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Report

Commissioned by
Bundesverband der deutschen Bioethanolwirtschaft e.V. (BDB^e)

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1 Project definition

The discussion on sustainability criteria for bioenergy, which has been conducted with great ferocity over the last two years, is gradually getting closer to defining a set of basic principles. This was also reflected in the European Directive on the Promotion of the Use of Energy from Renewable Sources (2009/28/EC)("Renewable Energy Directive – RED") at the end of April 2009. Indirect land use change (ILUC) is the aspect where the available data and the applicability still leave the most important questions unanswered in this respect [1] .

Article 19 (6) of the Directive thus stipulates that the European Commission is to submit a report that analyses this situation by the end of 2010 (but it will most likely be ready prior to March 2010) and, if possible, proposes a concrete methodology for taking greenhouse gas emissions caused by indirect land use changes (ILUC) into account based on the best scientific knowledge available.

This type of approach was incorporated into legal regulations for the first time in California in March 2009 (LCFS 2009). The US EPA (2009) also submitted a proposal in May, the implementation of which, however, was obstructed by a five-year moratorium arising from an agreement in the House of Representatives on 24 June 2009. The proposal will be subject to a scientific review in the meantime.

Because there are so many of these processes, the debate about the "best possible" method for evaluating the ILUC will intensify in both the European and international context. Contributions to this debate are both necessary and desirable from every group involved in this intrinsically very complex and (potentially) politically far-reaching issue.

Against this background, the BDB[e] commissioned the IFEU to create this synopsis. This study primarily aims to survey and assess current models and methods used to account for the effects of indirect land use changes. The strengths and weaknesses of each approach are analyzed, development possibilities for further policy goals determined and fields of action identified in this process.

To sum up, there are four distinct basic approaches to ILUC calculation which may be of relevance to further discussions on this issue:

- Complex **macro-economic/econometric and/or biophysical models**
  Models such as GTAP, FASOM, FAPRI, etc., which are primarily used for legislation in the US and California; the scientific basis relating to ILUC is provided by Searchinger et al. (2008), Kim et al. (2009), Plevin (2008).
- Simplified **deterministic approaches**
  Approaches such as the ILUC factor (Fritsche 2007, 2009) or the bonus according to the European Directive on Renewable Energy Sources (2009/28/EC)
- Other approaches which strike a **balance** between these two approaches (Lywood 2009, FoE 2008)

[1] According to André Aranha Corrêa do Lago, Co-Chair of the Global Bioenergy Partnership (GBEP) in his summary of the GBEP workshop on indirect land use change on May 15, 2009 in New York

- Approaches that focus on ILUC **risk minimization** (Dehue 2009, Eickhout 2008).

This synopsis includes a brief characterization of several of the approaches mentioned and an analysis of the respective strengths and weaknesses of the individual models and methods. With a view to the future outlook, potential for development of further political goals is also provided and fields of action identified.

2 Basic principles for capturing and analyzing ILUC effects

2.1 What is meant by "ILUC" effects?

The increase in biomass production for bioenergy intensifies pressure on the land available for agricultural use similar to an interconnected network. If land previously not used for agricultural purposes is converted, this is called direct land use change (DLUC). If the land was already used for agrarian purposes, the biomass for energy use now displaces the products that were previously produced for the food, animal feed and fiber markets and now have to be produced elsewhere.

It is an undeniable fact that these indirect correlations exist at a global level. The problem now is how to calculate and allocate the effects on biomass produced especially for energy use and the individual producers. The problems are based on the following points:

- The indirect effects are generally independent of regional correlations and have an impact via the complex mechanisms of the agricultural markets. Some of these effects can actually be closely tied to a region (e.g. increasing the demand for palm oil increases first and foremost the incentive to expand production of palm oil plantations, in other words, the pressure has an impact in the respective agricultural region).
  In the second approximation, however, the entire vegetable oil market responds to these incentives, thus spanning all crop regions (rapeseed, soy, canola, coconut, sunflowers, etc.).
  In the third approximation, the effect can also go beyond the specific product segment (vegetable oil in this case) because the opportunities can shift between the various product segments (oil, grains, fiber plants, etc.) due to changes in the markets.
- The use of one hectare of land for biomass does not necessarily mean that exactly one hectare of new land will be developed for the displaced food/animal feed/fiber plant. The indirect consequences of the demand for energy plants can also increase crop yield overall. In many regions of the world, it can be assumed that the potential yield per hectare of land is not fully exploited.
- The mix of food and animal feed sold on the market changes as a result of the connection between the production of biofuel and food/animal feed. Certain food/animal feed - already established in the market - is displaced by the newly offered products. As a result, there are complex shifts in global land use to produce the necessary food/animal feed and biofuels. If the efficiency of global land use (product yield per hectare) increases, this can curb demand for agricultural land.

The ILUC discussion focuses heavily on the carbon balance and thus the greenhouse balance. Seen as a guiding indicator, this makes a lot of sense and is completely justified (all the more so as the sustainability assessment in the US and California is currently limited to the greenhouse gas balance only). It should, however, be kept in mind that other impact areas are also affected such as:

- areas with nature protection purpose or those with a high level of biodiversity
- Food security

2.2 Which approaches exist for identifying and measuring ILUC?

Keeping in mind the mechanisms listed above that can be used to track the effects of ILUC, two very different methods are currently available for identifying the effects:

- A very complex approach that attempts to simulate the mechanisms in numeric terms using multilayered models (macroeconomic and/or biophysical models). The impact of additional biomass production on the agricultural markets, on the production methods in the agricultural sector and finally on the dynamics of land use change is thus calculated per model.
- A very simplified method that assumes that additional biomass production by definition results in additional land use, roughly calculates how much and allocates it to biomass production (proportionally where necessary). This type of method is called "deterministic" because approximate figures are taken here instead of the sensitivity of complex models.

In addition to these two opposing methods, there are also approaches that strike a balance between the two. In these approaches, model calculations or findings of such are incorporated into a simplified schematic calculation of land use changes and resulting greenhouse gas sources and/or sinks.

Within the context of the ILUC discussion there are also approaches that identify production methods that aim to eliminate the occurrence of the negative indirect effects or minimize the risk that they will occur.

There are already various implementation concepts that exist for the approaches mentioned. These are described below. One specific focus is the macroeconomic and econometric models that require a more in-depth analysis due to their complex nature. We would like to point out that this overview study cannot provide a detailed analysis of the models.

3 Econometric/biophysical models

Current legislation in the US and California relies on what are known as econometric models to calculate the greenhouse gas emissions arising from indirect land use changes. These models were generally developed to predict impacts on and changes to the markets resulting from changes in the flow of trade for certain goods for agricultural policy measures using predefined scenarios. Because these market interdependencies in principle incorporate the indirect effects described above, these models are also considered suitable for estimating data on the scope of land use changes. If the models are linked to biophysical data in a second step, they can be used to calculate greenhouse gas emissions. In the following section, the available models are first presented in brief and then the proposed model combinations discussed.

3.1 Econometric models

Econometric models are used to simulate the economic impacts of political decisions at national, European or international level (to estimate the consequences of different politicy options). If the macroeconomy as a whole is represented, this is called a general equilibrium model (section 3.1.1). In contrast, when only an individual market is considered, this is called a partial equilibrium model (3.1.2).

3.1.1 General equilibrium models

In the economic sciences, a general equilibrium model[2] is defined as a model that represents the entirety of a macroeconomy (or the global economy) and searches for a simultaneous equilibrium on all relevant markets. Table 1 shows a selection of general equilibrium models.

Table 1: Selection of general equilibrium models

Acronym	Name of model
GTAP	Global Trade Analysis Project
LEITAP	
MIRAGE	Modeling International Relations Under Applied General Equilibrium
DART	Dynamic Applied Regional Trade

GTAP (Global Trade Analysis Project)

One of the most well-known general equilibrium models is the **GTAP model** that was developed at Purdue University (USA). GTAP represents the global economic activity in the world overall, in individual countries and regions. It captures the interdependencies between agriculture, the upstream and food industry as well as the commercial economy and service sectors. The intraregional and interregional linkages of markets and actors are taken into account along with the resulting feedback effects. The current version 7 includes 113 regions and 57 commodities (reference year: 2004).

