	0.06	0.14	0.52	72.25	-0.95	-6.01	-78.15	9.18	-122.94	-98.19	580.98	-567.00	-9.97	2457.66

Table 55 FAPRI-CARD - EU rapeseed biodiesel scenario - production changes (average 2017 to 2023) in tonnes per Mtoe extra biofuel

	BA	CO	KS	ML	OA	PE	RI	RS	RY	SB	SG	SJ	SK	US	WH
A7_	1.39	-0.55		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.10
AG_	0.14	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.40
AR_	3.06	-18.88		0.00	0.00	-0.00	0.06	0.00	0.00	-99.77	-0.49	2.55	0.00	24.98	1.22
AU_	6.83	-0.12		0.00	0.00	0.00	0.25	39.89	0.00	0.00	-0.77	6.45	0.00	0.00	-66.98
BR_	1.19	152.79		0.00	0.00	0.00	-2.87	0.00	0.00	-60.95	0.00	142.49	0.00	0.00	3.13
CA_	-47.41	-67.43		0.00	-1.88	0.00	0.00	364.37	0.00	-4.15	0.00	0.00	-11.98	0.00	-402.21
CN_	2.16	-818.40		0.00	0.00	27.12	-52.24	558.03	0.00	-15.12	0.00	-0.44	0.17	-8.28	-472.70
E7_	1.06	-1.76		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.30
EG_	0.00	-0.39		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.40	-0.32	0.00	5.55
EU_	-221.73	-202.74		0.00	-39.12	0.00	0.06	686.30	-24.59	-2.56	0.00	0.00	-204.49	61.71	-521.66
F0_	2.10	20.42		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
IN_	0.00	21.57	0.00	0.16	0.00	-30.79	-15.30	260.53	0.00	-54.07	0.49	-1.68	0.00	0.00	196.68
JP_	0.60	0.00		0.00	0.00	0.00	1.05	0.08	0.00	-0.01	0.00	0.06	0.21	0.00	1.50
KR_	0.00	*0.01*		0.00	0.00	0.00	0.37	0.00	0.00	-0.00	0.00	0.00	0.00	0.00	0.00
M0_	5.32	0.34		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ML_	0.00	0.06	30.12	121.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00
MX_	2.22	-10.31		0.00	0.00	0.23	0.00	0.00	0.00	-0.05	-3.31	0.56	0.00	0.00	6.58
PH_	0.00	4.26		0.00	0.00	0.00	3.10	0.00	0.00	0.00	0.00	3.99	0.00	0.00	0.00
PK_	0.68	-0.76		0.00	0.00	0.00	1.08	0.00	0.00	0.00	-0.18	2.68	0.03	0.00	33.32
R2_	0.00	0.00		0.00	0.00	0.00	0.00	9.98	0.00	-0.82	0.00	0.00	0.00	-10.46	0.00
RU_	4.53	1.38		0.00	-5.33	0.00	0.00	0.00	2.19	0.00	0.00	0.00	-0.97	0.00	52.55
S0_	3.17	-2.26		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.42
SF_	0.66	-2.03		0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.44	2.49	0.00	0.00	0.00
TA_	0.00	0.09		0.00	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TH_	0.00	1.51		0.00	0.00	0.00	0.72	0.00	0.00	0.00	0.00	0.96	0.00	0.00	0.00
U9_	-3.10	345.06		0.00	-1.50	5.76	-0.36	6.98	0.00	-113.24	-18.78	11.27	-29.81	19.49	155.44
UK_	2.04	0.03		0.00	-0.43	0.00	0.00	11.50	0.53	0.00	0.00	0.00	-1.16	-15.30	9.81
VN_	0.00	2.37		0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
W0_	3.68	1.50	3.33	10.15	-8.73	0.61	3.83	32.39	1.31	-5.65	-9.26	24.32	2.29	46.32	4.17
W1_	**-229.85**	**-569.04**	**58.65**	**222.56**	**-57.20**	**2.94**	**-54.07**	**1970.04**	**-20.32**	**-359.33**	**-32.08**	**216.99**	**-243.29**	**118.46**	-923.80

Table 56 FAPRI-CARD EU - wheat ethanol scenario - percentage yield changes (average 2017 to 2023) per Mtoe extra biofuel

	BA	CO	OA	PE	RI	RS	RY	SB	SG	SJ	SK	US	WH
A7_	0.0000	-0.0004											0.0060
AG_	0.0000	-0.0035											0.0066
AR_	-0.0000	-0.0017		0.0000	0.0001			-0.0006	-0.0170	0.0005		0.0000	0.0019
AU_	-0.0000	-0.0184			-0.0011	0.0000			-0.0570	0.0002			-0.0128
BR_	*-0.0000*	-0.0314			-0.0030			-0.0154		0.0063			0.0090
CA_	*-0.0001*	-0.0025	0.0000			0.0000		-0.0013			0.0001		0.0020
CN_	*-0.0002*	0.0446		0.0000	0.0010	0.0000		-0.0028		0.0001	0.0002	0.0000	0.0510
E7_	0.0000	-0.0028											0.0020
EG_		0.0000			0.0000					0.0004	0.0002		0.0000
EU_	-0.0012	-0.0676	0.0000		-0.0002	0.0000	0.0011	-0.0099		0.0000	0.0000	0.0000	0.0918
F0_	0.0000	-0.0022											
IN_		0.0997		0.0000	0.0000	0.0000		-0.0049	0.0608	0.0002			0.0917
JP_	0.0000	-0.0021			0.0019	0.0000		-0.0025		0.0001	0.0000		0.0016
KR_		-0.0019			0.0000			-0.0054					0.0020
M0_	0.0000	-0.0009											
ML_		-0.0000			0.0000					0.0005			
MX_	0.0000	-0.0025		0.0000	0.0141			-0.0028	-0.0158	-0.0000			0.0016
PH_		-0.0090			0.0030					*0.0005*			
PK_	0.0000	-0.0069			0.0000				-0.2781	0.0006	0.0007		0.0057
R2_	-0.0000	-0.0062	0.0003			0.0000	-0.0007	-0.0042				0.0000	0.0053
RU_	*-0.0000*	-0.0125	0.0000				0.0000				0.0010		0.0042
S0_	*0.0000*	-0.0048											0.0042
SF_	0.0000	-0.0056							-0.0439	0.0004			
TA_		-0.0028			-0.0002			0.0000					
TH_		-0.0025			0.0000					0.0009			
U9_	0.0006	-0.0016	0.0009	-0.0004	-0.0002	-0.0000		-0.0030	-0.0226	-0.0011	-0.0009	-0.0004	0.0017
UK_	*-0.0000*	-0.0054	0.0000			0.0000	0.0000				0.0005	0.0000	0.0019
VN_		-0.0059			*0.0000*								
W0_	0.0000	-0.0025	0.0000	0.0000	-0.0007	0.0000	0.0000	-0.0012	-0.0198	0.0004	0.0004	0.0000	0.0021
W1_	**0.0400**	**0.0066**	**0.0839**	**-0.0012**	**0.0001**	**-0.0553**	**0.0015**	**-0.0083**	**-0.0647**	**0.0039**	**-0.0812**	**-0.0037**	0.1631

Table 57 FAPRI-CARD - EU rapeseed biodiesel scenario - percentage yield changes (average 2017 to 2023) per Mtoe extra biofuel

