Green*ergy* Response to the EU Commission Consultation on Indirect Effects of Biofuels

Executive Summary

Upon review of the recent attempts to model the indirect land use change and associated indirect greenhouse gas impacts of EU biofuels policy, Green*ergy* considers that the econometric models do not accurately reflect the dynamic system of agricultural development and land use. We recommend that policy be implemented without delay at EU Member State Level to guarantee biofuels' direct sustainability and high greenhouse gas savings, through the execution of RED. Further research is required to analyse ILUC, with an emphasis on observation and analysis, and practical mitigation measures.

In the meantime, to avoid greenhouse gas emissions from ILUC, mitigation actions as proposed by Ecometrica[1], E4Tech[2] and UK LowCVP[3] [add references as foot note], should be pursued wherever possible. This will be most effective if implemented as an integrated international policy to cover agricultural development, resource efficiency and biocarbon preservation. Green*ergy* has proposed a strategy to achieve this using available technology, including BioCarbonTracker[4] [add reference as foot note].

Introduction

As experts meet at the UN Convention on Biodiversity to discuss the loss of important biodiversity habitats, and the UN FAO announces the need for action on food security to meet the likely doubling of food demand in the next 40 years, it is clear that agriculture represents the single largest driver of global land use change.

Where national and international governance do not protect land, economic operators involved in agriculture and forestry dictate the fate of the world's terrestrial biocarbon reserves and important habitats. It is therefore of global importance that agricultural producers take full account and responsibility for their land use decisions. With these pressures on land, effective regulation is required to ensure that all agricultural production is controlled sustainably and efficiently.

At the same time the threat to all ecosystems and agricultural systems from climate change demands a rapid transition to a low carbon economy including the delivery of low carbon alternatives to fossil fuels. Biofuels can contribute important greenhouse gas savings where they have taken full account of their lifecycle emissions, and their production does not cause environmental damage.

Within the European Renewable Energy Directive are mandatory sustainability criteria for biofuel production. By achieving these criteria, biofuels will be pioneering the practices and regulations that can guide sustainable land use decisions, protect carbon stocks and biodiverse areas against uncontrolled agricultural expansion. Any delay in implementation of the RED allows the continued incentivisation of potentially unsustainable biofuels in EU markets, and continued dependency on and emissions from fossil fuels. In addition any reduction in the scope of RED will send the wrong economic drivers for the production and use of sustainable biofuels in the EU.

1) Do you consider that the analytical work referred to above, and/or other analytical work in this field, provides a good basis for determining how significant indirect land use change resulting from the production of biofuels is?

None of the models used provides an adequate basis to understand ILUC or to be used to determine policy on biofuels. The analytical work provides a wide range of possible outcomes, but given the complexity of markets in agricultural commodities and the multiple factors involved in land use change, it is very difficult to assess whether any of these results are reliable.

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[1] Ecometrica 2010 (unpublished) Analysis of the effect of Regional Mitigation Actions on Land Use Change.

[2] E4Tech, 2010. A causal descriptive approach to modelling the GHG emissions associated with the indirect land use impacts of biofuels.

[3] LowCVP response to Commission ILUC Consultation.

[4] www.BioCarbonTracker.com

Green*ergy* believes that ILUC emissions should be calculated on the basis of actual data, looking at the actual causes of land use change in specific areas and allocating land use change emissions to real rather than predicted causes. This is preferable to economic modelling which relies heavily on subjective, unproven and outdated assumptions about the behaviour of commodity markets and about the decisions of policy-makers in producing countries worldwide.

To summarise the following issues are of concern regarding the analytical work:

- Large variation in results;
- Inherent assumptions;
- Over sensitivity;
- Use of historical data;
- Inability to account for policy changes.

To investigate the potential risk of ILUC emissions, economic models have attempted to simplify the relationships between the many factors which influence a land use change decision[still not clear what "these relationships" relates to] to develop a forecast of a future land use scenario under the RED.

To understand the model outcomes and respond to the Commission consultation, Green*ergy* undertook an academic review of the best available science presented in the consultation and other academic reviews of similar models. Our detailed report in Annex A focuses on the six models commissioned by the EU JRC Institute for Energy in 2010 (AGLINK-COSIMO, FAPRI-CARD, IMPACT, G-TAP, LEITAP, CAPRI) as this increases the comparability of results significantly.

From this work we have reached the conclusion that economic models provide an important understanding of the relative weight of macro-economic and bio-physical factors that influence land use change decisions and emissions. Models indicate that the three primary factors affecting land use change are; the future changes in consumption of crops, changes in agricultural intensification and/ or expansion, and governance of land use, particularly in relation to the conservation of high carbon stock ecosystems. From observation of the influences on the models, useful conclusions can already be reached that ILUC can be avoided and minimised by; encouraging low-carbon agricultural intensification, the successful protection of biocarbon reserves and maximising the efficiency of crop consumption.

Similar to the DG Energy Literature Review 2010, and the findings of Edwards et al. 2010 and Lywood 2010, our review found that the conclusions that can be drawn from the models are extremely limited by their data and assumptions.

The large variation in the results shows the sensitivity of these models to the type and scope of model used, the assumed relationships, trajectories and base data. To facilitate the efficiency of modelling, assumptions have been made on key parameters in the system. The different treatment of these parameters across the models reduces the ability to compare model results and adds to the uncertainty of any conclusions from the pool of results. The key parameters are the; crop mix used to produce biofuels, the integration of by-products, yield growth, the allocation of production changes to region and land type, and consumption changes.

These assumptions create some of the core limitations of the models as they do not reflect the dynamic system of agricultural demand, trade, policy, land availability, land use efficiencies, development, technology and the inter-relationships between food and fuel products and co-products. Generalising these factors and ignoring others removes the socio-agricultural feedbacks, natural limitations and policy decisions that will occur in the agricultural system to regulate and respond to opportunities and threats.

The implications of the key assumptions are summarised below:

- Crop Mix - Different models assume a limited and fixed variety and flow of feedstocks to meet EU biofuels demand. This ignores the ever fluid market for feedstocks and biofuels. As commodity prices from different crops and countries vary by the day, transport costs change, technologies are developed and feedstocks are incentivised, the portfolio of fuels will change intricately throughout the policy scenario. In Europe this mix will be guided toward sustainable, ILUC avoiding biofuels due to performance against the RED. Domestic markets may create biofuels policies that reverse trade flows and remove the applicability of this assumption.

- Co-products - The extent to which co-products like soy meal and DDGS are considered in the models has a strong impact on the indirect land use effect of the production of soy or wheat. Not only does the co-product dictate the profitability of the crop and its economic viability as a fuel, but acknowledgement of the replacement effect of land requirements for animal feed significantly reduce the ILUC effect for the main product (Lywood 2010). As the models treat co-products and replacement relationships differently, and do not account for the reduced ILUC effect for pasture land all the models likely over estimate the ILUC effect.

- Yield Growth - In determining the land needed to produce the volume of biofuels required for biofuels scenarios, a yield based on historic data and observed price-yield elasticities has often been used. The models do not account for the full potential of yield increases, especially in the developing world where actual versus genetic potential yields have significant potential for improvement. Historic yield trends are also not representative as observed improving yields will reach a genetic plateau and currently low yielding crops may go through rapid increases with improvements in agricultural training, investment, and agronomic practices. As these are a key development goal of developing nations and will be achieved at different phases for different nations or regions, applying generic yield growth assumptions is inappropriate. GM varieties also offer potential yield increases not yet included in models but likely to make a substantial impact in developing nations, though not in EU.

- Changes to production region and land type - Where the additional land use occurs is determined by models of the assumed market flows and dictates the yield and emissions associated with land use. Full consideration is not taken of the potential of degraded land to absorb LUC. Globally, the World Resources Institute estimates that over 1 billion hectares of land has restoration potential. Some models assume historic trade flows of feedstocks while others simplify or complicate the share of biofuel production based on price elasticities and trade regulations or simply based on a single world market (Edwards et al. 2010). The limitations of these approaches are clear in that historic trends are not representative and trade barriers or opportunities change frequently. A single world market is not realistic. Choosing land use types and emissions factors according to economic and bio-physical suitability are slightly more appropriate. However, DG Energy 2010 has identified that not even the suitability models have succeeded in reliably predicting where and on what type of land use change will take place. A better approach would be to observe real land use change.