2 General Equilibrium Model (GEM) or Computable General Equilibrium Model (CGE model)

GTAP serves as the basis for a series of other GE models such as LEITAP, MIRAGE and DART. LEITAP is a further development of the GTAP by the Agricultural Economics Research Institute (Landbouw Economisch Instituut) of the University of Wageningen (Netherlands). It makes it possible, among other things, to establish a link to biophysical and integrated models (see sections 3.2 and 3.3) as was carried out, for example, in the "Eururalis" EU project[3]. The DART model (Dynamic Applied Regional Trade) of the Kiel Institute for the World Economy (Kieler Instituts für Weltwirtschaft - IfW) is used to analyze international climate policy and is combined with a partial equilibrium model and a choice of location model in, among other things, the BMBF-financed "NaRoLa" project[4]. DART is based on GTAP version 5 and includes 66 regions and 57 commodities (reference year: 1997).

GTAP is also used in other model combinations, e.g. at the Johann Heinrich von Thünen Institute (vTI), which links GTAP with several partial equilibrium models such as AGMEMOD, CAPRI and RAUMIS (see the following section).

The GTAP model plays an important role in ILUC modeling because it is a central component of the *Low Carbon Fuel Standard* approach (see section 3.4.2).

3.1.2 Partial equilibrium models

Unlike general equilibrium models, a partial equilibrium model[5] only looks at an individual market. Mutual dependencies and feedback effects between various markets are not considered. Partial equilibrium models have been used successfully for many years to model the agricultural sector, the forestry sector and the energy sector (see Table 2: Selection of available models in the agricultural, forestry and energy sectors).

A detailed description of all models with their respective advantages and disadvantages would go beyond the scope of this study. Consequently, only the two partial equilibrium models that are used for ILUC modeling in the US *Renewable Fuel Standard* approach are described (see also section 3.4.1). This method is based on the combination of two PE models: the FASOM model for the US market and the FAPRI model for the market outside of the US.

FASOM (Forest and Agriculture Sector Optimization Model)
The FASOM model was developed on behalf of the US Department of Agriculture by Texas A&M University in 1996. This is a complex, long-range model that tries to represent impacts such as changes in supply and demand, competition between products, availability and costs of land and labor. It models the US agricultural and forestry sector and was originally used to simulate the impacts of policy alternatives for carbon storage in trees on welfare and markets. Since then, however, it has also been used successfully for other policy scenarios. The University of Hamburg developed a European version of the model (EU-FASOM).

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3 Link of LEITAP, IMAGE and CLUE; http://www.eururalis.eu

4 "Renewable raw materials and land use - integration of bioenergy in a sustainable energy concept"; http://www.narola.ifw-kiel.de/

5 Partial Equilibrium Model (PEM)

FAPRI (Food and Agricultural Policy Research Institute)
The FAPRI model was developed by the institute of the same name at Iowa State University (US). It is made up of several sub-models (dairy products, grain, meat, oil crops, sugar crops and cotton) that represent both the US and the global agricultural sector. The most important import and export countries are handled separately for every commodity; all others are aggregated in the category "rest of the world". The FAPRI model is used for projections within the US and World Agricultural Outlook.

Table 2: Selection of available models in the agricultural, forestry and energy sectors

Acronym	Name of model
Agricultural sector	
AgLink / COSIMO	Worldwide Agribusiness Linkage Program / COmmodity SImulation MOdel
AGMEMOD	AGricultural MEmber State MODelling for the EU and Eastern European Countries
CAPRI	Common Agricultural Policy Regional Impact Analysis
CAPSIM	Common Agricultural Policy SIMulation Model
ESIM	European Simulation Model
EU-FASOM	EUropean Forest and Agricultural Sector Optimization Model
FAPRI	Food and Agricultural Policy Research Institute
FASOM	Forest and Agriculture Sector Optimization Model
IMPACT	Int'l Model for Policy Analysis of Agricultural Commodities and Trade
RAUMIS	Regionalisiertes Agrar- und UmweltInformationsSystem (Regional Agricultural and Environmental Information System)
Forestry sector	
EFI-GTM	Global Forest Sector Model
EFISCEN	European Forest Information SCENario Model
EU-FASOM	EUropean Forest and Agricultural Sector Optimization Model
FASOM	Forest and Agriculture Sector Optimization Model
GFPM	Global Forest Products Model
PICUS	
Energy sector	
BioTrans	
PEEP	Perspectives on European Energy Pathways
POLES	Prospective Outlook on Long-term Energy Systems
PRIMES	
Prometheus	
TIMER	Targets IMage Energy Regional Model
WEM	World Energy Model

FAPRI is used in the Renewable Fuel Standard (RFS) for the ILUC calculation in the international context (RFS 2009[6], Laughlin 2009). How the model is used here is explained by Hayes et al. (2009). Tokgoz et al. (2007) conducted the main base calculations for ILUC. The calculations of Tokgoz et al. (2007) were taken one step further by Searchinger et al. (2008) who focused them on the aspect of greenhouse gas emissions. Sensitivity for ILUC was triggered globally particularly by this work.

For all other models listed in Table 2: Selection of available models in the agricultural, forestry and energy sectors, please see the compilations in EEA (2008), JRC IPTS (2008) and Solberg et al. (2007).

3.2 Biophysical models

Biophysical models serve to describe processes in biological systems (e.g. agricultural production systems) in numeric terms. In the scientific community, a number of biophysical models are available with different thematic focuses. Table 3 shows a small selection. Detailed information about the individual models can be found, for example, in the EEA compilation (2008).

Table 3: Selection of biophysical models with their respective focus

Acronym	**Name of model**	**Focus**
Euromove		Biodiversity
GLOBIO	Global Methodology for Mapping Human Impacts on the Biosphere	Biodiversity
CENTURY / DAYCENT		Soil
EPIC	Erosion Productivity Impact Calculator	Soil
CLUE-s	Conversion of Land Use change and its Effects	Land use
LLN model	Louvain-la-Neuve Land Use model	Land use
EcoSense		Air quality
RAINS	Regional Air Pollution Information and Simulation	Air quality
SWAT	Soil and Water Assessment Tool	Water
SWIM	Soil and Water Integrated Model	Water

The CENTURY / DAYCENT model created by Colorado State University (USA) was linked to the FASOM model for ILUC modeling as part of the US *Renewable Fuel Standard* approach. It is used to model carbon and nitrogen flows in ecosystems and to simulate the impact of land use on emissions to the atmosphere and the hydrosphere (see also section 3.4.1).

3.3 Integrated models

In addition to numerous sectoral models, there are now also several integrated models such as the IMAGE model of the Netherlands Environmental Assessment Agency

6 http://www.epa.gov/OMS/renewablefuels/rfs2-nprm-preamble-regs.pdf

(PBL, Netherlands), the IF model (International Futures) and the PoleStar model of the Tellus Institute and Stockholm Environment Institute (SEI, Sweden).

The IMAGE model is made up of several sub-models (such as PHOENIX, FAIR, TIMER and HYDE) that link society, the biosphere and the climate with one another and also provides interfaces to GTAP and GLOBIO. It was also recently connected to LEITAP and CLUE in the EU project "Eururalis". Plans are in the works for further expanding the IMAGE model. The EEA compilation (2008) contains more detailed information on integrated models.

3.4 Model combinations for calculating ILUC effects

Econometric models designed to predict the impact of interventions in agricultural markets have been in use for some time now. However, they have only been recently used to model ILUC effects that were required by legal regulations in the US and in the US state of California. The US EPA (Environmental Protection Agency) relied on a model combination of FASOM and FAPRI to develop the *Renewable Fuel Standard* (RFS), while the Air Resources Board of the California EPA (CARB) based its development of the *Low Carbon Fuel Standard* (LCFS) on GTAP.

