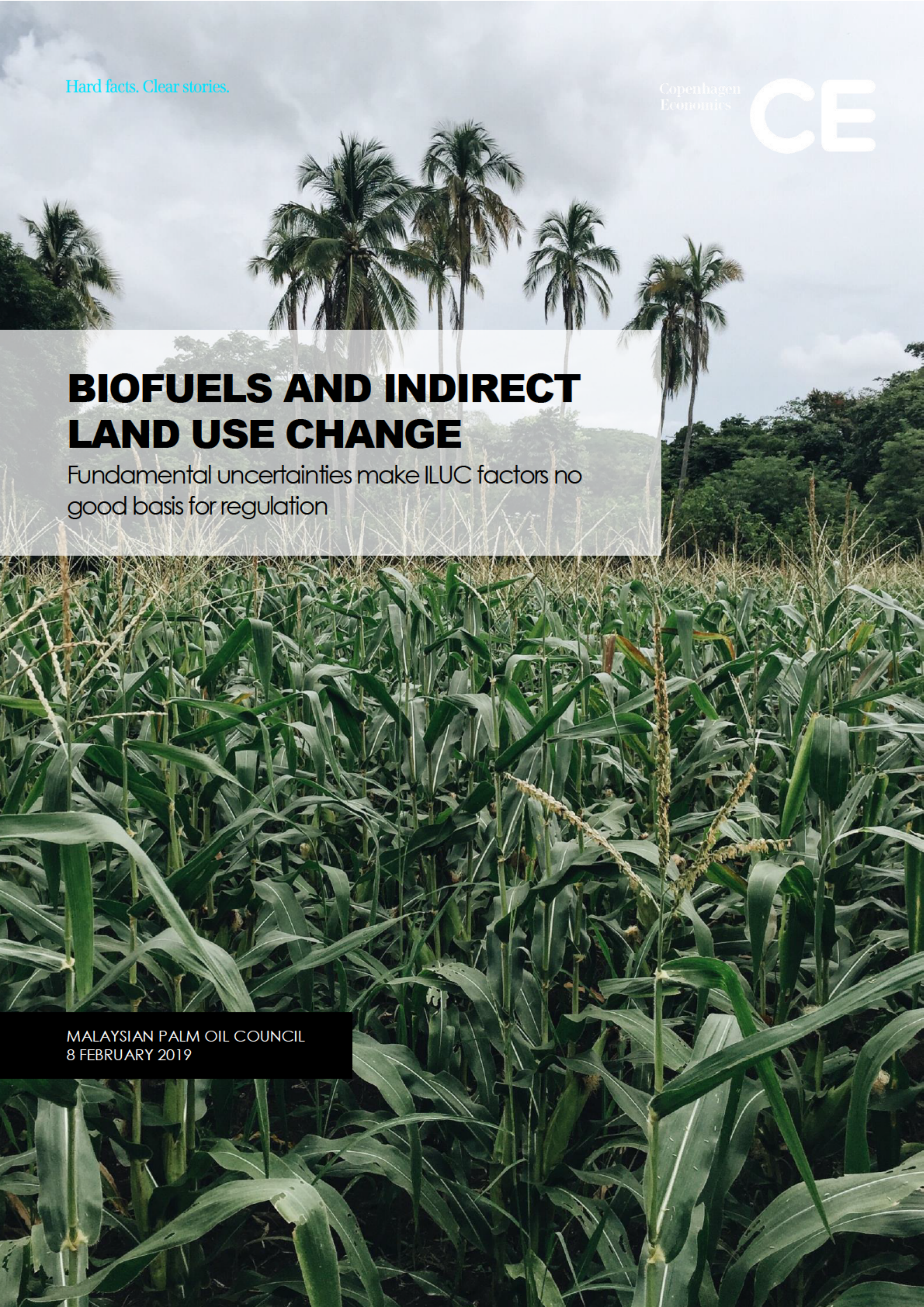


Hard facts. Clear stories.

