Kiel

Working Papers

Kiel Institute
for the World Economy

An evaluation of approaches for quantifying emissions from indirect land use change

by Ruth Delzeit, Gernot Klepper and Mareike Söder

No. 2035 | April 2016

Web: www.ifw-kiel.de

Kiel Institute for the World Economy, Kiellinie 66, 24105 Kiel, Germany

Kiel Working Paper No. 2035 | April 2016

An evaluation of approaches for quantifying emissions from indirect land use change

Ruth Delzeit, Gernot Klepper and Mareike Söder

Abstract: The contribution of biofuels to save greenhouse gas emissions has been challenged over the last years. A still unresolved question is how to quantify emissions from indirect land use change (iLUC). In this paper we review approaches to quantify iLUC-emissions. We conclude that economic simulation models have fewer drawbacks compared to two other approaches. We find that economic simulation models contain a high level of uncertainty with respect to key model parameters. Further, we conclude that it is inappropriate to calculate crop-specific iLUC-emissions and to include them into binding regulation. We argue that modelling results, particularly crop-specific ones, should not be used for policy decisions.

Keywords: CGE Modeling, indirect land use change, biofuels, greenhouse gas emissions

JEL classification: C61, Q16, Q42

Ruth Delzeit
Kiel Institute for the World Economy
The Environment and Natural Resources
D-24105 Kiel
E-mail: ruth.delzeit@ifw-kiel.de

Mareike Söder
Kiel Institute for the World Economy
The Environment and Natural Resources
D-24105 Kiel
E-mail: mareike.soeder@ifw-kiel.de

Gernot Klepper
Kiel Institute for the World Economy
The Environment and Natural Resources
D-24105 Kiel
E-mail: gernot.klepper@ifw-kiel.de

1. Introduction

In 2009, the EU extended its goal of a 5.75% share of renewable energy in the transport sector by 2010 (EU 2003) to a share of 10% by 2020 (EU 2009). In addition to increasing energy security and promoting the agricultural sector, the expected reduction in greenhouse gas emissions (called emissions in the following) is the main reason for subsidising biofuel production. This view that biofuels provide emission reductions was challenged by a publication by Searchinger et al. (2008). As a response, the EU-RED, recognising the need for a calculation of emissions, requires the accounting of emissions from LUC in the emission balance as part of the certification of biofuels (EU 2009). However, so far only the computing of emissions from the production process, transport and direct LUC (dLUC) is required. By definition, dLUC "occurs when a previous land use is converted to bioenergy crop production" (Plevin et al. 2010, p. 8015). These direct emissions are part of a standard emissions balance, which is used to calculate emissions for biofuels.[1]

Part of LUC is indirect. "ILUC-emissions occur when grassland and forest are converted to cropland somewhere on the globe to meet the demand for commodities displaced by the production of biofuel feedstocks" (Plevin et al. (2010), p.8015).[2] ILUC is caused by increasing prices for agricultural commodities, thus making land expansion profitable. It is therefore a global phenomenon that is transmitted through global markets for agricultural commodities. As a consequence, iLUC induced by national biofuel support policies may occur anywhere in the world and not necessarily in the country that implemented the policy. If this was the only cause of demand changes, iLUC indeed could be completely attributed to the promotion of biofuels.

However, the identification of iLUC is made difficult due to the complex interrelations in agricultural and downstream markets. Biofuel production is closely connected with food production, particularly meat, since e.g. meals for animal feed are jointly produced with

[1] as in the EU-RED (EU 2009), the US Energy Independence and Security Act (EISA) of 2007, and California's Low Carbon Fuel Standard (LCFS)

[2] For a definition of iLUC see also Gawel and Ludwig (2011).

vegetable oils which are used for both, biofuel and food production. Therefore, there is no direct causal relationship between increases biofuel production and iLUC.

Nonetheless, some studies suggest that iLUC-emissions may be larger compared to emissions from dLUC (e.g. Plevin et al. 2010), the European Commission (EC) aims at including iLUC-emissions into its regulation of biofuels. Thus, there is a need for quantified estimates of alleged iLUC-emissions for policy regulation. However, such estimations require a comprehensive analysis of the complex agricultural production systems. Several different conceptual approaches have been used to quantify iLUC-emissions. These different approaches result in quite different contributions to the identification and quantification of iIUC and to the determination of a causal relationship between iLUC and the expansion of biofuel production.