3.4.1 Renewable Fuel Standard (RFS) of the US EPA

A combination of two partial equilibrium models was selected for ILUC modeling in the US *Renewable Fuel Standard:* the FASOM model for the US market and the FAPRI model for the market outside of the US. Other models such as DAYCENT, GREET and MOVES played an important role along with biophysical data of the MODIS satellite (see Table 4).

Table 4: Overview of the models and data used within the framework of the US RFS method

Acronym	**Name of model**	**Type of model**
DAYCENT		Biophysical model for soil processes
FAPRI	Food and Agricultural Policy Research Institute	Partial equilibrium model (world)
FASOM	Forest and Agriculture Sector Optimization Model	Partial equilibrium model (US)
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Transportation model	Lifecycle model for emissions from the transportation sector
MODIS	Moderate Resolution Imaging Spectroradiometer	Satellite data on land use/cover
MOVES	Motor Vehicle Emission Simulator	Model for vehicle greenhouse gas emissions

FASOM is used to represent the US market with its variety of input parameters and a geographic resolution of 11 agricultural zones in the US and 37 other regions outside of the US.

In the **FAPRI** model, the most important import and export countries are handled separately for every commodity; all others are aggregated in the category "rest of the world". The number of the regions is thus different for each commodity.

Figure 1 shows a diagram of the combination of the FASOM and FAPRI models for ILUC calculations within the RFS (2009).

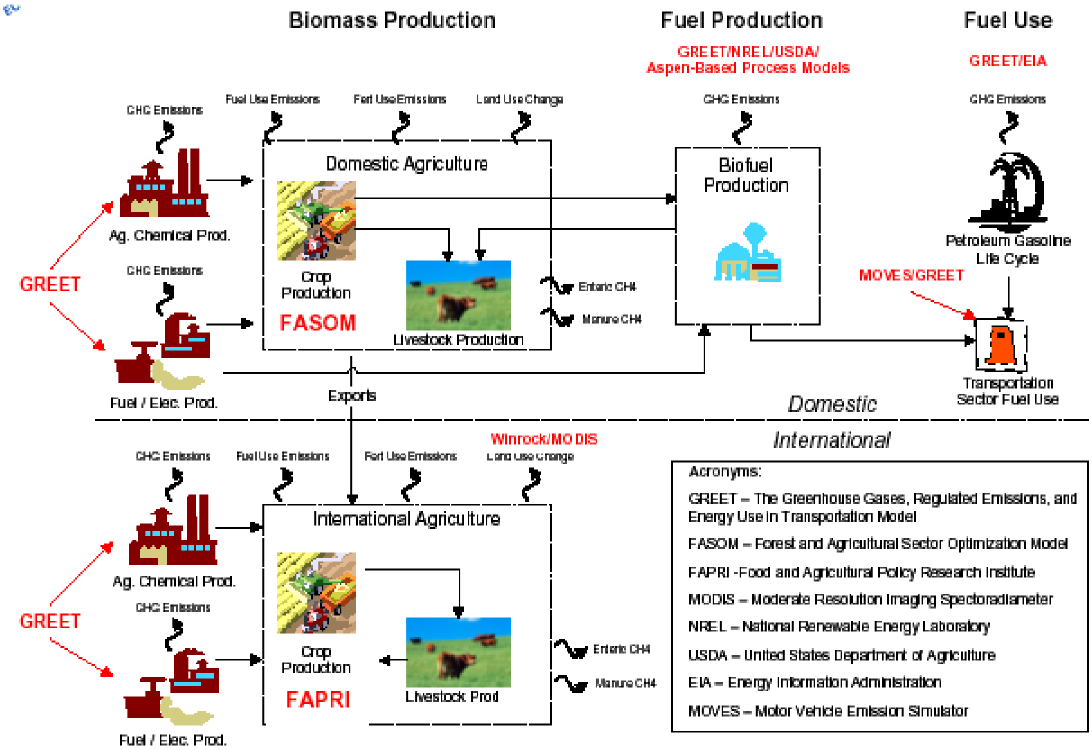


Figure 1 Combination of FASOM and FAPRI in the ILUC model of the US EPA for the Renewable Fuel Standard (RFS) (EPA 2009; Laughlin 2009)

Calculation of the greenhouse gas emissions based on ILUC effects

The DAYCENT model was linked to FASOM (RFS 2009[7], Laughlin 2009) for calculating greenhouse gas emissions in the US market. For greenhouse gas emissions in other countries of the world, Winrock International analyzed land use/land cover data of the MODIS satellites for the years 2001 to 2004 and assigned the land use/land cover classes (cropland, forest, savannah, grassland) with carbon stocks based on IPCC (2006).

Two future scenarios are analyzed for calculating LUC effects in the RFS2:

1. "Business as usual" with a portion of renewable fuel that would be produced without support from RFS2
2. "Business with RFS2" with a higher portion of renewable fuel as prescribed in RFS2 by 2022

[7] http://www.epa.gov/OMS/renewablefuels/rfs2-nprm-preamble-regs.pdf

For each scenario, the impacts on the greenhouse effect (that would result from changing the portion of renewable fuel) are calculated across the entire economic sector. Unlike the EU approach, no allocation is made but the range of the system for "LCA conditions" considerably extended.

General effects on the agricultural sector and resulting changes to GHG emissions were included in the calculation of greenhouse gas emissions of the scenarios, e.g.:

- Increased corn ethanol production results in an increase in price for corn and thus to a reduction in the number of livestock or
- Increased corn ethanol production results in more production of DDGS that makes production of other animal feed unnecessary

Because the entire agricultural economic sector is defined as the system for the GHG calculation in the RFS model, the substitution effect of co-products is also systematically included. However, it still remains unclear at what resolution the type of products substituted (which ones and produced by which LUC) is calculated.

Because the calculation is performed at the level of the overall agricultural sector, it is not possible to represent the situation for individual farms. Even though FASOM in particular offers a high level of resolution, certain products are also merged into larger units and product groups formed. Increases in productivity are included but it is unclear how they are differentiated.

3.4.2 Low Carbon Fuel Standard (LCFS) of the CARB

The GTAP model is the central component of the California *Low Carbon Fuel Standard* method for modeling ILUC effects. It belongs to the group of general equilibrium models and has been used for many years to analyze developments on agricultural markets (see section 3.1.1). These models attempt to represent a macroeconomy in its entirety by simulating a simultaneous equilibrium in a set of interdependent markets.

Land information broken down by agro-ecological zones (AEZ) was added to GTAP with the respective carbon stocks taken from IPCC particularly for incorporation into the greenhouse gas calculation in accordance with LCFS. This way, the modeled scenarios for ILUC effects can be calculated in g CO_2/MJ of bioenergy.

Increases in yield have not been included in the GTAP. They are calculated outside of the actual model.