	BA	CO	OA	PE	RI	RS	RY	SB	SG	SJ	SK	US	WH
A7_	0.0000	0.0145											0.0258
AG_	0.0000	0.0089											0.0630
AR_	0.0002	0.0075		0.0000	0.0003			0.0027	0.0024	0.0004		0.0000	0.0181
AU_	0.0002	-0.0011			-0.0020	0.0000			-0.0101	0.0002			0.0057
BR_	*0.0000*	0.0868			*0.0217*			-0.0011		*0.0107*			0.0816
CA_	*0.0005*	0.0057	0.0000			0.0000		-0.0024			0.0001		0.0197
CN_	*0.0020*	0.0335		0.0000	0.0026	0.0000		0.0052		0.0001	0.0001	0.0000	0.0396
E7_	0.0000	0.0081											0.0169
EG_		0.0000			0.0000					*0.0003*	*0.0002*		0.0000
EU_	0.0021	0.0622	0.0000		-0.0002	0.0000	0.0016	0.0007		0.0000	0.0000	0.0000	0.0397
F0_	0.0000	0.0153											
IN_		0.0742		0.0000	0.0000	0.0000		0.0048	0.0490	0.0002			0.0621
JP_	0.0000	0.0061			0.0048	0.0000		-0.0001		*0.0001*	0.0000		0.0140
KR_		0.0061			0.0000			-0.0005					0.0180
M0_	0.0000	0.0033											
ML_		-0.0094			0.0000					0.0004			
MX_	0.0000	0.0094		0.0000	0.0199			0.0008	0.0014	0.0001			0.0131
PH_		0.0289			0.0089					*0.0004*			
PK_	0.0000	0.0345			0.0000				-0.0006	*0.0004*	0.0006		0.0232
R2_	-0.0000	0.0221	0.0021			0.0000	-0.0007	0.0014				0.0000	0.0349
RU_	*0.0001*	0.0403	0.0000				0.0000				0.0008		0.0387
S0_	*0.0000*	0.0149											0.0374
SF_	0.0000	0.0175							0.0024	0.0003			
TA_		0.0092			-0.0004			0.0000					
TH_		0.0081			*0.0000*					0.0007			
U9_	-0.0018	0.0106	0.0031	-0.0048	-0.0014	-0.0001		-0.0019	0.0072	0.0089	0.0000	0.0189	0.0271
UK_	*0.0002*	0.0177	0.0000			0.0000	0.0000				*0.0004*	0.0000	0.0190
VN_		0.0192			*0.0000*								
W0_	0.0000	0.0073	0.0000	0.0000	-0.0032	0.0000	0.0000	-0.0020	-0.0010	0.0003	*0.0004*	0.0000	0.0141
W1_	**-0.0702**	**0.0180**	**-0.0257**	**0.0863**	**-0.0016**	**-0.0650**	**-0.0441**	**0.0216**	**-0.0059**	**0.0049**	**-0.0319**	**0.0346**	-0.0163

3. LEITAP

Crop results presented:

ARABLE	arable agricultural commodities
Pdr	paddy rice
Wht	wheat
Grain	other cereals
Oils	vegetable oilseeds
Sug	sugar beet and cane
Crops	other crops

Countries and regions:

Code	Countries
World	All countries in the world
EU27	All countries in the EU
can	Canada
usa	USA
mex	Mexico
rca	Rest Central America
bra	Brazil
rsa	Rest South America
naf	Northern Africa
waf	West and East Africa
saf	South Africa
rwe	Rest Western Europe
ree	Rest Eastern Europe
tur	Turkey
as_stan	Asia Stan
rus	Russia
me	Middle East
ind	India
rsas	Rest of South Asia
kor	Korea
chi	China
sea	Southeastern Asia
Indo	Indonesia
jap	Japan
oce	Oceania

Table 58 Change in area (kha per Mtoe) JRC-IEMaizeEthUSDemand

Countries	ARABLE	pdr	wht	grain	oils	sug	other crops
All countries in the world	**862.712**	**-1.349**	**-25.624**	**1032.869**	**-154.945**	**4.120**	**4.104**
All countries in the EU	-10.529	0.042	0.049	33.106	-45.784	0.079	0.618
Canada	68.280	0.000	1.312	70.493	-3.699	0.001	-0.001
USA	775.987	-2.713	-72.738	931.990	-68.962	-0.069	-8.738
Mexico	4.319	0.016	0.352	2.887	0.174	-0.002	0.242
Rest Central America	0.595	0.012	0.003	0.657	0.009	-0.551	0.237
Brazil	-10.440	-0.065	0.066	0.771	-16.529	4.286	0.546
Rest South America	14.499	0.140	2.252	7.024	3.434	0.083	1.081
Northern Africa	2.083	-0.031	1.081	1.546	-0.445	0.041	0.133
West and East Africa	2.986	0.311	1.064	-1.248	-1.269	-0.016	3.731
South Africa	-2.274	0.057	0.565	-0.351	-3.676	0.018	0.346
Rest Western Europe	0.080	0.000	0.002	0.089	-0.016	0.001	0.000
Rest Eastern Europe	0.607	0.001	-0.454	1.389	-0.351	-0.000	-0.017
Turkey	0.237	-0.005	-0.006	0.467	-0.526	-0.012	0.681
Asia Stan	0.325	0.011	-1.518	2.008	-1.116	0.079	0.590
Russia	16.259	0.043	11.609	8.906	-5.133	-0.043	0.329
Middle East	15.084	0.058	12.957	1.411	0.168	0.036	0.967
India	-1.118	1.068	0.740	-5.766	-1.253	0.090	2.082
Rest of South Asia	0.817	-0.311	3.360	-0.499	-0.327	-0.044	-0.793
Korea	0.072	0.014	0.000	0.037	0.027	0.000	-0.000
China	-6.296	-0.059	6.345	-10.464	-3.337	0.055	0.971
Southeastern Asia	-3.004	0.067	0.064	-3.057	-0.983	0.080	0.378
Indonesia	-0.669	-0.025	0.000	0.110	-1.502	0.012	0.624
Japan	0.015	0.036	0.147	-0.210	0.024	0.000	0.014
Oceania	-5.201	-0.016	7.125	-8.429	-3.873	-0.004	0.082

Table 59 *Change in yield (% per Mtoe) JRC-IEMaizeEthUSDemand*

Countries	ARABLE	pdr	wht	grain	oils	sug	other crops
All countries in the world	**0.0128**	**-0.0004**	**0.0015**	**0.1918**	**0.0065**	**0.0033**	**-0.0006**
All countries in the EU	0.0121	-0.0025	0.0031	-0.0049	-0.0186	-0.0026	-0.0016
Canada	0.0555	0.0000	-0.0006	0.0183	-0.0022	-0.0009	-0.0011
USA	0.2090	-0.0050	-0.0082	0.0446	-0.0055	-0.0012	-0.0041
Mexico	-0.0059	0.0015	0.0029	0.0014	0.0017	-0.0002	0.0012
Rest Central America	-0.0142	-0.0001	0.0010	0.0005	-0.0001	-0.0009	0.0002
Brazil	0.0495	0.0001	0.0001	0.0000	0.0012	-0.0008	-0.0001
Rest South America	-0.0082	-0.0003	-0.0006	-0.0012	-0.0004	-0.0004	-0.0006
Northern Africa	-0.0020	0.0028	-0.0011	-0.0041	0.0045	-0.0007	-0.0038
West and East Africa	-0.0012	-0.0002	0.0015	-0.0004	-0.0006	-0.0004	0.0007
South Africa	0.0046	-0.0003	-0.0006	-0.0000	0.0019	-0.0001	-0.0005
Rest Western Europe	-0.0012	0.0000	0.0002	-0.0003	0.0018	0.0003	-0.0002
Rest Eastern Europe	0.0018	-0.0009	0.0020	-0.0027	0.0052	0.0002	0.0014
Turkey	-0.0022	-0.0001	0.0002	0.0006	-0.0010	0.0001	0.0023
Asia Stan	0.0013	-0.0009	0.0016	-0.0023	0.0080	-0.0010	-0.0032
Russia	-0.0001	0.0011	0.0019	0.0016	-0.0045	-0.0003	0.0030
Middle East	-0.0210	0.0019	-0.0102	0.0004	0.0014	0.0016	-0.0100
India	0.0024	-0.0004	-0.0005	0.0030	0.0008	-0.0004	-0.0032
Rest of South Asia	-0.0024	0.0003	0.0003	0.0002	0.0002	0.0002	0.0002
Korea	-0.0028	0.0002	0.0006	0.0006	0.0001	0.0000	0.0003
China	0.0021	0.0001	-0.0018	0.0032	0.0012	-0.0002	-0.0012
Southeastern Asia	0.0029	-0.0002	-0.0033	0.0026	0.0003	-0.0003	-0.0011
Indonesia	-0.0031	-0.0003	0.0000	-0.0002	-0.0002	-0.0002	-0.0002
Japan	0.0007	-0.0003	-0.0068	0.0156	-0.0016	-0.0001	-0.0046
Oceania	0.0023	0.0005	-0.0013	0.0037	0.0053	0.0003	0.0001