Copenhagen Economics

BIOFUELS AND INDIRECT LAND USE CHANGE

Fundamental uncertainties make ILUC factors no good basis for regulation

MALAYSIAN PALM OIL COUNCIL
8 FEBRUARY 2019

AUTHORS

Helge Sigurd Næss-Schmidt, Partner
Martin Bo Westh Hansen, Managing Economist
Sabine Wilke, Economist

PREFACE

The Malaysian Palm Oil Council is an organisation with the mission to promote the market expansion of Malaysian palm oil and its products by enhancing the image of palm oil and creating better acceptance of palm oil through awareness of various technological and economic advantages (techno-economic advantages) and environmental sustainability. European policies that have the potential to affect market access for palm oil products – such as ILUC-based regulation – are therefore a topic of interest for the Council.

With the ILUC effect of biofuels back on the political agenda,[1] the Malaysian Palm Oil Council has asked Copenhagen Economics to assess whether there is a scientific consensus that would support the use of ILUC factors as a basis for regulation.

1 See chapter 1.2

TABLE OF CONTENTS

Preface **0**

Executive summary **4**

1 Background and context **7**

1.1 What is ILUC and why does it matter? 7

1.2 ILUC is back on the polical agenda 7

2 ILUC not a good basis for defining individual biofuel riskiness **9**

2.1 The estimates vary greatly 9

2.2 Complex modelling based on uncertain assumptions explain the variance 12

References **18**

LIST OF TABLES

Table 1 Ranking of feedstocks based on the median ILUC estimates 12

Table 2 Differences in models used to quantify ILUC effects 16

LIST OF FIGURES

Figure 1 Variance in ILUC estimates per feedstock across studies 5

Figure 2 Variance in ILUC estimates per feedstock across studies 10

Figure 3 Examples for large variance in ILUC estimates within models 11

Figure 4 Different consequences of an increase in rape seed production in different models 15

EXECUTIVE SUMMARY

ILUC still unfit as a basis for regulation

The use of biofuels in Europe have been promoted at EU level through several Directives with the aim of making the transport sector more sustainable, but have also been associated with pressure on land, leading to the conversion of carbon rich land (e.g. deforestation). The concern is that biofuels may not reduce emissions as much as hoped, since they can spur increased emissions elsewhere through land use change, either directly or indirectly.

Direct land use change (DLUC) is when cropland is expanded for biofuel feedstock production, e.g. when a forest in Europe is cut down in order to grow wheat for biofuel production there. DLUC is observable and can be monitored; in case of non-compliance with rules (e.g. forest conservation rules), authorities can enforce penalties. **Indirect land use change** (ILUC) also describes conversion of land to cropland, but caused indirectly through displacement of production in other locations. If e.g. European wheat has been used for food production before, but is now used for bioethanol instead, this could give rise to wheat production (or the production of a substitute crop) elsewhere in the world due to increasing wheat prices. The land that may be converted to cropland for this purpose is the indirect land use change effect of the wheat-based ethanol.

While ILUC can be just as real as DLUC, it cannot be monitored in the same way. It is practically impossible to establish a clear, quantifiable causality between the production of biofuel-crops and the ultimate land use change somewhere else in the world, since the latter is influenced by a countless amount of circumstances. In the attempt to estimate the ILUC effect of biofuels anyways, complex economic models are used, which need to make assumptions regarding a large number of highly uncertain parameters as explained with some examples below.