An understandable limitation of macroeconomic modelling is the inability to account for policy changes which could, very likely affect any of the factors or assumptions in the system. Where models have assumed expansion onto high carbon stock areas, like forest in Indonesia and to some extent Brazil, protection will come from policy decisions already being implemented in these areas. The rate of deforestation in Brazil has been significantly reduced in recent years by a moratorium on Amazonian soy and a concerted move to police regional logging bans.

Similarly, implementation of REDD in Indonesia will create a value for preserving forests and protecting against land use change. Implementation of the RED and similar product specific sustainability standards will protect carbon reserves, prioritise biofuels from wastes, incentivise land use on degraded land and encourage intensification as one method of meeting the mandatory minimum GHG target of 50% in 2017. Incremental benefits can come from the application of similar standards for other agricultural products. This will change the global demand for land, the locations and types of land used to grow additional crops, and the carbon emissions of ILUC. With incentivisation of waste biofuels in the UK in 2010, the proportion of UCO biodiesel in the feedstock mix has increased four-fold, causing a reduction in the proportion of Argentinean soy. Policy influences are clearly extremely influential and fast acting. The imminent adoption of the mandatory requirements of the RED, including incentivisation of wastes and degraded land could entirely change the modelled dynamics of trade flows and land use changes.

Food security is a core goal of the UN and national governments; they are likely to invest in improving the productivity of agriculture in the developing world. Here policy could drive yield improvements, land availability or could encourage land use conversion. These types of policy are more likely than they were 10 years ago on the back of the accepted global objective of climate change avoidance and a transition to a low carbon economy.

The threat of food price instability and concern over the record price of grain is already being tackled at the UN FAO, and depending on the strength of governance, should see increased investment in agricultural development. Unforeseen market events like the economic recession also attract investment to agricultural expansion and intensification. Oil price spikes or sustained changes will have a huge effect on agricultural market forces and on the viability of biofuels as an alternative transport fuel. Reform of the EU CAP may also have an imminent effect on land use regulation and productivity.

2) On the basis of the available evidence, do you think that EU action is needed to address indirect land use change?

While avoidance of ILUC may require global intervention, Green*ergy* believes that EU has an important role to play in setting policy which at its core encourages best practice in relation to managing land use change. By nature, indirect land use decisions are beyond the control of renewable biofuel providers and would be more effectively controlled by direct policies on carbon stock protection, agricultural efficiency and/or direct carbon accounting for consumer products.

Green*ergy* is one of the largest petrol, diesel and biofuels suppliers in the UK and is also the UK"s largest producer of biodiesel from waste. Green*ergy* has been at the leading edge of the industry transition to understand and report the sustainability of biofuels production. Under the guidance of the UK Renewable Transport Fuels Obligation, Green*ergy* has developed the ability to trace and control the environmental sustainability of the biofuels sourced, right back to the fields and farmers that grow the feedstock. As an impartial buyer in a global market, Greenergy is not restricted from choosing the biofuels with the greatest possible greenhouse gas savings (GHG) and the lowest possible environmental and social impact.

We do not believe that the greenhouse gas targets of the RED or the UK RTFO are ambitious enough. As a result, we have set an internal target to achieve double the RED minimum; a 70% GHG saving from our biofuels this year. We will aim to achieve this target by prioritising biofuels from wastes, Brazilian sugarcane and by investigating the production efficiencies of suppliers. Such an ambitious target will deliver important greenhouse gas savings from the UK transport sector; Green*ergy* biofuels saved 1.4 million tonnes of CO_2 equivalent in 2009/2010, equivalent to the emissions from 500,000 cars in the UK. High direct GHG savings of the production process will ensure net emission reductions even after consideration of potential ILUC. This approach should be adopted across the entire transport fuel industry.

Green*ergy* have already implemented a number of mechanisms to assess the sustainability and identify potential land use change of biofuels supplied:

1. Use of the best available science and methods to verify the sustainability claims of our suppliers and where these are not available we have developed them in cooperation with international sustainability and third party carbon experts e.g. Green*ergy*'s "gold standard"[5] for Brazilian sugarcane bioethanol.

2. We have established relationships with our suppliers and work with them to verify the real environmental impacts and benefits of their biofuel production.

3. Through the use of land-use satellite data and aerial photography we examine and take account of emissions from land use change, where applicable.

4. As the emissions from direct land use change would have considerable effect on the direct GHG savings of our biofuels we preferentially source from farms that have not converted additional land to cropland.

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[5] Renewable Fuels Agency, January 09; http://www.renewablefuelsagency.org/rfa/news&pressreleases/news.cfm?cit_id=257&FAArea1=customWidgets.content_view_1

5. Where local environmental and labour regulations are weakly enforced, and the potential for emissions losses by land use conversion is relatively high we have taken additional measures to; enforce legislation, incentivise reforestation, conservation, environmental management and improved working conditions.

6. Most recently Green*ergy* has developed BioCarbon Tracker, a satellite mapping tool that provides interactive maps of biocarbon stored in vegetation (trees, shrubs, grasses) and soil. It can identify where biocarbon is at risk from agricultural expansion and monitor changes in high risk areas. BioCarbon Tracker will also identify opportunities for increasing biocarbon through improved land management and ecosystem restoration.

We intend to use BioCarbon Tracker to guide land use decisions and configure our sustainability practices according to identified risk. The tool will be available to other biofuel suppliers and other economic operators to identify biocarbon risks associated with their sourcing locations. Public disclosure of these land use activities will hold suppliers accountable for their decision making process. Where all suppliers implement sustainable management practices and carbon accounting, there will be no indirect land use change effects.

While biofuel farmers and suppliers are beginning to control the sustainability of their own operations, their influence on global land use decisions is only proportional to their scale. Global biofuels production is limited to approximately 3% of agricultural land. To protect global biocarbon effectively policy should focus on the following:

- Sustainability criteria including GHG accounting should apply equally to all agricultural and forestry products;
- Governments, NGOs and economic operators should monitor and enforce preservation of important carbon and biodiversity stocks;
- Investment should in low carbon, high production agricultural efficiencies;
- Use of degraded land in agriculture;
- Reduction of food wasted and encouraging the best use of wastes for climate change mitigation.

Together the preceding policy focus would help to jointly deliver the provision of global nutrition and the reduction of the causes of global climate change.

Current ILUC Mitigation
Direct emissions of land use conversion for biofuel production are accounted for and controlled under the direct accountability requirements of the RED. However, on a regional level all agricultural systems have some level of capacity to increase output while avoiding land use change and if demand for agricultural and biofuel feedstock production exceeds this carrying capacity the carbon emissions released may be attributed to the causes of the land use change. This regional capacity will depend on a combination of factors that include:
- The base level of productivity relative to the productive potential;
- The cost of increasing yield through intensification relative to the cost of converting new land to agriculture;
- The rate of development of new crop cultivars and yield improving machinery;
- Laws and policies protecting high carbon stock land;
- The relationship between livestock and arable cropping sectors.

Where a region's carrying capacity is in danger of being exceeded there are a number of actions which may be implemented to mitigate (or protect against) ILUC. For example, a region could increase investment in agricultural infrastructure, or research and development, or strengthen the protection of its high carbon stock land. These measures can help to mitigate ILUC within the region (intra-regional ILUC) and may also mitigate the transmission of ILUC pressures to other regions (inter-regional ILUC).

Production of crops for biofuel may remove grains and/or oilseeds from the food market and so biofuels have a marginal effect on the dynamic agricultural system. Biofuels represent only a small proportion of global agriculture so their market effect and their indirect influence on land use decisions is likely to be represented by a fraction of this proportion. Any indirect effects are caused directly by land use decisions made by other agricultural operators, dictated by the interrelationships between market forces, geophysical constraints, legal and human factors.

Attempting to accurately quantify and justifiably apportion the direct land use change emissions of an indirect land use conversion to one of the infinite indirect causes is almost impossible. However details within RED already promote ILUC avoidance; by encouraging production efficiency, biofuels from wastes and degraded land.