Table 60 Change in area (kha per Mtoe) JRC-IE WheatEthFraDemand

Countries	ARABLE	pdr	wht	grain	oils	sug	other crops
All countries in the world	**730.567**	**2.613**	**1132.175**	**-315.669**	**-164.789**	**71.751**	**8.143**
All countries in the EU	403.495	0.495	813.238	-277.020	-110.544	-0.955	-2.934
Canada	0.389	0.000	1.084	0.127	-0.827	0.003	0.008
USA	51.699	0.000	60.033	-4.718	-4.649	0.003	-0.030
Mexico	16.900	0.306	58.762	-38.821	-6.142	0.041	1.890
Rest Central America	1.460	0.001	0.849	0.110	0.005	0.008	0.103
Brazil	1.785	-0.036	0.012	0.156	-0.016	0.221	0.608
Rest South America	18.668	-0.880	-1.186	-6.915	-35.068	71.411	-4.774
Northern Africa	13.300	0.369	6.094	1.307	2.718	0.090	1.348
West and East Africa	11.307	-0.657	12.038	0.077	-0.610	-0.011	0.052
South Africa	13.169	-0.600	3.381	0.457	-1.420	0.022	4.269
Rest Western Europe	5.312	-0.010	1.046	-0.293	-1.562	0.158	1.052
Rest Eastern Europe	0.656	0.000	0.226	0.364	0.006	0.006	0.001
Turkey	6.677	0.001	7.954	-1.100	-0.277	0.004	0.022
Asia Stan	23.787	-0.006	23.589	-0.074	-0.172	-0.005	0.465
Russia	25.954	0.005	19.640	5.754	-0.193	0.108	0.530
Middle East	84.385	0.030	72.837	11.606	-1.077	0.138	0.270
India	16.079	-0.014	14.700	0.520	0.155	0.047	1.013
Rest of South Asia	1.656	1.273	1.117	-0.892	0.150	0.018	0.407
Korea	1.656	-0.026	3.935	-0.741	-0.154	0.087	-0.692
China	0.023	0.008	0.000	0.012	-0.000	0.000	0.003
Southeastern Asia	0.708	0.692	3.955	-3.266	-4.289	0.050	2.147
Indonesia	4.761	1.681	0.232	-0.829	1.725	0.226	0.943
Japan	0.932	-0.038	0.000	0.119	-0.640	0.024	1.236
Oceania:	0.058	0.010	0.053	-0.011	0.007	0.001	0.002

Table 61 Change in yield (% per Mtoe) JRC-IE WheatEthFraDemand

Countries	ARABLE	pdr	wht	grain	oils	sug	other crops
All countries in the world	**0.0531**	**0.0004**	**0.3230**	**-0.0557**	**0.0054**	**0.0498**	**-0.0004**
All countries in the EU	0.0782	0.0352	0.7024	-0.1343	-0.0087	0.0543	0.0362
Canada	-0.0144	0.0000	0.0116	-0.0022	-0.0026	-0.0005	-0.0019
USA	-0.0208	0.0004	0.0061	-0.0020	-0.0005	-0.0000	0.0005
Mexico	-0.0004	-0.0000	0.0069	-0.0001	-0.0001	-0.0000	0.0004
Rest Central America	-0.0018	-0.0006	0.0042	-0.0003	-0.0005	-0.0001	0.0006
Brazil	0.6320	-0.0006	-0.0001	-0.0003	0.0015	-0.0157	0.0002
Rest South America	-0.0068	-0.0006	-0.0013	-0.0005	-0.0005	-0.0005	-0.0008
Northern Africa	-0.0220	0.0206	-0.0295	0.0027	0.0067	0.0037	0.0008
West and East Africa	0.0019	-0.0010	0.0052	-0.0007	-0.0009	-0.0006	0.0005
South Africa	0.0079	-0.0004	-0.0015	-0.0003	0.0004	-0.0007	-0.0016
Rest Western Europe	-0.0069	0.0000	-0.0032	-0.0017	0.0001	-0.0005	-0.0027
Rest Eastern Europe	-0.0265	-0.0006	-0.0338	0.0023	0.0040	-0.0003	-0.0019
Turkey	-0.0265	0.0008	0.0078	0.0012	0.0007	0.0012	0.0027
Asia Stan	-0.0164	0.0004	-0.0152	-0.0067	0.0023	-0.0010	-0.0024
Russia	-0.0091	0.0002	0.0108	0.0016	-0.0016	0.0001	0.0020
Middle East	-0.0209	0.0036	-0.0115	0.0024	0.0020	0.0015	-0.0102
India	-0.0002	-0.0002	-0.0005	0.0006	-0.0000	0.0000	-0.0005
Rest of South Asia	-0.0008	0.0006	0.0005	0.0004	0.0004	0.0004	0.0004
Korea	-0.0006	0.0001	0.0003	0.0003	0.0001	0.0000	0.0001
China	0.0016	0.0001	-0.0010	0.0012	0.0017	-0.0000	-0.0026
Southeastern Asia	0.0007	-0.0007	-0.0121	0.0003	-0.0011	-0.0010	-0.0030
Indonesia	-0.0034	-0.0004	0.0000	-0.0003	-0.0003	-0.0003	-0.0003
Japan	-0.0004	0.0004	-0.0020	0.0012	0.0000	0.0004	-0.0003
Oceania	-0.0176	-0.0001	-0.0064	0.0006	0.0036	-0.0003	-0.0003

Table 62 Change in area (kha per Mtoe) JRC-IE BiodDEu

Countries	ARABLE	pdr	wht	grain	oils	sug	other crops
All countries in the world	**1927.836**	**-0.830**	**-34.855**	**-350.142**	**2344.617**	**-17.055**	**0.762**
All countries in the EU	496.197	0.232	-156.805	-233.511	900.276	-3.305	-1.027
Canada	48.687	0.000	26.459	-6.935	27.715	0.003	-0.014
USA	204.603	-0.087	16.579	-65.856	253.135	0.053	0.546
Mexico	2.255	0.006	0.467	0.395	0.593	0.011	0.192
Rest Central America	2.962	0.005	0.003	0.091	1.113	0.251	0.931
Brazil	419.264	-1.193	-2.118	-28.028	487.880	-14.863	-13.200
Rest South America	79.805	0.434	5.119	-0.659	73.045	-0.004	1.285
Northern Africa	9.515	-0.045	4.661	0.215	4.528	0.052	0.213
West and East Africa	95.864	-1.042	1.064	-1.148	93.316	0.004	3.291
South Africa	23.075	-0.082	0.674	-1.039	18.925	0.171	1.233
Rest Western Europe	0.674	0.000	0.134	0.389	0.126	0.005	0.001
Rest Eastern Europe	-0.148	0.001	1.569	-5.520	3.555	0.018	0.093
Turkey	18.772	-0.010	5.147	0.253	12.695	-0.003	0.772
Asia Stan	32.477	0.008	2.751	7.550	21.431	0.175	0.567
Russia	234.101	0.021	33.590	8.025	192.592	-0.133	0.073
Middle East	7.559	0.018	20.402	-17.797	3.893	0.041	1.364
India	2.726	0.035	-0.181	-0.477	6.527	-0.001	0.578
Rest of South Asia	1.391	0.245	1.295	-0.410	0.271	0.126	0.250
Korea	0.146	0.050	0.000	0.019	0.079	0.000	0.003
China	37.130	0.845	4.446	-3.880	32.999	0.063	1.835
Southeastern Asia	49.192	0.745	0.086	-1.268	47.002	0.269	1.235
Indonesia	32.892	-1.012	0.000	-0.138	32.987	-0.017	1.040
Japan	0.116	0.045	0.064	-0.080	0.086	0.001	0.004
Oceania:	128.580	-0.049	-0.261	-0.333	129.849	0.026	-0.504