This paper offers insights into the sources of uncertainty regarding the results on the quantity of greenhouse gas emissions from iLUC (iLUC-emissions) Furthermore, we analyse different quantifications of iLUC-emissions by reviewing the pros and cons of various approaches. This paper adds important insights to the debate on how to address the iLUC compared to existing reviews on land use change (LUC) modelling (e.g. Golub and Hertel (2012), Dumortier et al. (2011)).

The paper is organised as follows. In section 2, we provide an overview of the current discussion about LUC regulations in the EU. In section 3, we discuss and assess the various methods that have been used to quantify iLUC-emissions. In section 4, we present modelling results that quantify the price and LUC effect of biofuel promotion and discuss possible limitations of the models. Finally, we summarise our findings and conclude the paper.

2. Emissions from LUC in the EU-RED

To understand the request of the EC for a quantification of iLUC-emissions, we briefly review the existing biofuel regulation and proposals for iLUC regulation.

The current regulation of emissions in the EU-RED has two major components:

- EU-RED prohibits using land with high carbon stocks[3] or high biodiversity for producing feedstocks for biofuel production.
- For production in all other areas, the certification procedure must include an assessment of emissions throughout the value chain.[4] The assessment of emissions must include emissions from transport and production and emissions from dLUC. The resulting emission balance is evaluated and compared with comparable emissions from fossil fuels (diesel or gasoline). Each biofuel must achieve a minimum emission saving threshold (MEST) of 35%.

Only biofuels that meet these requirements are eligible for inclusion in the national quotas, and hence receive a price premium on the market.[5]

The 35% MEST can be interpreted as a precautionary measure to ensure that biofuels indeed lead to emission savings in light of the uncertainties involved in assessing a particular biofuel produced in a particular location that enforces more or less global criteria. Consequently, the required 35% MEST, combined with the default values, could be understood as a "risk premium" that prevents biofuels from potentially violating the objective of climate change mitigation. Because the "risk premium" for emissions from the production process and the dLUC do not explicitly account for iLUC-emissions, the question is whether the 35% MEST is high enough to cover potential iLUC-emissions.

It is questioned whether iLUC-emissions are sufficiently covered by the current 35% MEST (USC 2011). After discussing several options regulating iLUC-emissions within EU biofuel framework (EC 2010 p. 14), in June 2014, the Energy Council of the EU reached a political agreement on a draft directive on iLUC[6] (EC 2014). The EC proposes to

- limit the consumption of conventional biofuels from 10% to 7% (the current share) by 2020;

[3] which are all continuously forested and peat land areas
[4] This can be conducted using the default values of the EU-RED, the individual emissions values of a particular value chain, or using normalised (standardised) regional emission values.
[5] For a detailed discussion of these EC guidelines, see Lange (2011).
[6] This directive amends the fuel quality directive (98/70/EC) and EU-RED (EU 2009).

- increase the amount of advanced biofuels to achieve the 10% target by 2020 by double-counting them;
- report on iLUC and its influence on emissions savings based on estimated iLUC.factors;
- retain the option to introduce adjusted estimated iLUC-factors into the sustainability criteria.

The proposal implies that the EC does not see the need to immediately increase the MEST, but rather, it aims to reduce the market share of conventional biofuels. Additionally, it preserves the option to introduce additional iLUC regulations in the future. Therefore, it is deemed important to assess and discuss possibilities to quantify emissions from iLUC as well as the factors driving iLUC based on scientific assessments. However, before reviewing approaches for calculating iLUC-emissions, the theoretical requirements for determining iLUC must be assessed.

3. Calculating GHG emissions from ILUC: A review

3.1. Requirements

A disaggregated determination of iLUC-emissions requires a series of analytical steps: first, a site-specific identification of replacements of food and feed production by biofuel feedstocks; second, an economic analysis of the global market responses to this replacement; and third, a site-specific identification of land cover change to produce a particular food or feed as a result of the market response.

Thus, it is first necessary to identify where feedstock for biofuels are produced. This is accomplished using the certification systems approved by the EU in accordance with the EU-RED. Then the response of increasing feedstock production for biofuels in the market for agricultural commodities via the response of market prices must be assessed. The economic drivers for the magnitude of the price effect, and thus LUC, are the demand and supply conditions for food and feed products. Contiguous to changes in the demand for biofuel feedstocks, there are numerous other changes in demand and supply that are important. Because the feedstocks for biofuels often carry joint products, these parallel developments must be taken into account as well. These changes are not confined to local market responses because today, most local markets are integrated into the global demand and supply conditions of agricultural products. The global market conditions, in turn, are the simultaneous result of many factors that have sectoral, geographic and temporal dimensions.