3) If action is to be taken, and if it is to have the effect of encouraging greater use of some categories of biofuel and/or less use of other categories of biofuel than would otherwise be the case, it would be necessary to identify these categories of biofuel on the basis of the analytical work. As such, do you think it is possible to draw sufficiently reliable conclusions on whether indirect land use change impacts of biofuels vary according to:

- feedstock type?
- geographical location?
- land management?

No, the work undertaken is inadequate to reach a conclusion. The inherent assumptions within the analytical work create some of the core limitations of the models as they cannot then reflect the dynamic system of agricultural demand, trade, policy, land availability, land use efficiencies, development, technology and the inter-relationships between food and fuel products and co-products.

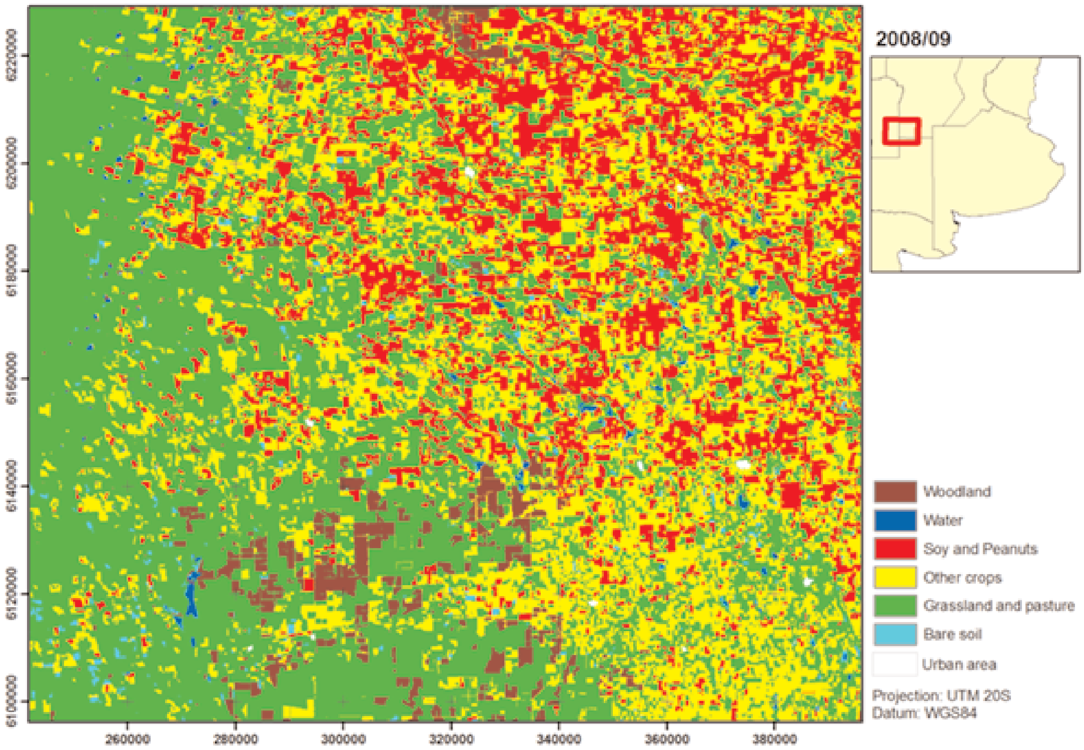
The assumed scenarios for the key parameters and those that determine them are so varied and without indication of probability that they have little or no likelihood of giving an accurate representation of future reality from which to derive an additional land use requirement or ILUC factor resulting from the demand for biofuels in the RED. The variation in results for additional land areas, and the subsequent indirect land use emissions are so large that they give no view of the scale of ILUC attributable to biofuels. As discussed above, the economic models commissioned to date do not take into account the full variety of factors determining the drivers for land use change - in general econometric models will not be able to capture this level of detail and relativity.

4) Based on your responses to the above questions, what course of action do you think appropriate?

Monitoring and promotion of measures to protect carbon stocks constitutes the most effective action. Existing mechanisms for favouring categories of biofuel with low direct GHG will also encourage biofuels with lower than average indirect impacts. The EU should push for rapid, harmonised implementation of RED in Member States. Increasing the minimum greenhouse gas saving threshold for biofuels would strengthen the push for lower carbon biofuels. Imposing an ILUC penalty on biofuels at this stage would be arbitrary and not based on real evidence.

Green*ergy* proposes a practical, evidence-based approach to deal with the risk that GHG emissions from ILUC may arise as a result of the rate of replacement of fossil fuels with biofuels. While economic modelling indicates that expansion of biofuel demand may give rise to negative displacement effects on biocarbon, the evidence also indicates that ILUC is not inevitable and may be avoided or controlled, given the right combination of incentives and governance measures.

Case study: Using satellite data to calculate land use change in Argentina.
In a study of a 150 square mile area in Argentina Green*ergy* has shown that it is possible to use satellite imagery to accurately and cost-effectively measure the greenhouse gas emissions associated with direct and indirect land use change. The method demonstrated in this study is more accurate than economic models which have been applied so far.



Green*ergy* tested a methodology to attribute actual land use change emissions to different causes. This method was peer reviewed and followed consultation with stakeholders including the UK Government, European Commission and interested industrial and NGO parties. The research demonstrated that it is possible to use satellite imagery to measure the actual land use change impact of particular crops.

Summary of Results from Green*ergy* Study on LUC in Argentina
A novel method for quantifying CO_2 emissions from direct and indirect land use change using satellite based sensors was developed and applied to an area of 2.1 million ha in Argentina.
From 2002/03 to 2008/09 the conversion of grassland to cropland within the study area resulted in the emission of 4.7 million t CO2. 3.7 million t CO_2 were produced as a result of direct conversion to soy and 1 million t CO_2 as an indirect effect of soy displacing other crops (mainly corn) which in turn expanded into grassland.

The resulting emissions were attributed to the agricultural outputs using marginal (consequential LCA) and average (attributional LCA) methods. The marginal ILUC factor for soy based biodiesel produced on pre-existing cropland was 10.9 g CO_2 / MJ and the average ILUC factor for the period was 6.6 g CO_2 / MJ.

Additional UK analysis of ILUC factors – Ecometrica and E4Tech for DfT
The causal-descriptive modelling work commissioned by the UK Government transparently identifies several parameters which influence the possible magnitude of ILUC emissions (E4tech 2010). Taking palm oil as an example, the key parameters which determine ILUC risk are identified as: level of expansion onto peatland; expansion onto forest land; abandoning plantations after one planting cycle; changes in yield. The modelled ILUC effect varies from approximately 81gCO_2e/MJ to as low as 6gCO_2e/MJ, depending on the values for these parameters.

If appropriate actions are taken to limit expansion onto peatland and forest land (e.g. REDD+), plantations are used beyond a single planting cycle (e.g. through disseminating best management practices), and palm oil yields are increased (e.g. through increased R&D, or extension programmes etc), the risk of ILUC can be mitigated.

The same approach can be applied to any biofuel feedstock by identifying the key parameters which influence ILUC risk, and implementing actions to mitigate that risk.

Understanding land use change emissions through BioCarbon Tracker
Green*ergy* is using satellite imagery in the development of BioCarbon Tracker, a web platform to understand where biological carbon reserves are located, and which are most at risk from agricultural expansion. By presenting a "big picture" of land use change, BioCarbon Tracker will provide valuable input to the ILUC debate.

BioCarbon Tracker will provide interactive maps of biocarbon stored in vegetation (trees, shrubs, grasses) and soil. It will identify where biocarbon is at risk from agricultural expansion and monitor changes in high risk areas. BioCarbon Tracker will also identify opportunities for increasing biocarbon through improved land management and ecosystem restoration.

By improving understanding of the relationship between agriculture and land use, BioCarbon Tracker will provide positive outcomes in terms of managing biocarbon resources and avoiding both direct and indirect emissions from land use change.

Recommended Actions to address the risk of ILUC

Green*ergy* proposes a practical, evidence-based approach to deal with the risk that GHG emissions from ILUC may arise as a result of the rate of replacement of fossil fuels with biofuels. While economic modelling indicates that expansion of biofuel demand may give rise to negative displacement effects on biocarbon, the evidence also indicates that ILUC is not inevitable and may be avoided or controlled, given the right combination of incentives and governance measures.