Table 63 Change in yield (% per Mtoe) - JRC-IE BIODDeu

Countries	ARABLE	pdr	wht	grain	oils	sug	other crops
All countries in the world	**-0.0791**	**0.0009**	**-0.0941**	**-0.0672**	**0.1188**	**-0.0068**	**0.0022**
All countries in the EU	-0.3040	0.0068	-0.2296	-0.2159	2.3749	0.0458	-0.0007
Canada	-0.0306	0.0000	0.0045	-0.0029	0.0093	-0.0005	-0.0015
USA	-0.0810	-0.0002	0.0017	-0.0032	0.0166	0.0000	0.0001
Mexico	-0.0016	0.0004	0.0038	0.0000	0.0062	-0.0001	0.0009
Rest Central America	-0.0052	-0.0006	0.0008	-0.0006	0.0056	-0.0002	0.0010
Brazil	-0.5457	-0.0071	-0.0055	-0.0049	-0.0375	-0.0038	-0.0040
Rest South America	-0.0587	-0.0010	-0.0015	-0.0006	-0.0065	-0.0007	-0.0012
Northern Africa	-0.0188	0.0052	-0.0088	0.0030	-0.0235	0.0005	-0.0053
West and East Africa	-0.0191	-0.0012	0.0012	-0.0009	0.0161	-0.0006	0.0002
South Africa	-0.0155	-0.0004	-0.0011	-0.0003	-0.0106	-0.0008	-0.0019
Rest Western Europe	-0.0171	0.0000	-0.0016	-0.0018	-0.0109	-0.0002	-0.0036
Rest Eastern Europe	-0.0185	-0.0025	-0.0075	0.0105	-0.0532	-0.0026	-0.0088
Turkey	-0.0313	0.0001	0.0021	0.0008	0.0264	0.0006	0.0029
Asia Stan	-0.0260	0.0001	-0.0013	-0.0090	-0.1463	-0.0021	-0.0024
Russia	-0.0882	-0.0008	0.0042	0.0003	0.1626	-0.0022	-0.0006
Middle East	-0.0053	0.0028	-0.0176	0.0340	-0.0270	0.0015	-0.0151
India	-0.0029	0.0002	0.0004	0.0004	-0.0043	0.0001	-0.0007
Rest of South Asia	0.0008	0.0005	0.0004	0.0003	0.0003	0.0003	0.0003
Korea	-0.0053	0.0002	0.0004	0.0004	0.0000	0.0000	0.0002
China	-0.0122	0.0005	-0.0008	0.0018	-0.0110	0.0004	-0.0018
Southeastern Asia	0.0031	-0.0007	-0.0048	0.0006	-0.0192	-0.0012	-0.0039
Indonesia	0.0332	-0.0002	0.0000	-0.0002	-0.0002	-0.0002	-0.0002
Japan	-0.0005	0.0008	-0.0020	0.0068	-0.0049	0.0010	-0.0004
Oceania	-0.0590	0.0003	-0.0003	-0.0003	-0.1689	-0.0005	0.0004

Table 64 Change in area (kha per Mtoe) JRC-IE BiodIndo

Countries	ARABLE	pdr	wht	grain	oils	sug	other crops
All countries in the world	**425.287**	**-10.186**	**1.688**	**-66.245**	**515.060**	**-8.573**	**-3.930**
All countries in the EU	-12.377	-0.004	-1.330	8.047	-20.281	0.098	0.401
Canada	-14.193	0.000	-1.055	-8.957	-4.476	-0.001	0.014
USA	-58.013	0.106	1.637	-50.663	-10.119	-0.023	0.962
Mexico	-0.382	-0.001	-0.052	-0.181	-0.069	-0.001	0.010
Rest Central America	-0.624	-0.001	-0.001	-0.077	-0.060	-0.412	0.052
Brazil	-11.484	0.049	0.163	1.111	-6.554	-7.814	1.117
Rest South America	-2.149	0.017	-0.458	-1.949	-0.177	0.014	0.469
Northern Africa	-0.097	0.107	0.102	-0.076	-0.213	0.015	0.103
West and East Africa	-1.598	0.129	0.084	-1.673	-1.501	-0.007	1.521
South Africa	-2.164	0.034	0.047	-0.634	-1.738	0.004	0.145
Rest Western Europe	0.018	0.000	-0.007	0.034	-0.009	-0.000	0.000
Rest Eastern Europe	-0.029	0.000	-0.454	0.643	-0.222	-0.001	-0.022
Turkey	-1.659	-0.007	-1.602	-0.209	0.004	-0.007	0.348
Asia Stan	-1.199	0.006	-1.990	0.891	-0.706	0.049	0.435
Russia	8.181	0.023	5.555	4.682	-2.497	-0.078	0.133
Middle East	5.245	0.024	3.322	1.814	-0.020	0.014	0.365
India	-1.039	1.944	0.090	-3.525	-0.245	0.030	0.778
Rest of South Asia	-0.333	-0.033	-1.053	-0.104	-0.050	-0.008	0.481
Korea	-0.018	-0.020	0.000	0.009	-0.008	0.000	0.001
China	-2.502	-0.367	2.358	-5.633	0.406	0.006	0.608
Southeastern Asia	4.067	0.407	-0.020	-1.491	4.788	0.096	0.154
Indonesia	526.236	-12.549	0.000	-4.229	560.535	-0.543	-12.845
Japan	-0.044	-0.039	-0.022	0.029	-0.008	-0.001	0.001
Oceania:	-8.557	-0.011	-3.627	-4.105	-1.721	-0.002	0.840

Table 65 Change in yield (% per Mtoe) - JRC-IE BIODIndo

Countries	ARABLE	pdr	wht	grain	oils	sug	other crops
All countries in the worl	**0.0236**	**0.0004**	**0.0003**	**-0.0097**	**0.5560**	**-0.0046**	**0.0070**
All countries in the EU	0.0101	-0.0024	0.0011	0.0028	0.0108	-0.0010	-0.0009
Canada	-0.0030	0.0000	0.0001	-0.0022	-0.0014	-0.0000	0.0006
USA	-0.0076	0.0003	0.0003	-0.0024	-0.0006	-0.0000	0.0004
Mexico	0.0003	-0.0001	-0.0003	-0.0001	-0.0007	-0.0000	0.0001
Rest Central America	-0.0064	0.0001	-0.0002	-0.0001	-0.0003	-0.0006	0.0001
Brazil	-0.0601	0.0002	0.0002	0.0001	0.0006	0.0018	-0.0001
Rest South America	0.0013	0.0001	0.0001	0.0003	0.0000	0.0000	-0.0001
Northern Africa	0.0012	-0.0023	0.0002	0.0009	0.0018	-0.0004	-0.0039
West and East Africa	-0.0000	-0.0001	0.0000	-0.0003	-0.0004	-0.0002	0.0003
South Africa	0.0024	-0.0001	-0.0000	0.0000	0.0009	-0.0000	-0.0002
Rest Western Europe	-0.0004	0.0000	0.0002	-0.0001	0.0010	0.0002	-0.0001
Rest Eastern Europe	0.0021	-0.0009	0.0020	-0.0013	0.0033	0.0002	0.0018
Turkey	0.0005	-0.0003	-0.0004	-0.0001	-0.0000	-0.0001	0.0011
Asia Stan	0.0017	-0.0005	0.0019	-0.0009	0.0051	-0.0006	-0.0024
Russia	-0.0001	0.0006	0.0010	0.0009	-0.0022	-0.0005	0.0012
Middle East	-0.0077	0.0008	-0.0021	-0.0019	0.0013	0.0008	-0.0036
India	0.0010	-0.0007	-0.0001	0.0018	0.0001	-0.0002	-0.0012
Rest of South Asia	0.0007	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001	-0.0001
Korea	0.0005	0.0000	0.0001	0.0002	0.0000	0.0000	0.0000
China	0.0004	0.0001	-0.0008	0.0016	-0.0002	-0.0001	-0.0009
Southeastern Asia	0.0020	-0.0001	0.0010	0.0012	-0.0020	-0.0003	-0.0005
Indonesia	0.6274	0.0044	0.0000	0.0034	0.0121	0.0035	0.0030
Japan	-0.0002	-0.0002	0.0006	-0.0025	0.0001	-0.0003	-0.0007
Oceania	0.0055	-0.0001	0.0006	0.0015	0.0021	-0.0001	-0.0014