3.5 Results of the model

Below is a short summary of a selection of previous calculation results of models used in the US. The following results are considered particularly relevant:

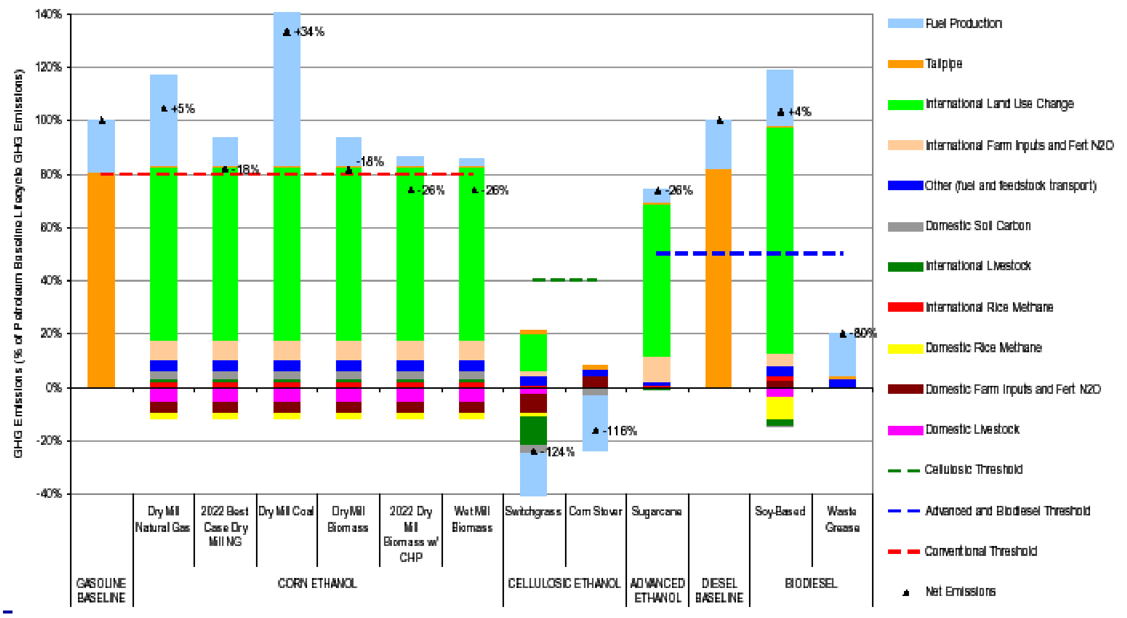
- The US EPA for the RFS (2009) with the FASOM/FAPRI method
- The California LCFS (2009) with the GTAP method

- The calculations of Searchinger et al. (2008)

Figure 2 contains the RFS results. Two different options were used to consider the assessment time frame: one uniformly over 30 years and one over 100 years associated with real greenhouse gas savings annually discounted by 2%. In the draft of the legal ruling, it is left open which approach is to be used as a basis. In the preamble, however, a general preference is expressed for the first option. According to this option, approx. 65 g CO2eq/MJ can be derived as the net LUC value for bioethanol from corn from the upper part of Figure 2 (US). For bioethanol made from sugarcane (Brazil), this option produces approx. 70 g CO2eq/MJ. If the second option is used, the values are reduced to just around 50 CO2eq/MJ corn bioethanol and approx. 53 CO2eq/MJ sugarcane bioethanol[8].

Table 5 and Table 6 summarize the GTAP estimates for LUC for corn and sugarcane bioethanol in accordance with the LCFS (2009). The results here are 30 CO_2eq/MJ corn bioethanol and approx. 46 CO_2eq/MJ sugarcane bioethanol.

[8] The values are based on previous interpretations of the extensive representations in the RFS documents assuming the following comparators:
"baseline gasoline" => 98.395 g CO2eq/mmBtu = 93.26 g CO2eq/MJ
"baseline diesel fuel" => 96.843 g CO2eq/mmBtu = 91.79 g CO2eq/MJ
(1 mm BTU = 1.055 GJ)



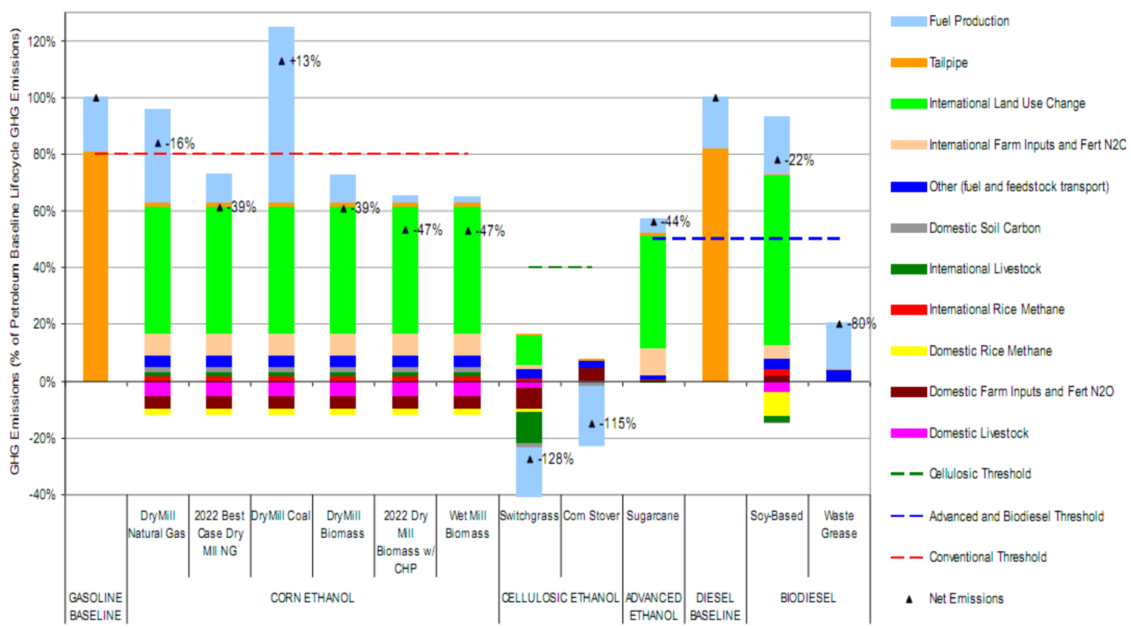


Figure 2 GHG balance results of various lifecycles including ILUC modeling with FASOM and FAPRI by the US EPA for the Renewable Fuel Standard (RFS);
Top: Balance baseline 30 years, no discounting;
Bottom: Balance baseline 100 years, 2% discounting p.a.
(EPA 2009,[9] Laughlin 2009)

9 US EPA: Draft Regulatory Impact Analysis: Changes to Renewable Fuel Standard Program; EPA-420-D-09-001; May 2009
http://www.epa.gov/OMS/renewablefuels/420d09001.pdf

Table 5 GTAP model results for corn ethanol in accordance with LCFS (2009) (Tab. IV-10)

Scenario	A	B	C	D	E	F	G	Mean
Economic Inputs								
EtOH production increase (bill. gal.)	13.25	13.25	13.25	13.25	13.25	13.25	13.25	
Elasticity of crop yields wrt area expansion	0.5	0.75	0.5	0.5	0.5	0.66	0.75	
Crop yield elasticity	0.4	0.4	0.2	0.4	0.4	0.25	0.2	
Elasticity of land transformation	0.2	0.2	0.2	0.3	0.1	0.2	0.2	
Elasticity of harvested acreage response	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
Trade elasticity of crops	See Appendix C							
Model Results								
Total land converted (million ha)	4.03	2.68	5.48	4.56	3.01	3.83	3.66	**3.89**
• Forest land (million ha)	1.04	0.37	1.46	0.89	1.00	0.73	0.55	**0.86**
• Pasture land (million ha)	3.00	2.32	4.02	3.65	2.01	3.10	3.10	**3.03**
U.S. land converted (million ha)	1.74	1.16	2.01	2.12	1.14	1.46	1.32	**1.56**
• U.S. forest land (million ha)	0.70	0.36	0.82	0.81	0.48	0.46	0.40	**0.58**
• U.S. pasture land (million ha)	1.04	0.79	1.19	1.31	0.66	1.00	0.92	**0.99**
LUC carbon intensity (gCO_{2e}/MJ)	33.6	18.3	44.3	35.3	27.1	27.4	24.1	**30**

Table 6 GTAP model results for sugar beet ethanol in accordance with LCFS (2009) (Tab. IV-12)

Scenario	A	B	C	D	E	Mean
Economic Inputs						
EtOH production increase (bill. gal.)	2.00	2.00	2.00	2.00	2.00	
Elasticity of crop yields wrt area expansion	0.50	0.75	0.50	0.50	*	
Crop yield elasticity	0.25	0.25	0.25	0.25	0.25	
Elasticity of land transformation	0.20	0.20	0.30	0.10	0.20	
Elasticity of harvested acreage response	0.50	0.50	0.50	0.50	0.50	
Trade elasticity of crops	See Appendix C					
Model Results						
Total land converted (million ha)	1.28	0.85	1.46	0.94	0.94	**1.09**
• Forest land (million ha)	0.43	0.22	0.36	0.40	0.26	**0.33**
• Pasture land (million ha)	0.85	0.63	1.10	0.54	0.68	**0.76**
Brazil land converted (million ha)	0.89	0.59	1.06	0.60	0.55	**0.74**
• Brazil forest land (million ha)	0.30	0.15	0.25	0.26	0.13	**0.22**
• Brazil pasture land (million ha)	0.59	0.44	0.81	0.34	0.42	**0.52**
ILUC carbon intensity (gCO_{2e}/MJ)	56.7	32.3	54.5	48.3	38.3	**46**

* Brazil = 0.80, all other = 0.50

Searchinger et al. (2008) calculated 104 CO_2eq/MJ corn bioethanol also using GTAP calculations. When comparing these values, the bandwidth shows the uncertainties in the calculations. In Figure 3, O'Hare (2009) shows the overlap of range of the calculations of Searchinger and of Purdue (for LCFS) using Monte Carlo simulations.