There are several inter-connections among the agricultural sector, the energy sector and the land markets which vary according to the crops used as a biofuel feedstock. Thus, it is important to differentiate between different biofuel feedstocks that replace food and feed production because their impact on the need to expand the agricultural area can differ substantially. Quantifying these market responses requires an elaborate modelling framework not only for the agricultural but also for the energy market.

Further, it is necessary to assess how the price effect of an increased biofuel demand influences the demand for agricultural land. Probably the most difficult challenge for quantifying iLUC-emissions is to quantify how much area is actually converted as a response to the increased demand for land. This LUC is local by nature and thus strongly determined by local conditions, such as land use regulations, the rule of law, land ownership structures, alternative land use options, land prices, regional support policies, and infrastructure among others. The amount of LUC additionally depends on the geographic and temporal possibility to intensify agricultural production on the existing cropland compared to the potential to convert new land to produce crops. Thus, approaches and studies that in combination with global repercussions reflect land markets, agricultural technology and geophysical production conditions at a highly disaggregated level better identify the location of LUC.

Knowledge about the location of LUC is necessary to determine the amount of iLUC-emissions. Such determination requires detailed information about emission factors for land conversion (e.g., gCO_{2eq}/ha of land type) for each geographic location.

3.2. Literature Review

Several methods have been proposed to quantify emissions from iLUC in practice. They can be classified as a) ad-hoc/deterministic approaches, b) econometric analyses and c) numerical simulation models. The most important studies are reviewed herein.

3.2.1. Deterministic Approaches

The current iLUC debate advances several ad-hoc deterministic approaches to quantify emissions from iLUC. Ad-hoc deterministic approaches are not based on economic models (econometric or simulation), but rather, assumptions are made on correlations from past trends observed in the data. For policymakers and stakeholders not familiar with economic models, the models sometimes appear as black boxes (Böhringer et al. 2013), which causes doubts regarding the reliability of results.

One ad-hoc deterministic approach that is discussed by stakeholders and policymakers is the iLUC – Factor of Fritsche et al. (2010). They derive the global amount of past LUC resulting from the land area used to produce the current globally traded agricultural commodities by first deriving the amount of land used to produce agricultural commodities for export in each country. The sum of this land represents the global mix of land used to produce the globally traded agricultural commodities. Second, they combine this global mix with the CO_2 emissions released in the past for converting this land into agricultural production areas. On average, this is 13.5 t CO_2/ha/year for a 20-year period. Fritsche et al. (2010) further assume that due to yield increases one hectare for producing biofuel feedstock on land formerly used for other production causes 0.25 to 0.5 ha of iLUC. Accordingly, they conclude that emissions of 3.4 to 6.8 t CO_2/ha/year are caused by the displacement, which Fritsche et al. (2010) call the iLUC-factor. Thus, the amount of iLUC-emissions is determined by using simple interpolations of past experiences.

In a similar way, Cornelissen and Dehue (2009) promote the notion of identifying biofuels that have a higher risk of causing iLUC-emissions rather than trying to quantify emissions.

Low risk iLUC production is defined as that which expands into land without provisioning services[7] or production that results in increased productivity.

We identify four important drawbacks of the deterministic approaches. a) The interrelation of sectorial, temporal and geographical factors influencing the quantity of iLUC-emissions described herein is not reflected in the approaches. b) Future impacts of biofuel policies do not necessarily follow trends of the past (EC 2012). In fact, as iLUC estimates are nonlinear and specific to particular scenarios, the iLUC-factor does not remain constant (Khanna et al. 2012). c) Given strong assumptions compared to economic models, the range of results and uncertainties cannot be addressed. d) Because the iLUC-factor is determined at a country-wide level, it might be perceived as a trade barrier (Klepper 2008).

3.2.2. Econometric Approaches

In contrast to deterministic approaches, econometric approaches do not attempt to approximate the mechanism of iLUC. Instead they aim at finding evidence for iLUC by examining historical data to find statistical evidence for the amount of land expansion caused by biofuel policies. Kim and Dale (2011) correlate US biofuel production with deforestation in other regions of the world and find no evidence for iLUC induced by US biofuel production. Their approach is criticised by O'Hare et al. (2011) for correlating two variables in a system with many interacting factors.