4. IMPACT

Table 66 Land cover change per Mtonne of feedstock increase (Not Mtoe)

crop	Full name	**US Maize Ethanol**		**US Wheat Ethanol**		**EU Coarse grains Ethanol**		**EU Wheat Ethanol**	
		Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
cass	Cassava and Other Roots & Tubers	0.0	-0.1	-0.0	-0.1	0.0	-0.3	-0.0	-0.1
chkp	Chickpea	-0.0	-0.2	-0.1	-0.5	-0.1	-0.6	-0.1	-0.5
cott	Cotton	-0.6	-2.6	-0.8	-2.6	-1.5	-6.3	-0.8	-2.6
grnd	Groundnut	-0.1	-1.2	-0.1	-0.6	-0.1	-3.0	-0.1	-0.6
maiz	Maize	**9.8**	**44.6**	-0.1	1.4	5.5	23.2	-0.1	1.4
mill	Millet	-0.0	-2.0	-0.1	-1.4	-0.1	-5.0	-0.1	-1.4
ogrn	Other Grains	**1.2**	**8.8**	**0.6**	**3.7**	**11.3**	**81.8**	0.6	3.7
othr	Other crops	-1.0	-7.3	-2.3	-6.9	-2.5	-18.4	-2.3	-6.9
pigp	Pigeonpea	-0.0	-0.1	-0.0	-0.2	-0.0	-0.3	-0.0	-0.2
pota	Potatoes	-0.1	-0.5	-0.2	-0.9	-0.3	-1.2	-0.2	-0.9
rice	Rice	-2.0	-2.3	-0.5	-0.4	-2.3	-3.2	-0.5	-0.4
sorg	Sorghum	-0.0	-1.2	-0.1	-1.0	-0.1	-3.3	-0.1	-1.0
soyb	Soybean	-0.4	-9.2	-0.3	-6.8	-0.7	-16.9	-0.3	-6.8
subf	Sub-Tropical & Tropical Fruits	-0.4	-1.2	-0.4	-1.1	-1.0	-3.2	-0.4	-1.1
sugb	Sugar Beets	-0.2	-0.4	-0.2	-0.4	-0.4	-0.8	-0.2	-0.4
sugc	Sugar Cane	0.1	0.1	0.1	0.1	0.1	0.3	0.1	0.1
swpy	Sweet Potatoes & Yams	0.0	-0.1	-0.0	0.1	0.0	-0.1	-0.0	0.1
temf	Temperate Fruits	-0.6	-0.7	-0.6	-0.7	-1.3	-1.7	-0.6	-0.7
vege	Vegetables	-0.9	-1.5	-0.9	-1.5	-2.2	-3.5	-0.9	-1.5
whea	Wheat	-0.9	-3.7	**20.6**	**51.2**	-2.5	-15.1	**20.6**	**51.2**
	Total	**3.8**	**19.3**	**14.6**	**31.4**	**1.9**	**22.5**	**14.6**	**31.4**

Table 67 Yield change per Mtonne of feedstock increase (NOT Mtoe)

crop	**Full name**	**US Maize Ethanol**		**US Wheat Ethanol**		**EU Coarse grains Ethanol**		**EU Wheat Ethanol**	
		Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
cass	Cassava and Other Roots & Tubers	1.01	0.62	0.82	0.51	2.29	1.42	0.82	0.51
chkp	Chickpea	0.07	0.07	0.09	0.09	0.17	0.16	0.09	0.09
cott	Cotton	0.02	0.01	0.02	0.01	0.04	0.03	0.02	0.01
grnd	Groundnut	0.12	0.08	0.13	0.08	0.30	0.19	0.13	0.08
maiz	Maize	1.70	0.93	0.52	0.29	1.74	0.96	0.52	0.29
mill	Millet	0.08	0.06	0.07	0.05	0.19	0.14	0.07	0.05
ogrn	Other Grains	0.31	0.24	0.31	0.23	1.71	1.29	0.31	0.23
othr	Other crops	0.65	0.28	0.70	0.30	1.57	0.68	0.70	0.30
pigp	Pigeonpea	0.05	0.04	0.06	0.05	0.13	0.10	0.06	0.05
pota	Potatoes	0.94	0.66	1.01	0.71	2.22	1.57	1.01	0.71
rice	Rice	0.14	0.09	0.16	0.10	0.28	0.18	0.16	0.10
sorg	Sorghum	0.23	0.16	0.19	0.13	0.56	0.37	0.19	0.13
soyb	Soybean	0.05	0.04	0.03	0.02	0.09	0.06	0.03	0.02
subf	Sub-Tropical & Tropical Fruits	0.28	0.18	0.27	0.17	0.69	0.44	0.27	0.17
sugb	Sugar Beets	1.07	0.74	1.04	0.73	2.48	1.73	1.04	0.73
sugc	Sugar Cane	2.19	1.49	2.14	1.46	5.06	3.44	2.14	1.46
swpy	Sweet Potatoes & Yams	0.76	0.54	0.70	0.50	1.90	1.34	0.70	0.50
temf	Temperate Fruits	0.17	0.12	0.17	0.11	0.40	0.28	0.17	0.11
vege	Vegetables	0.32	0.20	0.31	0.19	0.77	0.48	0.31	0.19
whea	Wheat	0.25	0.16	1.05	0.67	0.60	0.39	1.05	0.67

APPENDIX II: Marginal CO_2 emissions from GTAP Land Use data

1. EU WHEAT ETHANOL

Table 68: Change in Land cover type for EU Wheat ethanol scenario

ha/Mtoe				
	Loss of forest	Forest gain from pasture	Gain in cropland	Loss of pasture
USA	-11568		57680	-46128
EU27	-270176		352288	-82096
BRAZIL		17504	39936	-57424
CAN	-59088		98992	-39890
JAPAN	-535		695.25	-156.78125
CHIHKG		36144	-6864	-29280
INDIA	-4048		12352	-8290
C_C_Amer	-1864		9304	-7424
S_o_Amer		66768	17556	-84320
E_Asia		1223	-63	-1144
Mala_Indo		5320	-3912	-1413.75
R_SE_Asia		5496	-2564	-2951.25
R_S_Asia	-1058		4600	-3536
Russia		94304	-16488	-77840
Oth_CEE_CIS		9812	43200	-53088
Oth_Europe		720	1324.75	-2045.5
MEAS_NAfr		262.375	23308	-23536
S_S_AFR		3360	141552	-145088
Oceania	-854		21570	-20672
Total	-108288		794496	-686336