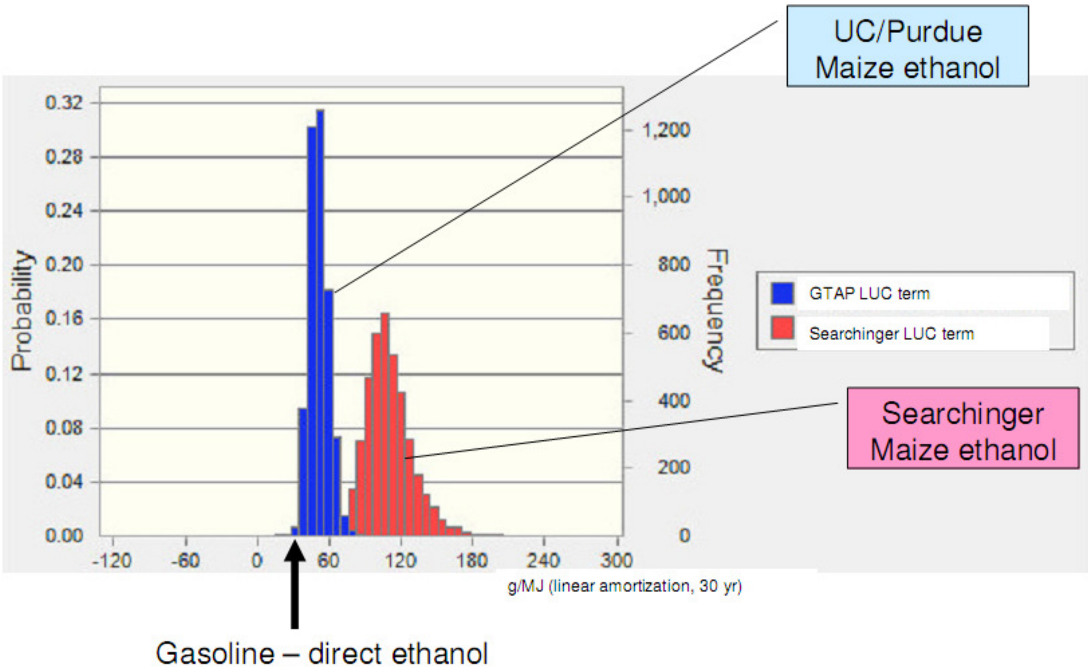


Figure 3 Uncertainty range of the model results from Searchinger et al. (2008) and the calculations of the Universities of California and Purdue for the LCFS; from O'Hare (2009)

3.6 Assessing the models

We would like to once again stress that this overview study cannot contain a comprehensive analysis of the models, which is why we will rely on the judgment of proven experts on this topic. Well-founded assessments on the FASOM/FAPRI model combination can be found in the peer review report recently published by ICF (2009) and Sheehan (2009) which are the primary references in the section below.

3.6.1 Analysis of strengths/weaknesses of the model combinations/models

Table 11 lists the strengths and weaknesses of the model combination proposed by the EPA and the GTAP model of the CARB.

Table 7 Overview of the strengths and weaknesses of the FASOM/FAPRI model of the US EPA and the GTAP model of the CARB (based on ICF 2009)

Strengths	Weaknesses
FASOM/FAPRI model combination	
☐ Higher resolution of the PE models used vis-à-vis GE models such as GTAP	☐ Missing link between agricultural market and the rest of the economy – particularly the energy sector – resulting from the use of PE models
	☐ No geographic reference
	☐ Inconsistencies between FASOM and FAPRI
	☐ The forestry sector was deactivated in the modeling with FASOM, i.e. interactions between the agricultural and forestry sectors were not adequately considered
	☐ The relatively short analysis timeframe selected by Winrock is considered problematic
GTAP model	
☐ The model can be adjusted to greenhouse gas reduction scenarios (performance-based modeling)	☐ GTAP is not dynamic
	☐ GTAP treats all oil and sugar crops as one commodity

In summary, it can be established from the experts[1] who have their say in ICF (2009) that despite being generally suitable, the model combination:

- cannot provide a model for the "correct" answer because each of the models has specific strengths and weaknesses and there are inevitably varying results
- the models are already too complex to enable transparency (Sheehan, Searchinger)
- the complexity is not yet adequate to incorporate all dependent factors sufficiently (Banse, Wang)

At a LUC workshop with high-ranking participants in Vonore, Tennessee, in May 2009, a similar conclusion was reached, i.e. an individual model can only address sub-aspects of the overall problem but further uncertainty is created through the formation of interfaces from the necessary combination of models (Dale et al. 2009). The step of

[1] Dr. Martin Banse (Univ. of Wageningen), Tim Searchinger (Princeton), John Sheeham (Univ. of Minnesota), Dr. Michael Wang (Argonne)

understanding which models lead to which results with which assumptions and input data still has to be completed.

3.6.2 Assessing the model application

We agree with Sheehan (2009) that, at this point in time, research is still in its infancy despite its thoroughly intensive approaches to calculating ILUC with econometric model calculation. At the same time, he emphasizes that the uncertainty that still exists in calculating the indirect effects cannot be a reason for leaving them out.

The broad variation in the results of the models (see section 3.5) is currently the core problem for their application for legislative purposes. Even though every type of default value can always be challenged from a factual standpoint, the calculation results of the econometric models, however, are hardly transparent to those not involved in their creation.

On the other hand, it is true that a high degree of expertise on the part of developers and large quantities of data have been and will continue to be incorporated into these models, and that they have been subject to numerous intensive reviews by third-party experts. It thus has to be assumed that plausible results can be generated in accordance with the initial premises. If it is also assumed that the initial assumptions are not "wrong", it can also be said that the greenhouse gas emissions caused by ILUC are of a relevant magnitude: between 30 and 100 g CO_2eq/MJ in the example of corn bioethanol in the US. In any case, the ILUC greenhouse gas emissions from the US and California fall in a range greater than zero for the calculated cases. Until this can be generally considered a “legal standard”, however, the uncertainty and weaknesses of the models discussed above have to be considerably reduced. The major differences between the documented results are a clear indication that there is still a great need for discussion and clarification when defining the assumptions, the input parameters and even, in some cases, in selecting the "right" model.

The question of selecting the right model and the "right" parameters and "factors" will likely not be answered with purely scientific discourse. The scientists involved, however, are urgently called on to plausibly explain the significant differences in the results and make it possible for the political decision-makers to come up with an internationally acceptable "default value" in the first place. The current discrepancies in the figures (that are not transparent in the short amount of time given the high complexity of the models) need, however, a fairly rapid convergence. In this respect, it is considered essential that a validation that goes beyond the circle of experts is carried out for the models in use. In the process, the certainty of the results of the model calculations should be validated and assessed against developments that actually occurred in retrospect.

4 Deterministic approaches (allocation)

While macroeconomic models in some respects possess the highest possible level of complexity for addressing the issue of ILUC, the deterministic approach represents the highest level of simplicity. The first ideas for this type of approach for ILUC in relation to biomass production were developed by Fritsche (2007)[10] and became known by the term “risk adder” and are now being further developed under the name “ILUC factor”.