As ILUC effects are transitional, reflecting adjustment of the agricultural sector to supply new streams of products, the approach should be aimed at achieving an effective transition to a reduced dependency on fossil fuels, while minimizing negative impacts. The proposed actions adhere to the following principles:

- Based on evidence of actual LUC and risk indicators, rather than theoretically modelled or predicted LUC;
- Proportionate to the risk of emissions;
- Focused on effective measures to reduce emissions from deforestation and degradation;
- Compatible with the goals of the Renewable Energy Directive;
- Working towards sustainability across the agricultural sector, regardless of the use of the end products;
- Consistent methods for accounting for greenhouse gas emissions.

Proposed Scope of Actions:

- Monitoring of land use change associated with expansion of commercial agriculture to identify where land of high carbon stocks is being converted.

  Greenergy has started an initiative to map global stocks of biocarbon and to monitor areas at higher risk (www.biocarbontracker.com). We believe that it is technically and economically feasible to provide timely information to supply chains and governance bodies to intervene, where necessary, to protect ecosystems with high carbon stocks. Vegetation monitoring can assist the improved governance of forests, and Brazil has demonstrated the feasibility of increasing agricultural output while reducing deforestation, using remote forest monitoring as part of its protection programme.

- Promotion of effective and consistent sustainability standards across production systems, regardless of the end-use of products. The problem of unintended indirect effects is partly the result of inconsistent standards. As long as some purchasers of feedstock are willing and able to purchase products with poor environmental performance the problem of leakage or activity shifting will persist. However, if all products are produced to an acceptable standard then no-one will buy sub-standard product. Actions that can be implemented to avoid indirect and direct LUC include: protecting high carbon stock ecosystems, investment in increasing yields and productivity of existing marginal agricultural land, increasing efficiency and optimisation of nutrients and energy within the livestock sector and reducing waste and post-harvest losses.

- Integration of sustainable agriculture and international REDD policy.

  The EU is supporting international efforts to improve forest governance in developing countries to reduce emissions from deforestation and degradation. Sustainable agricultural practices are an important part of this process. There is little evidence that actions to reduce the demand of agricultural output would be effective as long term measures to protect high carbon ecosystems at risk of conversion. We consider that biofuel and bioenergy strategies should be integrated with the REDD process, rather than treated separately.

- Adoption of an incremental, evidence and risk based response to LUC that may be associated with increased demand for biofuel feedstocks. We suggest a clear set of responses, along the following lines as a way of avoiding and controlling ILUC:
  - Where remote monitoring systems detect LUC from high carbon stock ecosystems to commercial agriculture, a joint industry – EU alert should be issued. The alert should request a rapid local assessment and, if necessary, corrective actions from government and agricultural organisations in the area concerned;
  - If the response to the alert is not deemed adequate, a set of incremental interventions, proportionate to the scale and duration of the problem, should be set in train;
  - Where the problem is localised within a region, an additional GHG emission factor should be applied to all feedstocks from the region;
  - If the local/ regional problems are not addressed and become widespread it may be necessary to increase the minimum GHG saving requirement for all biofuels of similar type, such that only biofuels with high GHG savings would be incentivised;
  - The judgment of whether to move from a locally applicable GHG factor to a broader-scale factor should be based on an assessment of effectiveness. If the problem can be resolved by local intervention, then this should be preferred over an intervention that may suppress demand for a wide range of fuels.

Green*ergy* operates a risk based approach to environmental risks within its own supply chain and would welcome an opportunity to share experiences and lessons in this area.

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Annex A.

Modelling Indirect Land Use Change – Review of Key Parameters

*Alexandra Purkus**

For Greenergy

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Executive summary

As part of its consultation on indirect land use change and biofuels, the European Commission published several studies, among them a literature review about land use change impacts and their modelling (study 3, cf. DG Energy 2010) and a comparison of modelling approaches (study 4, cf. Edwards et al. 2010). Based on an in-depth analysis of these two studies, complemented by additional literature research, the purpose of this review is to examine key differences and areas of agreement between models and to assess the uncertainties of land use change modelling. The focus lies on the six models commissioned by Edwards et al. (2010) to run aligned policy scenarios (i.e. AGLINK-COSIMO, FAPRI-CARD, IMPACT, G-TAP, LEITAP, CAPRI), as this increases the comparability of results significantly (Edwards et al. 2010).

Chapter one introduces the challenges of estimating indirect land use change impacts (ILUC) and defines the scope of the review. Chapter 2 examines key structural and assumptions-related differences between models, while chapter 3 discusses issues affecting land use change (LUC) outcomes which are generally neglected in modelling. Chapter 4 concludes with a discussion of the robustness and uncertainties of economic models and the scope for improvements.

As the indirect land use changes attributable to specific biofuel policies can not be directly observed, modelling provides an important instrument for estimating net LUC and the marginal impact of additional biofuel demand (DG Energy 2010). However, results between models differ considerably, even where scenarios are aligned (Edwards et al. 2010). The reason for this lies in structural differences between models, and, more importantly, in differences and significant uncertainties regarding the assumptions used to estimate key parameters (DG Energy 2010; Edwards et al. 2010). Especially important for net LUC results are assumptions concerning the crop mix used to produce biofuels, the integration of co-products, yield growth, the allocation of production changes to region and land type, and consumption changes (cf. Prins et al. 2010; Searchinger 2009; Keeney and Hertel 2009).

Structural differences concern the scope of the models – i.e. if the whole economy is modelled (General Computable Equilibrium models) or just the agricultural sector (Partial Equilibrium) –, the regions, countries and in some instances sub-national ecological zones included in the model, and the level of baseline demand (DG Energy 2010). While the choice of model type does not seem to consistently bias results (Edwards et al. 2010), the level of baseline demand would affect the result if LUC impacts increased with higher levels of demand, which may be a realistic assumption – however, all models assumed linearity (Prins et al. 2010). Models also differ in the choice and spatial resolution of the regions or countries they represent and the degree to which exogenous assumptions about production locations are introduced, affecting the regional allocation of LUC in a structural way (Edwards et al. 2010). To accurately quantify emissions, an allocation of LUC to different land types – such as high and low carbon ecosystems – would be necessary (Prins et al. 2010). Out of the models analysed by Edwards et al. (2010), however, only two attempt to do this calculation and report emission factors based on it. For others Edwards et al. (2010) apply average IPCC values to produce rough estimates.

General Computable Equilibrium models tend to determine the choice of crop mix used for additional biofuel production exogenously, as they feature only a limited number of crops (Edwards et al. 2010). The crop mix, however, has important repercussions for LUC effects, as it affects yields, co-product use and regional allocation of production (Prins et al. 2010). The extent to which co-products are used to displace other components of animal feed can lead to significant reductions in net LUC impacts – assumptions concerning substitution rates vary, and some models do not consider co-products at all (Edwards et al. 2010). Further, significant uncertainities exist about yield specifications, in particular concerning changes in yield growth in response to price and land use changes, and changes in average yields in response to changes in the crop mix or displacements of crops across regions (Edwards et al. 2010). The extent to which higher crop prices result in area expansion or yield growth is not only affected by these assumptions, but also by the spatial allocation of production changes, which is determined in an economic optimisation approach based on relative production costs, land rents, land suitability or historical land use trends (DG Energy 2010). However, assumptions about trade preferences and barriers play an important role in assessing how demand shocks in a scenario region translate to production changes in other countries – consequently, regional allocation results vary widely (Prins et al. 2010, Edwards et al. 2010). For assessing the types of land affected by LUC and their carbon stocks, a coupling of economic and bio-physical models is needed – while efforts are being undertaken, generating reliable predictions of where and on what type of land LUC will take place is still fraught with difficulties (DG Energy 2010). Finally, the extent to which higher prices translate into reductions in crop consumption acts as a negative buffer to LUC (Prins et al. 2010). While this may be problematic in the case of reduced food consumption (Searchinger 2009), most models predict main reductions to occur in animal feed demand, in part compensated through increases in grazing area which are not always modelled (Edwards et al. 2010).