Table 69: CO_2 Emissions for EU Wheat ethanol scenario

Tons CO_2/Mtoe					
	Emissions from forest loss	Sequestration to Forest gain	Sequestration from gain in crop area	Emissions from loss of Pasture	Tons CO_2/Mtoe
USA	-8791680	0	1038240	-4889568	-12643008
EU27	-80242272	0	6341184	-12806976	-86708064
BRAZIL	0	2870656	718848	-4134528	-545024
CAN	-41657040	0	1781856	-7818440	-47693624
JAPAN	-307090	0	12514.5	-13326.40625	-307901.9063
CHIHKG	0	8060112	-123552	-5738880	2197680
INDIA	-2323552	0	222336	-1624840	-3726056
C_C_Amer	-723232	0	167472	-534528	-1090288
S_o_Amer	0	10949952	316008	-6071040	5194920
E_Asia	0	272729	-1134	-97240	174355
Mala_Indo	0	1792840	-70416	-120168.75	1602255.25
R_SE_Asia	0	1852152	-46152	-250856.25	1555143.75
R_S_Asia	-991346	0	82800	-300560	-1209106
Russia	0	36967168	-296784	-12143040	24527344
Oth_CEE_CIS	0	3551944	777600	-8281728	-3952184
Oth_Europe	0	260640	23845.5	-319098	-34612.5
MEAS_NAfr	0	15480.125	419544	-1929952	-1494927.875
S_S_AFR	0	433440	2547936	-6238784	-3257408
Oceania	-331352	0	388260	-2025856	-1968948
				TOTAL emissions	**-129379454**
				g CO2/MJ (30 years	**-3091.504284**

2. EU BIODIESEL

Table 70: Change in Land cover type for EU Biodiesel scenario

ha/Mtoe				
	Loss of forest	Forest gain from pasture	Gain in cropland	Loss of pasture
USA		4848	12624	-17456
EU27	-103056		135368	-32284
BRAZIL	-6928		36360	-29408
CAN	-17576		29296	-11718
JAPAN	-126		186.25	-53.75
CHIHKG		14784	-1472	-13280
INDIA	-4276		9184	-4914
C_C_Amer		324	3252	-3568
S_o_Amer		22800	13344	-36128
E_Asia		493	-50	-456
Mala_Indo	-44		676	-636.5
R_SE_Asia		2224	-944	-1237.25
R_S_Asia	-433.5		1912	-1484
Russia		39152	-7440	-31696
Oth_CEE_CIS		5324	12928	-18272
Oth_Europe		550	327.8125	-888.5
MEAS_NAfr		152.375	8964	-9120
S_S_AFR	-3120		67872	-64896
Oceania		515	8492	-9056
Total	-44416		330880	-286720

Table 71: CO_2 Emissions for EU Biodiesel scenario

Tons CO_2/Mtoe					
	Emissions from forest loss	Sequestration to Forest gain	Sequestration from gain in crop area	Emissions from loss of Pasture	Tons CO_2/Mtoe
USA	0	1061712	227232	-1850336	-561392
EU27	-30607632	0	2436624	-5036304	-33207312
BRAZIL	-2688064	0	654480	-2117376	-4150960
CAN	-12391080	0	527328	-2296728	-14160480
JAPAN	-72324	0	3352.5	-4568.75	-73540.25
CHIHKG	0	3296832	-26496	-2602880	667456
INDIA	-2454424	0	165312	-963144	-3252256
C_C_Amer	0	53136	58536	-256896	-145224
S_o_Amer	0	3739200	240192	-2601216	1378176
E_Asia	0	109939	-900	-38760	70279
Mala_Indo	-41228	0	12168	-54102.5	-83162.5
R_SE_Asia	0	749488	-16992	-105166.25	627329.75
R_S_Asia	-406189.5	0	34416	-126140	-497913.5
Russia	0	15347584	-133920	-4944576	10269088
Oth_CEE_CIS	0	1927288	232704	-2850432	-690440
Oth_Europe	0	199100	5900.625	-138606	66394.625
MEAS_NAfr	0	8990.125	161352	-747840	-577497.875
S_S_AFR	-951600	0	1221696	-2790528	-2520432
Oceania	0	101970	152856	-887488	-632662
				TOTAL emissions	**-47474549**
				g CO2/MJ (30 years)	**-1134.39782**

3. US MAIZE ETHANOL

Table 72: Change in Land cover type for US Maize ethanol scenario

ha/Mtoe				
	Loss of forest	Forest gain from pasture	Gain in cropland	Loss of pasture
USA	-22480		67952	-45504
EU27	-7984		12984	-5008
BRAZIL	-2512		11244	-8720
CAN	-9504		17156	-7648
JAPAN	-268		347.25	-79.15625
CHIHKG		3264	1760	-5024
INDIA	-844		1968	-1134
C_C_Amer	-940		3020	-2080
S_o_Amer		5280	6288	-11552
E_Asia		446	55	-496
Mala_Indo		1296	-900	-398.25
R_SE_Asia		528	-80	-438.75
R_S_Asia	-144		708	-564
Russia	18944		-3208	-15752
Oth_CEE_CIS	-96		6840	-6816
Oth_Europe	-100		226.125	-131.75
MEAS_NAfr	62.625		3144	-3216
S_S_AFR	-2832		30128	-27200
Oceania	62		4890	-4928
Total	-17920		164608	-146688

Table 73: CO_2 Emissions for US Maize ethanol scenario

Tons CO_2/Mtoe					
	Emissions from forest loss	Sequestration to Forest gain	Sequestration from gain in crop area	Emissions from loss of Pasture	Tons CO_2/Mtoe
USA	-17084800	0	1223136	-9965376	-25827040
EU27	-2371248	0	233712	-1812896	-3950432
BRAZIL	-974656	0	202392	-1430080	-2202344
CAN	-6700320	0	308808	-3319232	-9710744
JAPAN	-153832	0	6250.5	-17651.84375	-165233.3438
CHIHKG	0	727872	31680	-1120352	-360800
INDIA	-484456	0	35424	-252882	-701914
C_C_Amer	-364720	0	54360	-341120	-651480
S_o_Amer	0	865920	113184	-1894528	-915424
E_Asia	0	99458	990	-110608	-10160
Mala_Indo	0	436752	-16200	-134210.25	286341.75
R_SE_Asia	0	177936	-1440	-147858.75	28637.25
R_S_Asia	-134928	0	12744	-190068	-312252
Russia	5891584	0	-57744	-6174784	-340944
Oth_CEE_CIS	-28512	0	123120	-2467392	-2372784
Oth_Europe	-29700	0	4070.25	-47693.5	-73323.25
MEAS_NAfr	9519	0	56592	-189744	-123633
S_S_AFR	-863760	0	542304	-3508800	-3830256
Oceania	24056	0	88020	-975744	-863668
				TOTAL emissions	**-52097453**
				g CO2/MJ (30 years)	**-1244.861472**

4. PALM OIL BIODIESEL FROM MALA-INDO

Table 74: Change in Land cover type for Mala-Indo Biodiesel sceanario

ha/Mtoe				
	Loss of forest	Forest gain from pasture	Gain in cropland	Loss of pasture
USA	-624		2864	-2272
EU27	-2496		5312	-2852
BRAZIL	-1296		3716	-2416
CAN	-2952		4892	-1942
JAPAN	-56		57.75	-1.5
CHIHKG	-336		1136	-800
INDIA	-2744		4736	-1977
C_C_Amer		72	404	-504
S_o_Amer	-160		2920	-2800
E_Asia		1	14.5	-16
Mala_Indo	-28944		29028	-78.75
R_SE_Asia	-424		408	3
R_S_Asia	-257		812	-552
Russia		3136	-112	-3064
Oth_CEE_CIS	-92		1544	-1568
Oth_Europe	-6		48.125	-41
MEAS_NAfr		7.625	852	-864
S_S_AFR	-3344		8000	-4736
Oceania	-118		1736	-1600
Total	-40704		68480	-28160