Other econometric studies do not focus specifically on biofuel policies but attempt to find a significant relationship between the expansion of an agricultural production process in a certain location and LUC elsewhere. Thus, these studies search for statistical evidence to support their hypothesis on the location of LUC induced by increased production elsewhere, without modelling the market response itself. In a spatial temporal regression model, Arima et al. (2011) link the expansion of mechanised agriculture in existing agricultural areas in Brazil to pasture conversion for soy production on distant, forest frontiers in the Amazon. In a similar way, Andrade de Sá et al. (2012) analyse the spatial-temporal relationship between

[7] e.g., areas without food or feed supply or any other crucial ecosystem service

sugarcane expansions in the south of Brazil and cattle ranching in the Amazon, thus suggesting that the former is displacing the later in the forest frontier.

The general drawback of the results regarding iLUC caused by biofuels is that the discussions ignore regional demand and production changes in other commodities and developments on global agricultural markets into which Brazil is highly integrated. As suggested by Arima et al. (2011) and Andrade de Sá et al. (2012), a price effect due to the expansion of agricultural production in one region may have regional impacts on LUC decisions in another region. However, by not including the development of prices in the analysis, these studies might only detect parallel developments without finding evidence for causality.

Econometric approaches allow estimating past correlations between land expansion and biofuel policies. Since they cannot take into account structural changes, these correlations do not necessarily hold for the future.

3.2.3. Numerical Simulation Models

There is a growing literature that attempts to simulate the impact of certain policies on land use by using numerical models that reflect, as accurately as possible, real market interactions (e.g. OECD 2008; Dumortier et al. 2009; Dumortier et al. 2011; Rosegrant et al. 2008; Prins et al. 2011; Hertel et al. 2010; McDougall and Golub 2009, Lapola et al. 2010). They equilibrate supply and demand for goods and services given the existing technologies, resource endowments, and policies. These models usually create a baseline scenario that simulates current trends on the markets up to a certain target year in the future. This baseline scenario is then used to compare the impact of alternative scenarios that may contain additional policy measures, such as biofuel targets. The comparison of the baseline scenario with the policy scenario provides the information necessary for the assessment of the policy measure. Price effects, LUC, and welfare impacts can be derived from such simulation models.

Regarding the model's suitability for quantifying the LUC caused by biofuel policies, it is necessary to distinguish between two model types: partial equilibrium (PE) models and computable general equilibrium (CGE) models. Even though PE models capture the agricultural sector in greater detail than CGE models, they cannot incorporate feedback effects between other sectors because they treat changes in other sectors exogenously. CGE models treat these changes endogenously, as they address repercussions on other markets, but usually have a lower sectoral aggregation.

In the EU, a controversial discussion regarding the ability of economic models to quantify iLUC arose from a modelling exercise introduced by Laborde (2011) and commissioned by the EC. Its objective is to assess iLUC-emissions under the EU biofuel target. Laborde (2011) uses the CGE model MIRAGE and tests the sensitivity of his results to some of the key model parameters. Valin et al. (2015) recently published a follow-up study also commissioned by the European Commission by using a tailored version of the PE model GLOBIOM. Their similar sensitivity analysis show an even higher range of model results than Laborde´s earlier results. In addition, Golub and Hertel (2012) identify a lack of empirical evidence for several sensitive parameters by reviewing the key assumptions that influence results on LUC caused by biofuels based on the GTAP-BIO model. Also Dumortier et al. (2011) find massive differences in iLUC-emissions depending on the assumptions set and conclude that policymakers should be aware of these differences.

Given that error margins can be displayed by sensitivity analysis in numerical models and that the models have the ability to conceptually incorporate market interactions on a disaggregated level, we conclude that among the described approaches to quantify iLUC-emissions, numerical models are best suited for studying the iLUC caused by biofuel policies. Furthermore, numerical models can simulate future biofuel policies, and take market interactions into account.

However, we argue, consistent with Dumortier et al. (2011), that for policy inferences based on the model results, policymakers must be aware of the effect of key assumptions driving the results of iLUC-emissions estimates. In the following section we shortly present these key assumptions identified in the literature in order to evaluate model results regarding their suitability to support binding regulations.

3.2.4. Quantifying emissions from iLUC using numerical models

We now discuss the model structures, assumptions and different steps along this mechanism that drive differences in the model results in order to evaluate the uncertainty involved with currently available model results of iLUC-emissions.

Price changes for agricultural goods caused by biofuel production create incentives for LUC and are therefore one of the key indicators when assessing the effect of biofuel policies. However, an overview on different price effects resulting from different modelling exercises provided in Kretschmer et al. (2012) shows high ranges of results, thereby making it difficult to determine the “real” level of price effects induced by biofuel policies.