In reality, further factors affect the LUC impacts of biofuels, and may lead to considerable deviations from modelling results. Policy restrictions like sustainability criteria, the protection of high carbon stock land, measures to avoid deforestation as well as agricultural and trade policies have important consequences for the types of land converted for crop expansion and the selection of regions from which additional production is predominantly sourced (DG Energy 2010). Another shortcoming is the models' focus on crop area changes and related emissions, while emissions from farming newly converted land as well as from intensification are neglected, as are other environmental impacts connected to LUC (Edwards et al. 2010; Searchinger 2009). Apart from this, more work is clearly needed on the spatial allocation of LUC – a new methodology for this has recently been published by Hiederer et al. (2010). Also, a lack of transparency as to assumptions and their impacts is criticised, as well as the lack of models trying to calculate the impact of biofuels per se, and not just changes in demand (DG Energy).

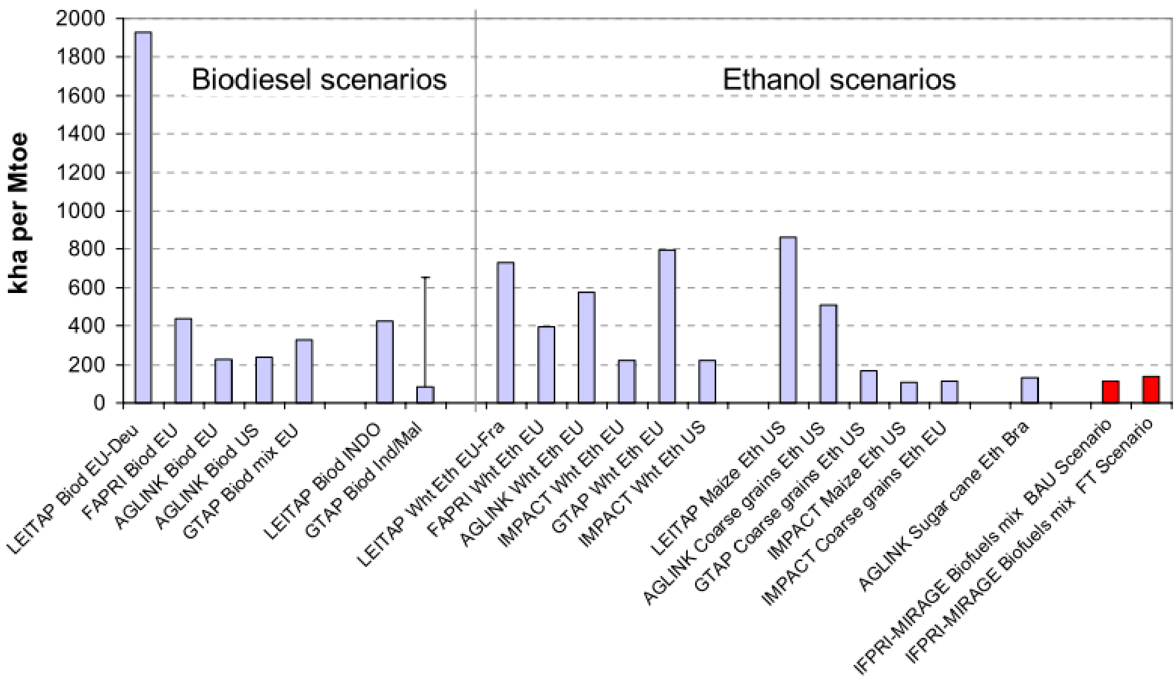
In sum, a review of assumptions shows that significant uncertainties exist regarding the quantitative values of key parameters and net LUC impacts. However, models agree that significant LUC has to be expected, and most of them estimate the greater share of it to occur outside of the region where additional demand is promoted by policy measures (Edwards et al. 2010). Work on improving models is underway with regard to several important issues, e.g. yield specifications, the combination of economic and bio-physical models and improved spatial allocation of results (Prins et al. 2010; Edwards et al. 2010). Further research is also needed regarding the econometric estimation of key parameters, as well as the question whether and by how much crops, biofuels and origins differ in their LUC effects (DG Energy 2010; Edwards et al. 2010). However, poor availability of up-to-date data especially for developing countries limits the accuracy of estimates (DG Energy 2010). Also, the prediction of long-term human behaviour is inherently uncertain, and differences between assumptions may therefore be legitimate (Dumortier et al. 2009). Furthermore, the reality of LUC is more complex than models can depict, as land use decisions are affected by multiple factors (Tipper et al. 2009). Because of this, a more transparent handling of assumptions and an explicit treatment of uncertainties in models is highly recommendable – an approach attempting this exists in causal-descriptive modelling (E4Tech 2010). A more realistic assessment of net LUC impacts of biofuels may result from combining the exploratory power of economic models with findings of this more participative, cause and effect logic based methodology as well as with observations of actual LUC (Prins et al. 2010; E4Tech 2010).

Modelling land use change

Changes in demand for biofuels, caused for example through a political biofuels mandate, affect land use through a variety of crop substitution and displacement processes, which occur globally and simultaneously (Edwards et al 2010). Models present an option to analyse these complex interactions, and assess the net impact of new biofuel production chains on land use change (LUC) (Prins et al 2010). In particular, estimating the indirect land use change (ILUC) impacts of policy options requires modelling, as it seems virtually impossible to attribute the conversion of a particular piece of land to specific biofuel policies (DG Energy 2010). In comparing a baseline with no or limited biofuel promotion to policy scenarios including specific policy measures which increase the demand for biofuels and associated crops, models can estimate the effects of the introduced changes (DG Energy 2010). These results indicate the total net LUC, encompassing both direct and indirect impacts, although ILUC factors can be derived from this (cf. Prins et al. 2010). Generally, models first calculate the difference between scenarios in terms of prices and quantity of crops produced, which is then translated into the difference in land used to produce these crops (DG Energy 2010). Also, it has to be determined where land use changes happen, and which types of land are converted (Edwards et al 2010; DG Energy 2010). Only some models attempt to estimate greenhouse gas emissions based on this; for others, average carbon stock change values are used (Edwards et al 2010).

Comparison between models is complicated by the fact that modellers normally use different policy scenarios, different amounts and mixes of biofuels and focus on different regions (Edwards et al 2010). The modelling comparison effort of the European Commission's Joint Research Centre Institute for Energy (JRC-IE, see Edwards et al 2010) tried to address this issue by commissioning six well-known models (i.e. AGLINK-COSIMO, FAPRI-CARD, IMPACT, G-TAP, LEITAP, CAPRI) to estimate results for marginal increases in biofuel production from different feedstocks. Specifically, modellers were asked to model the effect of an additional biofuels demand of 1 Mtoe (Million tonnes of oil equivalent) for four different scenarios: (i) marginal extra ethanol demand in EU, (ii) marginal extra biodiesel demand in EU, (iii) marginal extra ethanol demand in US, and (iv) marginal extra palm oil demand in EU (for biodiesel or pure plant oil use), although additional scenarios were possible (Edwards et al. 2010). The results are summarised in figure 1.

Figure 1: Results of JRC-IE modelling survey, kha per Mtoe[6]



Source: Edwards et al. 2010, p. 8

The large variation between results is obvious. Key reasons for this can be found in differences between the models; such differences can either be structural, i.e. lie in what is modelled, the spatial resolution, and differences in baselines, or concern assumptions, for example about co-product effects, yield growth, the allocation of production changes to region and land type, the crop mix used to produce the additional biofuels, and changes in consumption following crop price increases (Edwards et al. 2010; DG Energy 2010). Differences in these latter assumptions are widely cited as the most important reasons in divergence (cf. Prins et al 2010; Searchinger 2009; Keeney and Hertel 2009). Edwards et al. (2010) conducted an in-depth analysis of the reasons why the above mentioned models differ

6 MIRAGE was not included in the comparative modelling exercise by Edwards et al. (2010), but results are included in this figure for illustrative reasons.

in their results, while DG Energy (2010) produced an extensive literature review about differences in various models. This report summarises these findings, complemented by additional literature.

Key differences between models

Structural differences

GTAP and LEITAP are Computable General Equilibrium (CGE) models taking all sectors of the economy and their global interactions into account, thereby enabling the analysis of the indirect effects which increased biofuel production has on the inputs of other sectors, e.g. the energy sector (Prins et al. 2010). The other four models are Partial Equilibrium (PE) models, focussing only on the agricultural sector, which in turn can be examined in a more detailed fashion than possible within a CGE framework (DG Energy 2010). Edwards et al. (2010) find that the choice of model type does not lead to consistently higher or lower results.