Table 75: CO_2 Emissions for Mala-Indo Biodiesel sceanario

Tons CO_2/Mtoe					
	Emissions from forest loss	Sequestration to Forest gain	Sequestration from gain in crop area	Emissions from loss of Pasture	Tons CO_2/Mtoe
USA	-474240	0	51552	-497568	-920256
EU27	-741312	0	95616	-1032424	-1678120
BRAZIL	-502848	0	66888	-396224	-832184
CAN	-2081160	0	88056	-842828	-2835932
JAPAN	-32144	0	1039.5	-334.5	-31439
CHIHKG	-192864	0	20448	-178400	-350816
INDIA	-1575056	0	85248	-440871	-1930679
C_C_Amer	0	11808	7272	-82656	-63576
S_o_Amer	-62080	0	52560	-459200	-468720
E_Asia	0	223	261	-3568	-3084
Mala_Indo	-27120528	0	522504	-26538.75	-26624562.75
R_SE_Asia	-397288	0	7344	1011	-388933
R_S_Asia	-240809	0	14616	-186024	-412217
Russia	0	1229312	-2016	-1201088	26208
Oth_CEE_CIS	-27324	0	27792	-567616	-567148
Oth_Europe	-1782	0	866.25	-14842	-15757.75
MEAS_NAfr	0	449.875	15336	-50976	-35190.125
S_S_AFR	-1019920	0	144000	-610944	-1486864
Oceania	-45784	0	31248	-316800	-331336
				TOTAL emissions	**-38950607**
				g CO2/MJ (30 years)	**-930.7193937**

APPENDIX III: WHAT DO WE KNOW ABOUT PEATLAND DRAINAGE EMISSIONS?

What % of new oil palm plantations are on peat?

There is a conspicuous lack of official statistics on the % of recent or planned palm oil plantations on peat: information can often only be obtained indirectly or from occasional admissions in “grey” literature. The fraction of oil-palm on peat increases with time, firstly because the technology for growing palm on peatland is newer than most of the established plantations, and secondly, because in some areas there is little non-peat land still available.

Malaysia

The Tropical Peat Research Institute (TPRI, 2009) (quoted in “Status of Peatlands in Malaysia” July 2009 report by Wetland International), displayed a conference poster showing that that the area of oil palm on peatlands in Malaysia increased by roughly 200 kha between 2003 and 2008. The Malaysian Palm Oil Board report that the total area of oil palm in Malaysia increased by roughly 600 kha in the same period. So according to this source, roughly **one third** of those new plantations are on peat. The great majority of the newly-converted peatland was in Sarawak state, where future expansion is most likely, because of land availability constraints in peninsula Malaysia. In Malaysia, land use policy is the responsibility of state governments, and in Sarawak there is no specific protection for peatland.
(The same status report gives figures showing that 12% of *existing* Malaysian peat plantations were on peat in 2008; and 23% of *existing* plantations in Sarawak, where most of the expansion is occurring.)

Indonesia

In Indonesia, palm oil is mostly grown in Sumatra, and some in Papua. (Hooijer, 2006) superimposed maps of concessions granted for palm oil plantations in these areas, on maps of peatland (table 4 in (Hooijer, 2006), and found that 25% of concessions were on peatland. It has been reported that in many cases the concession was used to allow logging of the forest, whilst the oil palm plantations were never established. However, there is no particular reason to suppose that this practice was more concentrated on peat-land forest than on other forest, so it is not clear in which direction this behaviour would change the figure for the fraction of new oil-palm plantation on peat.

Hooijer, (2006) argues that the % oil-palm on peat is likely to rise in future, and estimates that probably more than 50% of *future* palm oil plantations will be on peat. This figure has been confirmed by recent surveys, in (Casson et al., 2007) quoted in (CIFOR, 2009). Uryu (2008) reports that in Riau province of central Sumatra, the fraction of peat-forest in the total annual deforestation area has risen from 33% in 1982-‘98 to between 62% and 80% in 2000-2007.

In 2007 the Indonesian government announced a moratorium on peat land conversion, but this was reversed in February 2009, in the form of a decree stipulating that concessions for development of peatland would in future be granted ONLY for palm oil plantations, which can only increase the % of oil-palm on peat in the future.

Conclusion: at least 33% of new plantations in Indonesia and Malaysia are likely to be on peat.

Historically, the usual method of clearing the remaining standing biomass is fire, not only losing all the standing biomass to CO_2 but also sometimes setting fire to areas of peat which have been dried by unusually dry weather (as in the disastrous fires of 1997) or nearby drainage. Use of fire has been banned for a number of years, but is still extensively used, especially by smallholders who cannot afford heavy forest-clearing equipment. However, we shall not include peat fire losses in our estimates. The biomass is left to rot in piles (Verver, 2008), decaying quickly to produce predominantly CO_2 (rather than methane).

Depth of drainage

Peat is drained establishing oil-palm plantations. It allows air to penetrate the porosity of the peat, and peat oxidizes. Adequate drainage requires a costly and dense network of drainage canals. Peat is not deliberately drained for logging, although some shallow and temporary drainage sometimes happens by accident though channels made by illegal loggers for floating away the logs (drainage channels get filled up if not maintained).

A few access channels do not provide anywhere near sufficient drainage for planting palms (this requires a dense network of drainage ditches and canals), but may nevertheless cause some local emissions from peat oxidation (however, it has been reported that peat oxidation sometimes does not start until a threshold drainage depth of 20cm is reached, so small drainage depths may not in fact be damaging (Couwenberg, 2009)).

The initial peat drainage depth for palm oil is usually 80-95cm (it is possible still to grow palms with less initial drainage; for example to 60 cm, but then yield is reduced). A survey in Sumatra (table 7 in (Uryu, 2008) showed the average drainage depth of palm oil plantations on peat was 85cm (so the initial drainage depth was greater: values up to 165cm were recorded). The Indonesian decree allowing drainage of peat forest for oil palm specifies that drainage should be limited to 80cm for “sustainable” production of palm oil.

However, subsidence (which is initially fast) means that the ground level approaches the water table, and the drainage must be deepened when the surface sinks to around 30cm above the water level. Then the rate of subsidence increases again.

Rate of oxidation

The rate of oxidation of peat can be estimated in two ways:

- From measurements of fall in ground-level, using an assumed carbon density in the lost material and an estimated fraction due to compaction.
- By direct measurements of gas fluxes (various techniques)..

The first method is much easier and gives more consistent results. Flux measurements vary enormously with the weather and local position. Furthermore, they generally include a large contribution from root respiration, which should not count as an emission, as it comes from carbon fixed in the leaves. Compensating for all this is very uncertain. Thus a recent comprehensive review (Couwenberg et al., 2009) concludes that it is safer to use subsidence measurements as a basis for estimating the average rate of peat oxidation.

(Couwenberg, 2009) goes on to conservatively estimate of the rate of peat oxidation based on the subsidence data available for palm oil plantations (fig. 2 in that paper). Points for oil palm show that for drainage depth > 50cm, subsidence tends to level off[34] at about 4.5 cm/y (average for measurements 13-21 years after drainage.

The subsistence measurements probably include some residual root decay from the forest as well as some continuing root development by the oil-palms. To a first approximation we suppose these cancel so only peat oxidation is counted (they are anyway quite small effects compared to peat oxidation), Plantation litter (mostly palm fronds) is reported to decompose rapidly on the surface, and not to enter the soil, but anyway any contribution to soil carbon stock from this source would be taken into account in the measurement of ground level.