The bonus of 29 g CO_2eq/MJ introduced in RED Annex V No. 7 and 8 was derived using a comparable approach – in other words, a reversal of the penalty for the cases that do not explicitly bring about direct land use change.

In the last changes proposed by the EU Parliament for the RED, an e_{ILUC} penalty of 40 g CO_2eq/MJ was introduced[11] at the same time as the bonus by Rapporteur Turmes. It was derived using a comparable approach.

In the following section, Fritsche’s ILUC factor, the bonus solution of the RED based on this factor and another proposal by Tipper (2009) are described in brief and evaluated.

4.1 ILUC factor according to Fritsche

According to Fritsche’s approach (2007, 2009), the initial question is what form land use change can take in the worst case as a result of a displacement process with respect to the CO_2 balance - in other words, which land is affected. Because the displacement effects are global, all countries that participate as exporters in world trade are affected. The potential CO_2 emissions from ILUC are determined in a simplified fashion as a mean value of the percentage of land for agricultural exports broken down by global region and the respective C released as a result of LUC there (see Table 8).

Using this method, a type of theoretical emission potential of around 400 t CO_2/ha is calculated that, similar to the ruling in the RED, is divided by 20 years and produces a theoretical ILUC factor of 20 t CO_2/(ha x a). Because the production of biofuels does not result in indirect land use change in every case either fully or partially (partial use of fallow land, partial increase in yield, also future increase expected in biofuels from residuals), Fritsche derives a "conservative minimum" of 25 % of the theoretical ILUC factor.

[10] Fritsche, U.: GHG Accounting for Biofuels: Considering CO_2 from Leakage; Extended and updated version, Darmstadt (Germany), May 21, 2007

[11] Lowered to 10 g CO_2eq/MJ by Wijkman from the Committee on Environment, Public Health and Food Safety as a compromise

Table 8 Derivation of the potential CO_2 emissions caused by ILUC according to Fritsche (from the Öko-Institut/IFEU 2009)

Region, culture vs. type of land	**Assumptions about C from DLUC** (acc. to IPCC) t CO_2/ha	**Cultivated land in the "global mix"** Simplified percentages	**Land-weighted proportional GHG emissions for LUC in t CO_2/ha**
EU, rapeseed/wheat vs. pastureland	254	20%	51
USA, corn vs. pastureland	254	25%	64
Brazil, sugarcane vs. savanna	491	50%	246
Indonesia, palm oil vs. rain forest	972	5%	49
TOTAL			**400**
Annual [t CO_2/ha*a]	(20 years)		**20**

The LUC "sectoral average" obtained this way is allocated to the various biofuel types on the basis of the respective biomass yield per hectare and the respective conversion rates. The allocation methodology accounts for co-products according to their heating value (according to the Renewable Energy Directive).

A key element of this proposal is the link established between the ILUC factor and the specific land needed for the respective biomass: the higher the land yield (expressed in MJ of bioenergy), the lower the ILUC factor (in relation to kg CO_2eq./GJ of bioenergy). Because the land needed for the biofuels is allocated across the lifecycle, products with high proportions of co-products generally benefit.

Table 9 provides a selection of ILUC factors for specific products that are produced when the respective land yield values are used as a basis.

Table 9 Sample derivation of ILUC factors according to the Fritsche's proposal (2007, 2009) taking into account land yield values and allocation values according to Fehrenbach et al. (2007)

Region, culture vs. type of land	**Land needed m² / MJ biomass** [a] (primary and co-products)	**Allocation percentage for biofuel** [a] (primary product)	**ILUC value**[b] **in g CO_2/MJ**
EU, rapeseed	200	60%	60
EU, wheat	174	55%	48
USA, corn	131	55%	36
Brazil, sugarcane	121	88%	53
Indonesia, palm oil	79	48%	15

a) Figures from Fehrenbach et al. (2007) – not identical to the calculation basis of RE-DIR Annex V

b) Offset with 5 g CO_2eq./ha (25% of 20 g CO_2eq/ha)

Assessing the model application

As is evident in Table 9, the result of using one uniform, land-specific ILUC value that is considered the sectoral average regardless of regional effects is that biofuels from LUC and ILUC high-risk areas were assigned the lowest ILUC GHG emissions. In concrete terms, this means that: rapeseed crops in Germany with a lower yield per hectare produce a higher ILUC risk than palm oil crops in Southeast Asia that are seen in a closer geographical context with high-risk areas such as the tropical rainforest. This might be consistent if we assume the existence of a globally communicating system within the limited area of cultivable land available. In reality, however, all systems that have high per hectare yields are given preferential treatment even when these systems have a relatively direct correlation with the most problematic LUC effects (e.g. palm oil in the AEZ of the tropical rainforests). In addition, the various crop products show different potential for future increases in yield. A uniform application ignores the specific differences relating to ILUC risks.

Fritsche (2009) thus sees a need to adjust the current ILUC factor with reference to the empirical values of Gibbs (2009) and to add a type of regional "risk mapping". According to this, these types of crop growing regions are subject to a special assessment in which additional biomass cultivation is linked to certain ILUC risks in accordance the results of general equilibrium models (see section 3.1.1). The authors of this study also see the need to improve the methodology of the ILUC factor approach by taking into account regional and path-specific effects.

4.2 Bonus according to RED and ILUC penalty according to Turmes / Wijkman

In the EU discussion about the RED, a **bonus** of 29 kg CO_2/GJ, instead of an ILUC penalty (risk adder), was included for biofuels grown on degraded land which relates to Fritsche’s concept of the ILUC factor (2007, 2009). To make them easier to use and simplify the units, an energy reference was selected for the factor instead of a land reference.

The penalty proposed by Turmes (40 g CO_2/GJ), which was not incorporated into the directive, and the compromise proposed by Wijkman (10 g CO_2/GJ) behave the same way.

The concrete land use of biofuels is not taken into consideration here nor is the effect of co-products.

4.3 ILUC according to Tipper

Tipper et al. (2009) also propose a "practical approach" for implementing the ILUC in the political process. They allocate one portion of the currently measurable forest erosion at global level to the expansion of agricultural production (including biomass for energy) and derive a uniform ILUC penalty for all products using a "black box analysis". Reference data are the FAO estimates of 7.3 million ha of deforestation per year (time period 2000 to 2005) whereby 16 % is to be attributed to agricultural commodities. For this proportional deforestation, Tipper et al. calculate a total emission inventory of right around 2 billion tons CO_2 in accordance with the IPCC, relate this to the production increase of agricultural commodities across a timeframe of 25 years and arrive at a figure of 286 kg CO_2 per ton of additional production. Tipper et al. also take into account the co-products per allocation broken down by heating value (see also Figure 4).

Tipper et al. stress that this value (or the values allocated for individual biofuels) is to be considered an overall LUC that subsumes the DLUC and ILUC. LUC that is to be allocated directly to a sector or producer thus has to be taken from the remaining "pool". This way the responsibility of specific sectors can be directly assigned to LUC processes and CO_2 emissions.