Several important assumptions in the modelling frameworks that drive model results have been identified. First, considering by-products from biofuel production is of particular importance since an increased production of biofuel can lead to a substitution of parts of animal feed (Calzadilla et al. forthcoming, Taheripour et al. 2011). When this interrelation is included in the model, it reduces the demand from the livestock sector for land for animal feed production (Golub and Hertel 2012, Taheripour et al. 2010). When ignoring this relationship, Taheripour et al. (2010) find that cropland conversion due to the US and EU biofuel mandates can be overestimated by approximately 27%. Second, differences in the change of food demand following a change in crop prices is a key parameter for differences in model results (Khanna et al. 2012, and Golup and Hertel 2012). Third, the assumptions regarding changes in productivity resulting from price changes are of great importance as they directly influence the production potential of the existing cropland and, in turn, the capacity to absorb increases in demand (Edwards et al. 2010). Fourth, the elasticity of substitution for animal feed is determined to be crucial for the resulting price effect (Calzadilla et al. forthcoming, Edwards et al. 2010). Finally, Calzadilla et al. (2014) show that the price effect is, inter alia, driven by the approach of how LUC is modelled.

After determining the price effect of biofuel policies, the next step is to determine the resulting LUC effect on the existing managed land (substitution effect) and on land that formerly has not been used for production (land expansion).

Modelling results of LUC standardised by Edwards et al. (2010) vary from 242 to 1928 kHa/Mtoe for biodiesel and from 223 to743 kHa/Mtoe for bioethanol. Thus, consistent with the already high range of results in price effects from different model exercises, results on land expansion also show a wide range of results.

Regarding the substitution effect, in many CGE models, the constant elasticity of transformation (CET) approach is applied as it allows managed land to be transformed to different uses while the ease of transformation between different uses is characterised by elasticities of transformation. These elasticities are crucial when analysing LUC as they determine the magnitude of a price effect on the LUC of different types of land use.

Land expansion into unused areas can either be modelled endogenously by presuming, e.g., a land supply curve or by adding additional land endowment in a scenario analysis. In the case of the latter, the expansion into unused land (e.g., unmanaged forest) is assumed to be exogenous and based on, e.g., historic trends of land expansion in a scenario. When using land supply curves, assumptions regarding the productivity of the thus far unused land must be made. These assumptions are an important factor in determining the profitability of land use expansion.[8]

For determining GHG emissions from the modelled land use change, several assumptions are made which cause differences in LUC-emissions. Edwards et al. (2010) find that the standardised results indicate a considerably large range of emissions for all biofuel options: biodiesel emissions range between approximately 40 gCO_2/MJ and 350 gCO_2/MJ/yr,

[8] Plevin et al. (2015) find that parameter assumptions on crop yield and productivity of newly converted cropland for US corn ethanol, Brazilian sugar cane ethanol, and US soybean biodiesel lead to a variation in GHG emissions from LUC between ±20 g CO_2e MJ^{-1}.

bioethanol emissions range between approximately 25 and 140 gCO_2/MJ/yr. Hertel et al. (2010) calculate a range of emissions between 15 and 90 gCO_2/MJ/yr from US-bioethanol derived from corn, depending on the inclusion of by-products, price responses in the food sector, and price responses in yields. Thus, again, model results differ substantially.

Results indicate that the assumption on where additional managed land expands into former unused land is particularly sensitive in the case of tropical forests and/or peat land as these areas represent large carbon sources. Differences in the assumption about the portion of land use expanding into these rich carbon sinks result in huge differences in the calculated emissions from LUC.

Given that our objective is to evaluate EU policies on iLUC-emissions, we discuss the already mentioned study by Laborde (2011). He applies the CGE model MIRAGE. The results are used for the reporting on iLUC-emissions proposed in the new EU directive (EC 2014).

Laborde (2011)[9] simulates the LUC effect of the EU biofuel target for 2020 and its related emissions using the renewable energy projections as published in the National Renewable Energy Action Plans of the European Member States (EC 2011). The model includes a detailed representation of important biofuel feedstock and biofuel options. LUC is addressed both in the form of substitution within cropland between different agricultural products on these croplands and the expansion of croplands on new land. The conversion of cropland used to produce food and feed into cropland used to produce biofuel feedstock represents a pure substitution effect. The conversion of new land into cropland used to produce food, feed or biofuel feedstock represents either dLUC or iLUC.