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[34] although “recent evidence suggests there is further increase in subsidence until drainage depths of ~1m are attained.”, and this is consistent with measurements on European peat

Converting subsidence measurements to CO_2 emissions depends on what fraction of the subsidence is assumed to come from oxidation (the rest is compaction). Looking at data on all types of peat in the world shows this fraction can range from 35-100%, and (Couwenberg, 2009) considers that the fraction of subsidence due to oxidation of tropical peat must be *at least* 40%, and uses this figure together with his chosen subsidence rate of 4.5cm/y estimate that the rate of peat oxidation must be *at minimum*

45 **tCO_2/ha/y**. But the best-estimate value would use an average oxidation-fraction of 61%, estimated for Malaysian peat using the bulk-density profiles of (Salmah, 1992), and rounded to 60% by (Wösten, 1997). Assuming a symmetrical uncertainty range, the rate of CO_2 loss from peat oxidation based on subsidence measurements is thus **57 ± 12 tCO_2/ha/y.**

This figure is still conservative because it adopts the bulk volumetric carbon density of 0.068 gC/cm^3 assumed by Couwenberg to arrive at the *minimum* level of peat-drainage emissions. The density figure is based on the average of measurements from deep peat; however, near the surface peat is generally more compacted, and especially after preparation for oil palm plantation (Couwenberg personal communication, 2010]. For comparison, (Wösten, 1997) uses 0.1 gC/cm^3, and (Brown, 1993) uses 0.15 gC/cm^3. The true emissions could thus easily be more than double those estimated above.

Stop press

A new paper (Ywih, 2010)[35] reports many measurements of bulk C density in palm oil plantations on peat measured in the top 50cm.of soil, up to five years after establishment. It is constant at about 0.134 gC/cm^3: double the value assumed by us and Couwenberg. This would appear to confirm that our estimate of CO_2 loss from peat oxidation is indeed too low, and should be revised up to 112 ± 24 tCO_2/ha/y.

For comparison (Reijnders, 2008) use 46 ± 9 CO_2/ha/y based on a study of flux measurements in Sumatra, (Wicke, 2008) averages IPCC values with measurements for shallow drainage depths to get 39 CO_2/ha/y, and (Fargione, 2008) estimates 64 ± 9 tCO_2/ha/y, based on IPCC and flux measurements. (Couwenberg, 2009) accidentally reports only the lower limit of emissions estimated by (Germer2008) using the subsidence method: their range is actually 33±16 tCO2/ha/y., as discussed below.
These are the same data sources collected in a report by Brinkman consultancy for the Round-table on Sustainable Palm Oil (RSPO, 2009], (but this description of peat oxidation rates disappeared in a later draft of the same report).

We investigated why Germer's value is lower than Couwenberg's, since both are apparently based on the same subsidence measurements. The reason [personal communication, J. Couwenberg 2010] is connected to the reduction in the rate of subsidence with time after drainage. Couwenberg obtained the original subsidence measurements, and used the rate of subsidence (4.5cm/y) for the measurements between 13 and 21 years after drainage. However, Germer did not have access to the original data, and used the long-term subsidence rate (2cm/year) which (Wösten, 1997) had projected for the period 28-40+ years after drainage, using a fitted model. But this is not relevant to an oil palm plantation, where the plantation is re-drained when the palms are renewed after ~25 years (furthermore often with intermediate deepening of drainage). Therefore Couwenberg's later revisit of the data gives a better estimate of the average subsidence rate over the lifetime of a plantation.

IPCC values for CO_2 emissions from agriculture on peat are for arable crops not requiring much drainage, and are not applicable to oil palm plantations, which needs deep drainage. They are based on the limited data available in 1996.

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[35] Curiously, this paper fails to consider that the level of the soil is decreasing with time, and so manages to conclude that soil carbon is not being lost at all!

The emissions from peat oxidation continue through the entire lifetime of the plantation, and should therefore be best included in the annual "direct" GHG emissions calculation. However, if emissions from peat oxidation have to be treated as if they are one-off land use change emissions, it is necessary to multiply them by the number of years over which the one-off emissions are spread. Therefore, if emissions from peat oxidation are to be spread over **20 years, a total of 1140+/- 240 tonnes CO_2/ha,** needs to be considered, and for spreading **over 30-years they are 1710 +/- 360 tonnes CO_2/ha**. As mentioned before, these extra emissions should be applied to 33% of the production of palm oil in Indonesia and Malaysia.

Other peat-related emissions are ignored

The net emissions (in CO_2 equivalents) of other greenhouse gases are rather uncertain, and reviews show them to considerably smaller than the uncertainty in the CO_2 emissions (Couwenberg 2009; Germer, 2008); we shall ignore them.

Melling showed that *in areas affected by drainage*, peat forest can give even higher emissions (per m^2) than palm oil plantations[36] (Verver, 2008). Thus, drainage for palm oil plantations causes emissions not only on the plantation area but also on any nearby peat-forest. These emissions should be ascribed to palm oil plantations, but there is insufficient data to estimate them.

Although illegal, fire is still often used to clear vegetation, especially by smallholders who cannot afford heavy machinery. But drainage can allow peat fires to break out years later, especially on the unpatrolled forest dried by the deep drainage system of a nearby plantation. These fires probably cause significant emissions, but lower than the emissions from peat oxidation, according to the review (Couwenberg, 2009). In the aftermath of the disastrous Indonesian fires, (Hooijer, 2006) and others estimated much higher emissions from peatland fires than later workers (although the emissions from *peat oxidation* in that paper are in line with later work). Due to the great range of uncertainty in the estimates of emissions due to fire, and how much of it should be attributed to oil palm plantations, we have not included fire-related emissions.

Undisturbed peat forest must sequester carbon (for peat to be accumulated in the first place) but the foregone sequestration is much smaller than the uncertainty in peat decomposition rates, so we shall ignore it.

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[36] Melling was also involved in a carbon balance of palm oil plantation on peat which terminates five years into the life of the new plantation. At this point the growth of the palms (together with the fossil carbon savings from the harvest) was estimated to almost compensate the loss of below-ground carbon. However, palm growth slows with time, and over the lifetime of a palm plantation on peat, all LCAs show clear carbon debits (see review: [Couwenberg 2009])

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European Commission

EUR 24485 EN – Joint Research Centre – Institute for Energy
Title: Indirect Land Use Change from increased biofuels demand - Comparison of models and results for marginal biofuels production from different feedstocks
Author(s): Robert Edwards, Declan Mulligan and Luisa Marelli
Luxembourg: Publications Office of the European Union
2010 – 145 pp. – 21 x 29.7 cm
EUR – Scientific and Technical Research series – ISSN 1018-5593
ISBN 978-92-79-16391-3
doi:10.2788/54137

Abstract

This study compares the ILUC results produced by different economic models for marginal increases in biofuel production from different feedstocks. The work is the result of a survey of marginal calculations launched by the JRC-IE during 2009, involving some of the best known models worldwide. The modellers were requested by JRC-IE to run scenarios corresponding as closely as possible to the following specification (e.g. marginal runs against existing baseline of the following scenarios):
A marginal extra ethanol demand in EU
B marginal extra biodiesel demand in EU
C marginal extra ethanol demand in US
D marginal extra palm oil demand in EU
The results from the different models and various scenarios are compared in this report in terms of hectares of ILUC per Mtoe of biofuels produced (marginal land use change).
In the EU ethanol scenarios, the total estimated ILUC (in the world) ranges from 223 to 743 kHa per Mtoe. For most of the EU ethanol scenarios the models project that the largest share of ILUC would occur outside the EU
In the EU biodiesel scenarios, total ILUC ranges from 242 to 1928 kHa per Mtoe
In all of the EU biodiesel scenarios the models project that the largest share of LUC would occur outside the EU
Although this is not the main purpose of this report, the range of GHG emissions which one could expect to correspond to the areas of LUC reported by all the models has been roughly estimated.
The report provides deep analysis of the reasons of differences between models and gives fundamental indications to policy makers on how to address the issue of ILUC in legislation.

The mission of the JRC is to provide customer-driven scientific and technical support for the conception, development, implementation and monitoring of EU policies. As a service of the European Commission, the JRC functions as a reference centre of science and technology for the Union. Close to the policy-making process, it serves the common interest of the Member States, while being independent of special interests, whether private or national.

LB-NA-24-485-EN-C

EUROPEAN COMMISSION

ISBN 978-92-79-16391-3

9 789279 163913

Publications Office