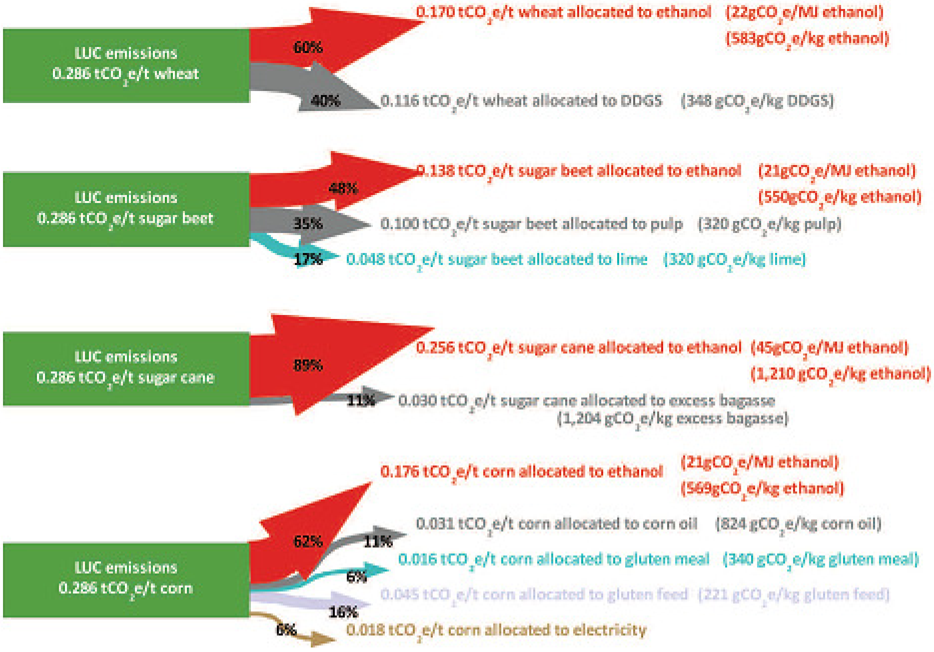


Figure 4 LUC allocation for four bioethanol production paths according to Tipper et al. (2009)

5 Other approaches

5.1 Spreadsheet models

What are known as spreadsheet models strike a balance between the very complex econometric/macroeconomic models and the deliberately simplified deterministic approaches. The proposal of Lywood (2009) is mainly discussed here. The work of DG Agri and Friends-of-the-Earth (FoE) is also mentioned.

The Lywood model

Lywood's model (2009) is based on the historical analysis of, on the one hand, increases in land yields and, on the other, regional and culture-specific patterns of land use change. It analyzes which proportion of a certain increase in demand for biomass is met by an increase in land use and which is met by an increase in productivity.

This analysis shows that, e.g. when global yield for wheat increases, there is a simultaneous decline in cultivated land globally. As a result, wheat is assigned a negative coefficient for the LUC calculation in the Lywood model: more cultivation of wheat leads to less need for land. Other production systems, on the other hand, (corn, rapeseed, soy, oil palm), result in increased land use when yields increase despite increases in specific yields.

The second key element of the Lywood model is the inclusion of co-products by means of a substitution calculation based on the nutritional values of protein (mix of wheat and soy meal). A similar result is also produced with US macroeconomic models, although which production patterns are behind substituted animal feed is hardly comprehensible to those not involved in their creation. Lywood addresses this clearly, performs an assessment, by, e.g. crediting DDGS produced in Europe with soy meal produced in South America with considerably lower crop yields per hectare, i.e. correspondingly considerable LUC effects. If the co-products were to produce such decisive (in the case of wheat, decisively positive) ILUC effects, such an approach would be justifiable. This effect was also shown in co-product scenarios in an IFEU study (Rettenmaier et al. 2008).

Assessing the model application

It generally has to be kept in mind that specifying a certain co-product as a substituted product is a justified way of assessing scenarios. However, for a general model, the question arises as to how the substitution of this very product (e.g. soy meal, produced in freshly cleared forests in South America) can be verified as applicable to the entirety of all co-products produced. An approach that takes the analysis one step further would therefore use scenario analyses to determine how the result would be affected by the consequences of possible (conceivable) substitutions other than soy substitution in the Lywood model.

Figure 4 shows the overall result of the GHG savings rates for a selection of production systems including the ILUC results. It is quite clear that biofuels from wheat, corn and rapeseed considerably increase GHG reduction through ILUC (due to soy substitution through the co-products and, for wheat, also due to the "negative" land use factor and primarily due to no direct conversion of forest for these products in the historical context). In contrast, the sugar beet remains unchanged through ILUC which is surprising because co-products used as animal feed are also created in this production path. The balances for sugar beet and, particularly oil palm and soy beans, as a result of ILUC are much worse in contrast.

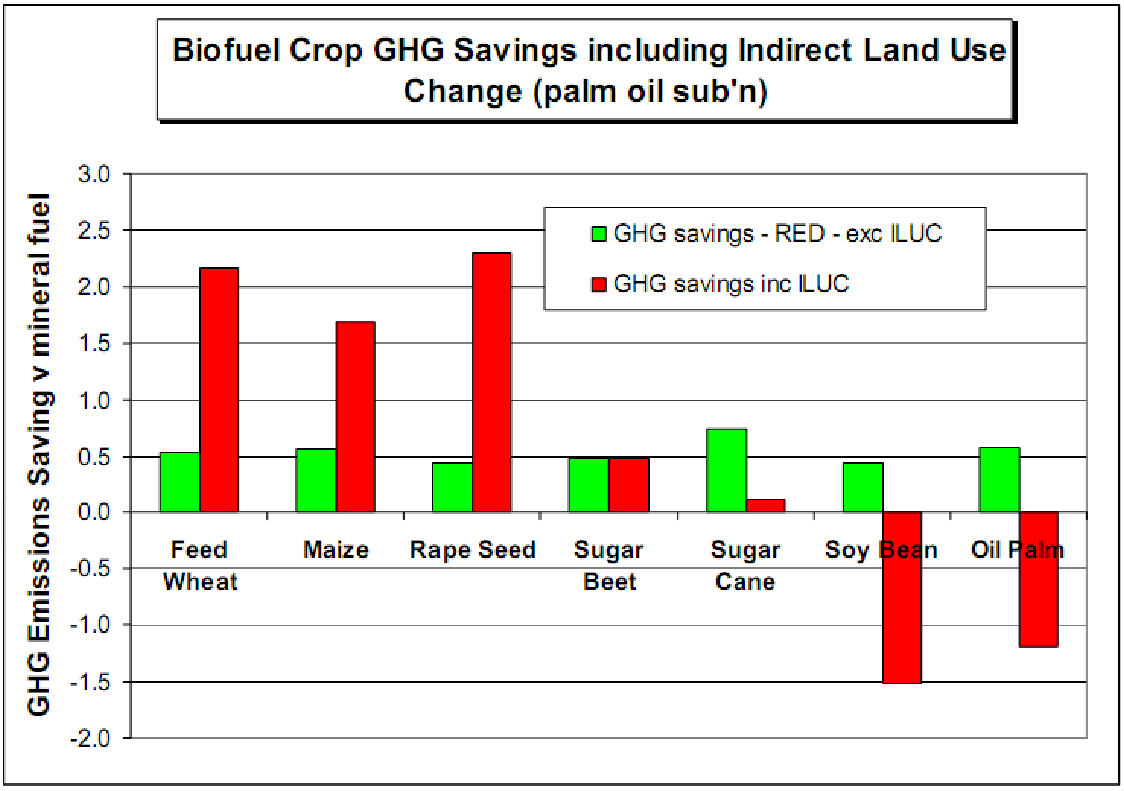


Figure 4 GHG emissions for a selection of production paths including ILUC using Lywood's approach (2009)

For this proposal, two detailed items must be looked at more closely in particular:

1. The historical context is certainly useful but the increases in yields are only considered globally.
2. If the co-products are included, there is a differentiation in various world regions. However, the correlations between the land uses in the various regions of the world created by the globalized market are not considered, i.e. the international interdependencies of ILUC remain unaccounted for.

However, it is always necessary to verify which assumptions sufficiently represent reality. To this end, comparative calculations could be performed with various macroeconomic models since they claim to be able to represent the “marginal” (limit) substitution effects. An extensive reciprocal reproducibility of the LUC values should be feasible if the relevant parameters are set identically. Based on the analysis status, this is not the case at present considering the results from the US and California, even though this cannot be negatively attributed to any one of the approaches alone because, in the opinion of the authors, none of them is sufficiently transparent at this time.