Emissions associated with the conversion of new land are computed by using the standard values from the EU-RED. Laborde (2011) presents his results in the form of specific marginal, biofuel feedstock specific emissions from LUC and aggregated global emissions

[9] A first version of this modelling exercise (Al-Raffai et al. 2010) is launched by the EC, and after a public consultation, several model assumptions are changed. A peer-reviewed version is then published by Valin and Laborde (2012).

from LUC. His results with respect to the LUC are the sum of dLUC and iLUC as the model is not able to differentiate between the two types of LUC. The results are presented for two policy scenarios - one simulating the EU biofuel target for 2020 with free trade and one without free trade.

Laborde (2011) investigates the range of model results driven by the uncertainty of several key model parameters with a Monte Carlo simulation and thus addresses, at least to some extent, the uncertainty of model results caused by the sensitive parameters discussed thus far.[10] Furthermore, Laborde (2011) assumes that a share of 33% of the new palm plantations expands into peat land in Indonesia and Malaysia, which is of particular importance with respect to emissions following a land expansion for palm production.[11]

With respect to model sensitivity, in addition to parameter assumptions and modelling approaches there are certain generic limitations in CGE models that should be kept in mind when drawing policy conclusions.

With regard to generic limitations, it must be emphasised that, in general, CGE models are a suitable tool to use to better understand certain effects, such as the influence of biofuel policies on the direction of changes in feedstock, energy prices and output quantities. However, when drafting an iLUC regulation based on model results, the following limitations should be considered:

- The effect of cropland d expansion is modelled in a simplified way and is driven by market effects. Other important factors that similarly play a major role in local land use decisions, such as land market regulations, environmental protection laws and their level of enforcement, tenure rights and other local institutional factors, are considered only indirectly, if at all.

---

[10] The characteristics of the Monte Carlo simulation are presented in the Annex.

[11] This assumption is not further addressed even though in the earlier version, Al-Raffai et al. (2010) assume that a share of 10% of the new palm plantations expand into peat land in Malaysia and a share of 27% do so in Indonesia. This in addition to other changes in assumptions (e.g., share of different biofuel mandates) that result in an increase in the average LUC factor from 17gCO2eq/MJ in the study by Al-Raffai et al. (2010) to 38.4 gCO2eq/MJ in the study by Laborde (2011).

- The LUC-emission applied represent average values for a particular land use category due to a limited differentiation within one land category. Only a further differentiation of different land categories in the model would result in more precise LUC-emission. This would require a much more elaborate database of the spatial distribution of global land categories.
- It is not possible to split the modelled LUC into iLUC and dLUC.[12] Because all markets are cleared simultaneously in the CGE models, only the net LUC can be computed. Thus, LUC-emissions calculated on the basis of a CGE model will always include dLUC and iLUC.
- A distinction between the effect of the EU biofuel target for a specific biofuel feedstock or for a biofuel production option is not possible, which is also due to simultaneous market clearing. The assumption that the marginal effect of a particular biofuel feedstock is the same as the effect of that biofuel feedstock when the model clears all markets and feedstocks simultaneously is, at best, doubtful as it assumes perfect linearity of effects.

Comparing these generic limitations and the data shortcomings for key model parameters with the requirements previously defined herein, it is clear that a conceptually correct identification of iLUC-emissions is, at this time, impossible. Therefore, the decision which iLUC policy leads to a reduction of emissions from using biofuels remains uncertain.

4. Summary and Conclusions

In this paper, we shed light on different approaches to quantify emissions from iLUC. LUC can be quantified using economic simulation models, while a distinction in emissions from iLUC and dLUC is not possible. The currently available models still contain a high level of uncertainty with respect to key model parameters which determine the price, LUC and resulting emissions of biofuel policies. Consequently, the transfer of the results of the current models into iLUC-factors as part of the sustainability criteria is not possible.

[12] See also Valin and Laborde (2012)

In addition, we argue that it is inappropriate to calculate crop-specific emissions from iLUC. This is because calculating LUC-emissions for different crops suffers from methodological drawbacks, as price effects on demand and substitution of feedstuff are an aggregated effect. Accordingly, LUC-emissions cannot be attributed to single crops. Furthermore, we show that econometric and ad-hoc approaches have greater drawbacks than do economic simulation models, and therefore, the econometric and ad-hoc approaches should not be used for policy regulation.

References

Al-Raffai, P., Dimaranan, B. and Laborde, D. 2010. Global Trade and Environmental Impact Study of the EU Biofuels Mandate. Report by ATLASS consortium, March 2010.

Andrade de Sá, S., Palmer, C., Di Falco, S. 2013. Dynamics of indirect land-use change: empirical evidence from Brazil. *Journal of Environmental Economics and Management*, *65*(3), 377-393.