Out of time considerations and because they reflect different world views of the models, baselines were not aligned across models (Edwards et al. 2010). In principle, the level of biofuel production in the baseline could have an impact on LUC in the policy scenario, if the relationship between land use and biofuel demand was non-linear; it is, for example, possible that higher levels of biofuel demand would be predominantly met by land conversion, as the scope for further yield growth decreases and more marginal land is used, resulting in lower yields per area (DG Energy 2010). All six examined models, however, assume a linear behaviour, so that differences in baselines should not impact marginal results (Edwards et al 2010).

Further structural differences affect the resolution and scope of the results (cf. Edwards et al. 2010, chapter 4). GTAP divides the world into 87 regions, whose land endowment is sub-divided into Agro-Ecological Zones (AEZ). IMPACT is the only other model providing a sub-national disaggregation of results, distinguishing between 281 spatial units and irrigated and rainfed areas. Also it is the only model integrating a water use module, which can show the increased demand for irrigation due to additional biofuel production. Among the models aggregating results into world regions and major producer and consumer countries, the

OECD's AGLINK-COSIMO model has been extended in recent years and represents the agricultural sectors and policies of many developing countries. By contrast, CAPRI focusses on the EU-27, Norway and Western Balkans, for which detailed results in 250 regions are given, while the rest of the world is treated as one region. Among the models, FAPRI-CARD is the only one which calculates marginal emissions, while GTAP reports emission factors by region (Edwards et al. 2010).

Key parameters and underlying assumptions

Below, key parameters which are treated differently by the models are discussed, alongside the assumptions responsible for these differences. These assumptions concern the crop mix used to produce biofuels, the integration of co-products, yield growth, the allocation of production changes to region and land type, and consumption changes. Also, it is pointed out which assumptions affect specific models in particular. Table 1 gives an overview of results for four models' key parameters, demonstrating how initial estimates of feedstocks needed to meet additional biofuel demand are affected by various assumptions and differing estimates.

Table 1: LUC and key model parameters for different models and scenarios

Model and scenario		Feedstock (tonnes)		Feedstock adjustments (%) By-products		Food consumption reduction		Average yield		Area without yield "savings" (ha)		Area adjustments (ha) Area "saved" by Yield increase		Area "saved" by crop displacement		LUC (ha/toe)
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

Source: Edwards et al. 2010, p. 89

Crop mix

The models vary in which crops are included in the model, and in the selection of crops grown to meet additional biofuel demand. Generally, PE models incorporate a wider range of crops and agricultural products; FAPRI-CARD and AGLINK-COSIMO also take second generation biofuels into account. Among the CGE models, GTAP's analysis is limited to grain based ethanol, sugarcane ethanol and biodiesel from oilseeds; LEITAP uses sugar cane for South and Central American Ethanol, wheat for EU ethanol, maize for ethanol from the rest of the world and vegetable oils for biodiesel. IMPACT and GTAP model all oilseeds as one crop, which in the case of IMPACT resulted in an inability to provide realistic results for biodiesel scenarios (Edwards et al. 2010). The mix of crop types and their origin can significantly affect the results, as they are associated with different yields and potential for co-product use (Prins et al. 2010). In its overall literature review, DG Energy (2010) states that large ranges of uncertainty and the existence of partly contradicting results across studies do not allow for definite conclusions to be drawn regarding the sizes of LUC effects of specific crops; however, some models attribute higher LUC impacts to biodiesel feedstocks, especially soya (DG Energy 2010). This tendency can not be observed in the results reported here (see fig. 1).

Co-products

The extent to which co-products of biofuel crops, like dried distillers grains with soluble (DDGS) or oilseeds meal, are used, is likely to have a significant impact on the net LUC impact of biofuels (Prins et al. 2010). Firstly, the use of co-products affects the profitability of certain crops, and thereby land use decisions and the crop mix used for biofuel production (Prins et al. 2010). Secondly – and more importantly – co-products can displace components of animal feed, in particular low-yielding soybeans, and thereby reduce the land requirements for animal feed crops (Lywood et al. 2009a). The net land use change effect of biofuels is therefore smaller than the gross effect, and model results are likely to vary according to their treatment of co-products (Lywood et al. 2009a). GTAP estimates that the fraction of gross feedstock saved by accounting for co-products amounts to between 22% for palm oil biodiesel and 52% for EU oilseeds biodiesel (Edwards et al. 2010). FAPRI-CARD shows similarly high values, whereas IMPACT does not consider co-products at all (see table 1). While FAPRI-CARD contains a detailed description of what commodities are displaced by co-products, AGLINK-COSIMO and CAPRI consider physical replacement ratios of protein and energy feeds, and GTAP and LEITAP use relative prices to determine substitutions. GTAP, however, uses empirical corrections and distinguishes between vegetable oil and cheaper oilseed meal production to arrive at realistic figures, whereas LEITAP consistently shows little impact of co-products (Edwards et al. 2010). Also, reductions in the area needed for fodder are not accounted for, as LEITAP models grasslands in a different sector. Consequently, LEITAP's results for LUC are likely to be overestimates across all scenarios (Edwards et al. 2010).

Yield specifications

In translating the additional quantity of crop production needed to meet the demand for biofuels into land use change, the values used for yields play a central role, as they determine the output per hectare (DG Energy 2010). Yield specifications affect the models in several ways: (i) through baseline assumptions for average crop yields; (ii) through changes in yield growth in response to price and land use changes, and (iii) changes in average yields in response to changes in the crop mix or displacements of crops across regions (Edwards et al. 2010). The baseline average yield depends on the datasets used, the crops included and the year modelled, and does not vary significantly between models (Edwards et al. 2010). More interesting are assumptions concerning (ii) and (iii), which explain large differences between LUC results.

Historically, yields have been shown to grow significantly faster during periods of higher demand growth (Lywood et al. 2009b). This can be for two reasons: firstly, following higher demand and prices, yields can be increased by using more non-land inputs (i.e. labour, machinery, fertilizer) on a given piece of land (DG Energy 2010). While the short-term elasticity of yield on price has been extensively documented for some countries and crops, data especially for developing countries is lacking; also, the emissions connected to such an intensification of agricultural production need to be taken into account, but are neglected by all models (Edwards et al. 2010). Secondly, sustained price increases can improve the rate of yield growth in the long term through technological developments, plant breeding etc. As these developments occur with a time lag, they often lie outside the timeframes of models; IMPACT and FAPRI-CARD, however, take the long-term price elasticity into account (Edwards et al. 2010).

Counteracting the land savings by increased yields are yield differences between old agricultural land and newly converted land. As prices rise, it becomes not only more profitable to invest in yield increases, but also to convert land which is more marginal than that already under production; consequently, average yields decrease (DG Energy 2010). The size of this effect depends on regional marginal/average yield ratios, for which only GTAP includes a factor (yields of crops on newly converted land are 0.66 of the average yield for a given crop and region; more detailed estimates are cited as a priority of the work on GTAP) (Edwards et al. 2010). A combination of LEITAP with the bio-physical IMAGE model estimates marginal yields based on potential rain-fed yields; however, due to weaknesses in this approach (cf. Edwards et al. 2010) marginal/average ratios are mostly close to one – improvements are under way (Edwards et al. 2010). FAPRI-CARD has recently updated its data and estimates of trend parameters in the yield equations of all countries, and includes short- and long-term yield responses to price, as well as variables that account for the impact of extended production on marginal land – resulting estimates for yield increases are moderate, with 16-24% of land area “saved” compared to a scenario without yield increases (Edwards et al. 2010). AGLINK-COSIMO and IMPACT do not include differences between yields on existing and newly converted crop land, resulting in likely underestimates of LUC; especially IMPACT estimates high area savings by yield increases, ranging between 45%-

92% (table 1). CAPRI calculates yields within the EU on a fine geographic scale, and accounts for exogenous yield improvements with time and a price-induced effect (Edwards et al. 2010).