5.2 Risk minimization models

The **Responsible Cultivation Area (RCA)** has to be mentioned here in particular (Dehue, Meyer 2009). It arose from an initiative in the private sector (Shell, Neste Oil, etc.) that the consulting company, Ecofys, commissioned in cooperation with NGOs such as Conservation International and WWF, to develop a method to carry out concrete bioenergy production projects with as little risk as possible in terms of ILUC. The key underlying elements are:

- Defining criteria for biomass with low ILUC risk:
- Identifying and using opportunities arising from biomass production to trigger an increase in productivity overall
- Carrying out infrastructure measures in regions without infrastructure
- Concentrating on degraded land

Ecofys oversees pilot projects in Indonesia and Brazil. Because of the involvement of industry, the approach appears promising. It must, however, be kept in mind that RCA is not designed as a quantified approach for ILUC effects.

6 Summary and conclusions

The effects of indirect land use change are generally considered a relevant aspect in evaluating cultivated biomass. The authors share this opinion.

With the time schedule of the European Commission and the discussion in the US, ILUC will be a core issue in sustainability requirements and greenhouse gas balances for bioenergy sources in the near future. The great uncertainty about the "right approach" that exists today stands in stark contrast to the importance of the issue, particularly when it comes to implementation in legal rulings (Renewable Energy Directive and national legislation). The characteristics of the existing approaches have been described in brief in this study and their respective strengths and weaknesses analyzed.

The various approaches to ILUC calculation can be generally broken down as follows:

- The complex econometric models/model combinations
- The "simplified" deterministic approaches
- Approaches that strike a balance between both

As has been shown extensively in this study, the main problem of **econometric models** lies in their complex nature – due to their complexity, the calculatory procedures and results are hardly comprehensible to experts not involved in their creation which necessarily involves having “faith” in these models. On the other hand, the strongly varying results among the prominent examples of the Renewable Fuel Standard in the USA with the FASOM / FAPRI model mix, the Low Carbon Fuel Standard of California with the GTAP model and Searchinger et al. (2008), demonstrate that an increase in complexity does not necessarily result in greater accuracy, since the differences in the results are virtually “pre-programmed” due to the large number of parameters used. The distinctly higher results of Searchinger, for example, are primarily a result of the fact that his calculations do not include future increases in yield. Whether the yields will increase in the future and, if so, to what extent, depends heavily on the culture being examined and the respective agro-ecological zone (AEZ).

However, the use of such models is extremely valuable for gaining knowledge about market reactions, interdependencies, sensitivities, and the magnitudes of effects. The question arises, however, as to whether this type of model should be implemented within the scope of legislation if the scientific community has not agreed which model is the “right” one. Results ranging from 30 to 104 g CO_{2eq}/MJ for corn ethanol (see Table 10), for example, don’t satisfy standards of scientific accuracy.

Even though the results derived from econometric models are widely varied, they at least give some orientation as to the potential order of magnitude and make it possible to recognize ILUC values consistently higher than zero for the cases calculated in the US and California. However, to be able to consider this a "legal standard" falls short due to a lack of transparency in the calculations despite extensive documentation and due to a considerable need for discussion and clarification with respect to defining the premises or the input parameters.

Deterministic approaches, on the other hand, are suitable for producing highly transparent values using extremely simple calculations. They are in some ways the opposite of macro-economic models, or model combinations, in terms of complexity. These types of methods are called "deterministic" because approximate figures are calculated here instead of the sensitivity of complex models.

In particular, the “risk adder” created by Fritsche (2007), which has been further developed into the **ILUC factor** (Fritsche 2009), has to be mentioned in this regard. This approach assumes that additional biomass production by definition (deterministic) results in additional land use. This is roughly estimated using simple data and allocated to biomass production. Curbing effects, such as future increases in yield, use of fallow land, transition to use of residuals and other LUC-reducing factors are included in the allocation. The ILUC factor represents a "sectoral average" in relation to the respective biomass yield per hectare. This means that it ignores regional effects. The resulting effect is that the lowest ILUC GHG emissions are allocated to biofuels from high-risk LUC and ILUC areas.

Fritsche is planning to further develop the ILUC factor using empirical values and including regional risk aspects (2009).

A combination of macroeconomic model information and its integration into a more simple deterministic approach could be the ideal solution. Various authors have already worked in this direction with **spreadsheet models**. Especially the model developed by Lywood (2008, 2009) should be mentioned in this regard. It first examines (on the basis of historical data) which proportion of a certain increased demand per biomass is met by increased land use and which is met by increased productivity. A net land use effect is produced after co-products are included. For the co-products, an assessment is performed to determine which intraregional and interregional substitution effects occur and which types of land are re-assigned to agriculture in the respective regions (also on the basis of historical data). This, in turn, yields the CO_2 emitted from the new areas which is converted into an annual ILUC factor. This approach is hence both biomass- and region-specific.

The fact that the correlations between the land uses in various regions of the world are only assessed in terms of the co-products is considered a disadvantage. The land used for biomass production remains in regional frames of reference and the international interdependencies of the ILUC go unaccounted for.

The significant differences between the approaches described thus also currently produce great differences in the results. Table 10 summarizes the most important aspects of the models and lists ILUC sample values for ethanol made from corn. The range spans +104 g CO_2eq/MJ (Searchinger) to -92 g CO_2eq/MJ (Lywood). The general reason for the core differences between the two values is: while the first does not include future increases in yields, credits an average mix of similar products for co-products and uses the forest and savanna as the foundation for land use change, the latter gives considerable credits for co-products and takes pastureland for land use change.

Table 10 Overview of the key models and approaches

	Complexity	Transparency	Uncertainty	Inclusion of co-products	Values for corn EtOH (g CO_2/MJ)
Econometric	**models**				
GTAP (LCFS - Cal)	Very high	Only for experts familiar with the model	Very high level	Integrated in the overall model	30
FASOM/FAPRI (US EPA, RFS)	Very high		Input data leads to	Integrated in the overall model	50 – 65
Searchinger (FAPRI)	High	Rudimentary	Considerable range	Integrated	104
Deterministic	**approaches**				
ILUC factor (Fritsche)	Low	High, because simpler approach	Simple estimate	Per allocation land-sensitive	36
Bonus / penalty (RE-DIR, EP)	Low		"Accuracy" per convention	Allocation not land-sensitive	-29 / 40 or 10
ILUC (Tipper)	Moderate	Relatively high	Convention	Per allocation	22 (wheat)
Spreadsheet	**models**				
Lywood	Medium	High in principal but calculation methods and reference data not published to date	Basic assumptions: historical trend and co-product substitution determine the result	Co-products heavily influence the overall results	- 92 (?) value read from graphic with % savings

Each of the approaches presented does not allow for a final assessment of this complex subject on its own. The great variations of the results indicate that a considerable deficit exists in limiting the quantitative magnitude of the effect. In any case, the results lead to significant effects in the overall life cycle assessment of bioenergy, regardless of the approach applied. This has considerable consequences when it comes to meeting the necessary emission saving rates.

The discussion about the “right” approach or the “right” model will therefore have to continue. The authors see the necessity of including ILUC adequately as a consequence of additional land use for biomass crops intended for energy purposes, food production, and fiber utilization. Whether one of the approaches mentioned above will prove successful as an acceptable standard remains to be seen. Most certainly, complex models are urgently needed to explore the indirect effects of additional biomass production which are dependent on market reactions and to identify correlations. However, a high level of transparency and results that can be understood, not just by experts, will be essential if they are to be incorporated into legal standards. At the moment, the scientific community is catching up with policymakers and their objectives. The goal should be to reach a stage where similar ILUC results can be reproduced with the various models and approaches because the reasons for deviations have been identified.

Regardless of which method is used to calculate an ILUC value, experts are aware that it can only serve as a support tool, albeit an acceptable one. In reality, the “indirect effects” of biomass production are direct effects caused by other sectors (e.g. food and fiber production). However, the ideal solution strived for in theory of finding a uniform model that encompasses all sectors (so that land use changes and the resulting greenhouse-gas emissions can be regulated globally) appears realistic in practice over the medium or long term at best, which makes this expansion of dimension more a theoretical idea.

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