Arima, E. Y., Richards, P., Walker, R., Caldas, M. M. (2011). Statistical confirmation of indirect land use change in the Brazilian Amazon. Environmental Research Letters, 6(2), 024010.

Bowyer, C., Kretschmer, B. 2011. Anticipated Indirect Land Use Change Associated with Expanded Use of Biofuels and Bioliquids in the EU – An Analysis of the National Renewable Energy Action Plans. Report by Institute for European Environmental Policy. http://www.ieep.eu/publications/2011/03/final-report-for-the-assessment-of-the-6th-environment-action-programme (09.09.2011)

Cornelissen, S., Dehue, B. 2009. Summary of approaches to accounting for indirect impacts of biofuel production. Report by Ecofys. http://www.globalbioenergy.org/bioenergyinfo/sort-by-date/detail/en/news/37271/icode/ (09.09.2011)

Delzeit, R., Holm-Mueller, K. 2009. Steps to discern sustainability criteria for a certification scheme of bioethanol in Brazil: Approach and difficulties. In: Energy (34), p.662-668.

DG Energy 2010. The Impact of Land use change on greenhouse gas emissions from biofuels and bioliquids – Literature review. An in-house review conducted for DG Energy as part of the European Commission's analytical work on indirect land use change. Brussels, July 2010.

Dumortier, J, Hayes, D. J., Carriquiry, M., Dong, F., Du, X., Elobeid, A., Fabiosa, J. F., and Tokgoz, S. 2009. Sensitivity of carbon emission estimates from indirect land-use change. Technical report, Working Paper 09-WP 493, Center for Agricultural and Rural Development, Ames, Iowa.

EC (European Commission) 2010. Report from the Commission on indirect land-use change related to biofuels and bioliquids. COM(2010) 811 final. Brussels, 22.12.2010.

EC (European Commission) 2011. Renewable Energy, Action Plans & Forecasts, National Renewable Action Plans. http://ec.europa.eu/energy/renewables/action_plan_en.htm (08.08.2012).

EC (European Commission) 2014. Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (first reading 10300/14), Brussels, 3 June 2014.

EC-Guidelines (European Commission) 2010. Commissions' Decision of 10 June 2010 on guidelines for the calculation of land carbon stocks for the purpose of Annex V to Directive 2009/28/EC. Official Journal of the European Union, L151/19 of 17.6.2010.

Edwards, R., Mulligan, D. and Marelli, L. 2010. Indirect Land Use Change from Increased Biofuels Demand: Comparison of Models and Results for Marginal Biofuels Production from Different Feedstocks, Joint Research Center - European Commission.

EEA (European Environment Agency Scientific Committee, 15 September), 2011. Opinion of the EEA Scientific Committee on Greenhouse Gas Accounting in Relation to

Bioenergy. http://www.eea.europa.eu/about-us/governance/scientific-committee/sc-opinions/opinions-on-scientific-issues/sc-opinion-on-greenhouse-gas

Erb, K.-H., Haberl, H., Krausmann, F., Lauk, C., Plutzar, C., Steinberger, J. K., Müller, C., Bondeau, A., Waha, K., Pollack, G. 2009. Eating the Planet: Feeding and fuelling the world sustainably, fairly and humanely – a scoping study. Commissioned by Compassion in World Farming and Friends of the Earth UK. Institute of Social Ecology and PIK Potsdam. Vienna: Social Ecology Working Paper, 116.

European Union (2003) Directive 2003/30/EC of the European Parliament and of the Council of May 2003 on the promotion of the use of biofuels or other renewable fuels for transport, Official Journal of the European Union, L 123/43 of 17.05.2003.

European Union (2009) Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union, L140/16 of 5.6.2009.

Fritsche, U. R., Hennenberg, K., Hünecke, K., 2010. The “ILUC Factor” as a Means to Hedge Risks of GHG Emissions from Indirect Land Use Change. Working Paper July 2010. Oeko Institut, Darmstadt.

Gawel, E., Ludwig, G. 2011. The iLUC dilemma: How to deal with indirect land use changes when governing energy crops?. Land Use Policy, 28(4), 846-856.

Global Carbon Project 2011. Carbon budget and trends 2010. www.globalcarbonproject.org/carbonbudget (4.12.2011)

Golub, A. A., Hertel, T. W. 2012. Modeling land-use change impacts of biofuels in the GTAP-BIO framework. Climate Change Economics, 3(03).