Finally, net LUC impacts vary if high yield crops deplace low yield crops or crop production shifts between countries with different yields. Edwards et al. (2010) call these “virtual” yield changes. All EU biodiesel scenarios show LUC increases due to crop replacement, while in tropical palm oil-based scenarios LUC decreases, as most crops have lower yields than palm fruit in this region (Edwards et al. 2010). LEITAP and FAPRI-CARD also report LUC decreases for wheat and maize as biofuel crops, while in GTAP and IMPACT the displacement of cereals to low-yield regions prevails, resulting in higher LUC. These regional displacements are strongly affected by assumptions about trade elasticities, which are discussed in more detail below.

Allocation of production changes to region and land type

To what extent intensification or new land conversion is chosen differs between crops and regions, making crop-mix and regional allocation important parameters to estimate overall yield changes (Lywood et al. 2009b). In countries with high land availability, like Brazil, it makes sense for models to choose land conversion over intensification, whereas for production increases in Europe or the US the opposite is the case (Prins et al. 2010). Moreover, the land type converted has consequences for crop yields, but also for LUC emissions – land highly productive for agriculture may also support carbon rich ecosystems (Searchinger 2009).

In allocating LUC to regions, models follow an economic optimisation approach, taking international differences in modelled production costs and land rents into account (DG Energy 2010; E4Tech 2010). Also, trade preferences play a vital role (Prins et al. 2010). Models either use parameters based on past developments to define regional shares of imports, or assume homogeneity for commodities from all origins (Prins et al. 2010). In the first case, Armington elasticities are used, which take transport costs, import tariffs, regulations and imperfect information flows into account; as a result, trade composition follows existing trade flows and changes only with a certain “stickiness” (Edwards et al. 2010). This approach is used by GTAP and LEITAP, and – neglecting imperfect information

– by FAPRI-CARD and AGLINK-COSIMO. Assuming a single world market without transport costs and other restrictions, IMPACT follows the second approach (Edwards et al. 2010). In models using the Armington approach, additional biofuel production tends to be more centered on the scenario region, where the demand shock occurs (Edwards et al. 2010). While taking trade barriers into account seems more realistic than a single world market assumption, estimating elasticities from real data poses challenges as they are likely to increase with time (Edwards et al. 2010).

For determining which shares of the increased production in a region are supplied by yield increases and land conversion, estimates of regional elasticities of yield and area on price are needed (Edwards et al. 2010). Also, some assumptions about regional production changes may be exogenously enforced, as is the case with FAPRI-CARD's EU wheat scenario where all extra wheat is assumed to be grown in the EU (Edwards et al. 2010). In sum, regional allocation of LUC depends on various assumptions, both concerning regional characteristics as well as regarding other key parameters, like crop mix, prices or yield elasticities – a complexity that is reflected in the spread of results. Table 2 shows the LUC share between the regions in which the policy change is implemented and the rest of the world. Results vary widely, and even more so if estimates for specific regions are compared (Edwards et al. 2010). However, most scenarios agree that the largest share of LUC will happen outside of the EU, both for biodiesel and ethanol (see table 2). The negative LUC outside of the EU in the cases of FAPRI-CARD and LEITAP can be explained by these models' focus on crop area effects, as meat production is shifted to grassland in the rest of the world (Edwards et al. 2010).

Table 2: Share of total LUC change 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%

Source: Edwards et al. 2010, p. 85

For estimating the emissions resulting from LUC, models need to assess the land use types affected. In the scenario runs commissioned by Edwards et al. (2010), however, only two models go on to estimate carbon emissions, making this assessment of land use types necessary – GTAP provides regional emission factors, whereas FAPRI-CARD reports on a detailed calculation of marginal emissions; emission estimates for other models are based on a central carbon stock change of 40 tC/ha, which was derived from IPCC default values and is applied by the authors of the study to general area changes, with error ranges given based on minimum and maximum values across land types (Edwards et al. 2010). A detailed methodology to assess emissions and the spatial allocation of land demand has recently been developed and published by the JRC (cf. Hiederer et al. 2010).

In general, two approaches exist to determine the types of land converted – historical approaches use data about past land conversion, and assume that future conversion will happen in the same proportion; suitability approaches assume that the most suitable land, according to bio-physical or economic criteria, will be converted (DG Energy 2010). Prins et al. (2010) seem to support this approach in stating that for estimating the land types converted, bio-physical information and feedbacks should be taken into account (Prins et al. 2010). LEITAP tries to achieve this in combination with IMAGE, by using regional land supply curves which weigh the costs for intensification against the costs for expansion. GTAP uses its information about Agro-Ecological Zones and can substitute forest and agricultural area for each region/AEZ combination (Prins et al. 2010). In combination with the model GreenAgSiM FAPRI-CARD considers vegetation maps and global ecological zones; crop expansion is undertaken in areas that already have a high proportion of that crop (DG Energy 2010). CAPRI examines only land expansion in Europe, while indirect impacts in the rest of the world cause changes in production; results for overall LUC are therefore low (Prins et al. 2010). DG Energy (2010) comment that so far not even models using the suitability approach have succeeded in reliably predicting where and on what type of land LUC will take place.

Consumption changes

Increased prices of feedstocks due to additional biofuel demand can lead to decreases in consumption of these crops (Prins et al. 2010). Even if this effect reduces LUC, it is considered as highly undesirable if it leads to reductions in food consumption, in particular among the world's poor who may be especially vulnerable to crop price fluctuations (Searchinger 2009). However, the models examined here report the main effects on consumption for the animal feed sector, rather than human food (Edwards et al. 2010). Apart from FAPRI-CARD, which sees almost the entire net crop requirement for rapeseeds supplied from a reduction in feed and food consumption, all biodiesel scenarios report relatively low reductions in consumption, while most models report medium reductions for ethanol feedstocks (see table 1). LEITAP shows very low reductions in consumption across all its scenarios, the reason for which was seen as unclear by Edwards et al. (2010).

However, the reduction in crop consumption for animal feed is not without consequences. FAPRI-CARD in particular predicts that this effect will lead to meat production shifting away from crop-fed livestock – mostly in the EU – to the grazing of livestock on ranches in extensive countries like Argentina or Brazil (Edwards et al. 2010). If additional land is converted to grazing, the resulting LUC impacts should be included in the model – FAPRI-CARD, however, only determines changes in crop area (Edwards et al. 2010).

Gaps in the models

Shortcomings of particular models as well as general challenges regarding the estimation of key parameters have been discussed above. However, there are further factors likely to have a considerable impact on the final LUC effects of biofuels, which are neglected across models. Among these are the impacts of land use policies and sustainability criteria, neglected emissions from yield increases and other environmental impacts, and issues related to the structure of the models.

Policy impacts

Policy restrictions could have important consequences for what types of land are used for biofuels and from which regions production is predominantly sourced (DG Energy 2010). The EU legislative framework for biofuels already incorporates minimum greenhouse gas saving requirements for biofuels and restrictions not to use raw materials from certain land types (DG Energy 2010). However, these requirements affect only direct land use change by biofuels and can in principle be avoided by dedicating existing agricultural land to biofuels, while converting new land to grow the displaced crops (Searchinger 2009). Edwards et al. (2010) argue that such avoidance would be limited by reputation losses in supply chains, as well as by positive incentives offered by sustainability criteria and additional income opportunities through certification. Apart from this, legislation in production countries can limit land use, e.g. through protecting land with high carbon stocks, and while models are likely to take existing protected areas into account in the baseline, likely future extensions of protected land are neglected (DG Energy 2010). The success of policy approaches to avoid deforestation is also likely to influence LUC impacts, as are supportive measures to increase yield growth or livestock productivity to free up land (Melillo et al. 2009; Dumortier et al. 2009; de Gouvello 2009). Further areas of relevance are agriculture and tariff policies in the policy scenario region, as they affect the ratio of domestic production to imports, which in turn influences the land types used and the propensity to meet new demand by intensification or conversion of new land (DG Energy 2010).

Environmental impacts

In calculating emission factors based on the models' net LUC results, only ILUC emissions from the conversion of additional land to cropland are taken into account (Edwards et al.