Haberl, H., Erb, K.-H., Krausmann, F., Bondeau, A., Lauk, C., Müller, C., Plutzar, C., Steinberger, J.K. 2011. Global bioenergy potentials from agricultural land in 2050: Sensitivity to climate change, diets and yields. Biomass and Bioenergy

Hertel, T., Golub, A., Jones, A., OHare, M., Plevin, R. and Kammen, D. 2010. Effects of US Maize Ethanol on Global Land Use and Greenhouse Gas Emissions: Estimating Market-mediated Responses, *BioScience* 60(3), 223-231.

Hertel, T.W., Tyner, W.E., Birur, D.K. 2008. Global bioenergy potentials from agricultural land in 2050. GTAP Working Paper No. 51

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.

Laborde D., Valin, H. 2011. “Modelling Land Use Changes in a Global CGE: Assessing the EU biofuel mandates with the MIRAGE-BioF model”, Forthcoming.

Laborde, D. 2011. Assessing the Land Use Change Consequences of European Biofuel Policies. Final Report prepared for the European Commission DG Trade. Implementing Framework Contract No TRADE/07/A2. http://trade.ec.europa.eu/doclib/docs/2011/october/tradoc_148289.pdf

Lange, M. 2011. The GHG balance of biofuels taking into account land use change. Energy Policy, 39, p. 2373–2385.

Lange, M., Klepper, G. 2011. Biofuels: The Best Response of Developing Countries to High Energy Prices? A Case Study for Malawi. Kiel Policy Brief No. 32.

McDougall, R., Golub, A. 2009. GTAP-E: A Revised Energy-Environmental Version of the GTAP Model. GTAP Research Memorandum No. 15.

O'Hare, M., Delucchi, M., Edwards, R., Fritsche, U., Gibbs, H., Hertel, T., Hill, J., Kammen, D., Laborde, D., Marelli, L., Mulligan, D., Plevin, R., Tyner, W. 2011. Comment on "Indirect land use change for biofuels: Testing predictions and improving analytical methodologies" by Kim and Dale: statistical reliability and the definition of the indirect land use change (iLUC) issue. Biomass and Bioenergy, 35(10), 4485-4487.

OECD, 2008. Economic assessment of biofuel support policies. (http://www.wilsoncenter.org/news/docs/brazil.oecd.biofuel.support.policy.pdf).

Plevin, R. J., Beckman, J., Golub, A. A., Witcover, J., O'Hare, M. 2015. Carbon Accounting and Economic Model Uncertainty of Emissions from Biofuels-Induced Land Use Change. Environmental Science & Technology, 49(5), 2656-2664.

Plevin, R. J., Jones, A. D., Torn, M. S., & Gibbs, H. K. 2010. Greenhouse gas emissions from biofuels' indirect land use change are uncertain but may be much greater than previously estimated. Environmental Science & Technology, 44(21), 8015-8021.

Prins, A., Eickhout, B., Banse, M., van Meijl, H., Rienks, W. and Woltjer, G. 2011. Global impacts of European agricultural and biofuel policies. *Ecology and Society* **16**(1): 49. [online] URL: http://www.ecologyandsociety.org/vol16/iss1/art49/.

Rosegrant, M.W., Zhu, T., Msangi, S. and Sulser, T. 2008. "Global Scenarios for Biofuels: Impacts and Implications." Review of Agricultural Economics, 30(3): 495-505.

Searchinger, T., Heimlich, R., Houghton, R. A., Dong, F., Elobeid, A., Fabiosa, J., ... & Yu, T. H. (2008). Use of US croplands for biofuels increases greenhouse gases through emissions from land-use change. Science, 319(5867), 1238-1240.

Taheripour, F., Hertel, T. W., Tyner, W. E., Beckman, J. F. and Birur, D. K. 2010. Biofuels and their by-products: Global economic and environmental implications, Biomass and Bioenergy 34(3), 278-289.

UCS (Union of Concerned Scientists), 2011. International Scientists and Economists Statement on Biofuels and Land Use - A letter to the European Commission. http://www.ucsusa.org/assets/documents/ global_warming/International-Scientists-and-Economists-Statement-on-Biofuels-and-Land-Use.pdf (12.12.2011).

Valin, H., Peters, D., Berg, M., Frank, S., Havlik, P., Forsell, N. Hamelinck, C. 2015. The land use change impact of biofuels consumed in the EU Quantification of area and greenhouse gas impacts. Study of Ecofys, IIASA and E4tech on behalf of the European Comission Ref. Ares(2015)4173087 - 08/10/2015. https://ec.europa.eu/energy/sites/ener/files/documents/ Final%20Report_GLOBIOM_publication.pdf