2010). Further indirect emissions which are neglected arise annually from the farming of the newly-planted areas, as well as from intensification efforts to achieve higher yields (Edwards et al. 2010). In the latter case, data used to assess the response of yield on price increases could be employed to estimate increases in fertilizer use; causing additional nitrous oxide emissions, this would have implications for the greenhouse gas balance of biofuels (Edwards et al. 2010). Also, intensification may have further environmental impacts, e.g. increased leaching of nutrients, eutrophication and loss of soil carbon (Kløverpris et al. 2008). The employment of sustainable cropping management practices, on the other hand, is a measure that could potentially decrease greenhouse gas emissions from land use change, but usually is not included in models (Kim et al. 2009). Focussing on emissions, models also neglect further impacts on the environment connected to increased LUC, e.g. increased water stress or impacts on biodiversity (Searchinger 2009; Fingerman et al. 2009). The results of modelling efforts focussing explicitly on these questions may also be of relevance for the ILUC discussion (cf. e.g. Hoogeveen et al. 2009, Hellmann and Verburg 2010).

Structural issues

Several criticisms focus on the structure of models. There is, however, scope for improvements, which are in some instances already underway (see the discussion about relative advantages of models throughout chapter 2.2). One such criticism relates to the linearity assumption made in Edwards et al.'s (2010) modelling comparison. Studies were asked to model the additional production of 1 Mtoe of specific crops, which would be less than 1% of the extra supply needed to meet a 10% biofuels target for the transport sector (Prins et al. 2010). With higher levels of demand a non-linear relationship seems likely, with increasing marginal LUC per unit of additional demand for growing levels of demand (Prins et al. 2010). GTAP takes this relation into account to a limited extent through its use of a marginal/average yield ratio, resulting in slightly non-linear behaviour (Edwards et al. 2010). In general, Edwards et al. (2010) argue that econometric data is too scattered to calibrate models for a non-linear relationship. The question of linearity, however, would gain in significance if biofuel mandates of several regions were taken into account. While most models focus on the impacts of policies in specific regions (e.g. the EU or the US), more research is needed about the combined effects and interactions between such programs (Hertel et al. 2010). For example, Hertel et al. (2010) find that the combined impacts of US and EU biofuel mandates on the rest of the world are much greater than those of either policy on its own.

The high uncertainties connected to the allocation of LUC to land type and region shows the need for modelling improvements in this area (cf. chapter 2.2, section d). More specifically, more work on integrated assessment models is needed to combine economic and bio-physical considerations, limits and feedbacks in determining where and which type of land is converted, and where intensification takes place (Prins et al. 2010). Following a broader interdisciplinary approach by integrating geography, remote sensing, economics, environmental and social sciences in a combined modelling framework could contribute considerably to the general understanding of land use patterns, dynamics and driving forces, although differences in perspectives across disciplines make such an integration challenging (Kløverpris et al. 2008).

DG Energy (2010) points out that the assumptions used in models and baselines are not always made clear; creating more transparency would help in the understanding and evaluation of results. Also, none of the models try to calculate a baseline in which no biofuels are used (Edwards et al. 2010). All models account at least for the demand that would arise from market forces alone, while some baselines include also current promotion policies – modelling efforts aimed at estimating the per se LUC impact of biofuels might be of interest (DG Energy 2010).

Uncertainty, empirical validation and scope for improvements

The review of assumptions above has shown that there are considerable uncertainties regarding the quantitative values of key parameters, and, resulting from that, the values for net LUC. However, despite their different assumptions all models come to the conclusion that significant net LUC impacts have to be expected, and most of them agree that the majority of LUC will occur outside of the region in which additional demand is promoted by policy measures (cf. fig. 1, table 2). Also, comparing results across models, statements can be made about likely ranges for LUC. While LEITAP is likely to overestimate LUC because of very low area savings by co-product use and reductions in food consumption, AGLINK-COSIMO's and IMPACT's neglect of differences between marginal and average yields results in likely underestimates; in the case of IMPACT, this is counteracted by not taking co-products into account (see chapter 2.2). FAPRI-CARD also has a tendency to produce underestimates, as LUC for extended livestock grazing is not taken into account (Edwards et al. 2010). For biodiesel scenarios, most results range between ca 200-400 kha per Mtoe, with LEITAP's “Biodiesel EU” (ca 1900 kha per Mtoe) and GTAP's “Biodiesel Indonesia/Malaysia” (ca 100 kha per Mtoe) scenarios as outliers (see fig. 1). The results for ethanol display a larger variance between about 100-850 kha per Mtoe. To understand the differences, a detailed analysis of key assumptions is necessary; estimating the various elasticities used in the models, for example, involves uncertainties and difficulties, magnifying potential errors in the final result (Searchinger 2010). Increased use of sensitivity analysis to demonstrate the effects and relative importance of assumptions would be helpful in this regard, and could also be used to examine the impact of different policy options (e.g. existence of sustainability criteria or protection of high-carbon stock land) (DG Energy 2010). However, the fact that complex models may have hundreds of parameters makes a transparent display and detailed assessment of assumptions difficult (Liska 2010).

Models are constantly improved, and work on several important issues, like the combination of economic and bio-physical models, the estimation of marginal to average yield ratios or the spatial allocation of demand changes is underway, as are baseline alignment efforts which may increase the comparability of results (Edwards et al. 2010). Further scope for improvement exists regarding the econometric estimation of model parameters, a field that is criticised for being underinvested in (DG Energy 2010). Especially regional ratios for the yield and area elasticities on price are critical to LUC, and need to be further investigated (Edwards et al. 2010). Also, more research is needed concerning the important question whether and by how much crops, biofuels or origins differ in their LUC effects (DG Energy 2010). A general problem is that detailed data is often only available for a limited range of countries, whereas most notably for developing countries there are gaps; also, the models vary in how much their data is up to date (Edwards et al. 2010). GCE models in particular tend to be based on relationships valid in developed countries, and apply these structures to all economies worldwide; while greater differentiation might be difficult to implement, this assumption may be questionable especially in the case of developing countries (DG Energy 2010).

While in some cases investment in econometric estimation efforts and better data availability may be able to produce more realistic assumptions, it is also important to keep in mind that the prediction of long-run human behaviour is fraught with inherent uncertainties – therefore differences in models' assumptions can well be legitimate (Dumortier et al. 2009). Also, models will always be simplified versions of reality – while they can make statements about the marginal LUC impact of additional biofuels demand, their results will never represent reality perfectly, as a multitude of factors interact to determine actual land use changes (Prins et al. 2010; Angelsen and Kaimowitz 1999). For example, even once improved models combining economic and bio-physical considerations to produce better estimates of which regions and land types will be affected by LUC are available, actual land conversion decisions depend also on factors like regional policies, proximity to roads, land tenure, taxes and subsidies or development strategies, to name but a few (Tipper et al. 2009; Geist and Lambin 2002). Also, short-term effects can confound long-term trends; in Brazil, for example, a high exchange rate and a soybean disease outbreak have recently limited the expansion of soybeans (Searchinger 2009). Uncertainties regarding future trade developments and the impact of climate change on yield growth are two further examples of factors which will cause model predictions to deviate from reality (Prins et al. 2010).

Observations, on the other hand, may be able to accurately depict actual land use changes, but will find it very difficult to distinguish ILUC impacts of additional biofuel demand from other influences (DG Energy 2010). For this, economic models are a helpful instrument – while there are high uncertainties concerning numerical values, their exploratory character is important and insights are generated about which parameters have the most important impacts (Prins et al. 2010; DG Energy 2010). Also, while relying on the results of any single model would involve considerable uncertainties, comparing the estimates for key parameters across different models allows for reasonable ranges of results to be derived (Searchinger 2010). Meanwhile, a different modelling approach taking these uncertainties explicitly into account exists in the causal-descriptive methodology, which uses cause and effect logic to describe and assess ILUC impacts (cf. E4Tech 2010). Employing extrapolation of historical trends, expert advice on future market developments and stakeholder input, this approach tries to identify all possible land use changes associated with biofuel production, and estimate ILUC impacts depending on different market responses (E4Tech 2010). Assumptions and their consequences are clearly stated and their impacts are shown in different scenario runs, making results and their uncertainty more transparent than is the case with partial and general computable equilibrium models (E4Tech 2010). To arrive at realistic estimates of LUC and ILUC, a calibration of models against observations of actual LUC and findings from the causal-descriptive methodology may be a promising approach (Prins et al. 2010; E4Tech 2010).

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