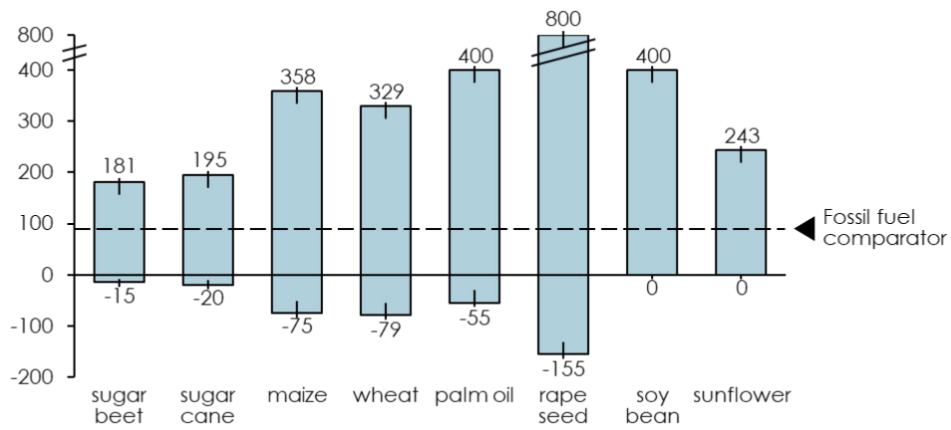
Now in 2019, the ILUC discussion is back on the political agenda. The European Union's recast of the Renewable Energy Directive to 2030 (RED II) includes an updated target for renewable energy used in transport of 14% with biofuels playing a major role in achieving this target. However, RED II limits the extent to which biofuels from feedstocks associated with high ILUC can contribute to the target of 14%: a Delegated Act is being prepared by the EU Commission in an attempt to determine 'high risk' or 'low risk' biofuels, based at least in part on ILUC. Biofuels associated with high ILUC may not exceed 2019 consumption levels, and are then to be phased out to zero by 2030. As of today, there is no clear definition of what high ILUC vs low ILUC risk biofuels are, but the Commission is required to set criteria for classifying this in 2019. This is the role of the Delegated Act.

While we acknowledge the overall ambition, we conclude that the concept of ILUC should not be a part of such regulation. The Delegated Act, if it attempts to base regulatory decisions on 'high risk' ILUC, would be outside of the current scientific consensus. The reason is that there is no scientific consensus about the ILUC effects of different biofuels that would support such a classification; if it is done anyways, it is likely that it does more harm than good.

The ILUC effect, or ILUC factor, is a term for the estimated emissions due to indirect land use change expressed in grams of CO2 equivalents per megajoule of biofuel (g CO2 equ./MJ biofuel). A negative ILUC factor means that the production of the biofuel entails an overall net reduction in greenhouse gas emissions. Positive ILUC factors mean positive net emissions, but those can still be lower than for fossil fuels. The fossil fuel comparator as determined by the Commission in RED II for the transport sector is 94 g CO2eq/MJ;[2] this means that the use of biofuels with a lower (higher) ILUC factor will entail a net decrease (increase) in emissions.

Indeed, we are currently far away from a consensus about the ILUC effect of different biofuels. The researchers' attempts to model the ILUC effects of biofuel production have resulted in estimates that vary enormously and do not allow for any robust conclusions. The predicted ILUC factor across models for wheat-based bioethanol for example ranges from -79 to 329 g CO2 equ./MJ biofuel, see Figure 1. This means that its ILUC effect lies somewhere between an emission reduction by 184% and an emission increase by 250% compared to using fossil fuel. The other feedstocks feature similarly large ranges in estimates. It becomes clear that no meaningful conclusions can be drawn from estimates with such variation.

Figure 1
Variance in ILUC estimates per feedstock across studies
g CO2 eq./MJ biofuel



Note: Break in continuity in the y-axis.
Source: European Commission (2017) and Copenhagen Economics (2014)

[2] See European Commission (2017), Annex V part C, point 19.

Substantial variation can be observed not only between, but even within models. A study from 2015[3] for example yields ILUC factors between -20 and 175 for sugar cane, and between 10 and over 400 for soybean. This illustrates how uncertain and complex ILUC modelling is: even when using the same modelling approach and overall assumptions, the ILUC effect is difficult to narrow down.

As a consequence of the large variation within and between models, no robust conclusions can be made about the relative ILUC effects. There is no clear consensus regarding the relative ranking of feedstocks in terms of ILUC effects. A study by OECD[4] for example estimates rape seed-based biodiesel to have a lower ILUC effect than wheat- and maize based bioethanol, while other studies[5] come to the exact opposite result.

This large variance in ILUC estimates is not a surprise. The results will vary depending on which modelling approach is taken, and which assumptions are made.[6] To arrive at an ILUC estimate, the model needs to go through several steps, all of which contain new assumptions and uncertainties. An example is whether and how by-products of biofuel feedstock production are included in the model. By-products are parts of the harvest that cannot be used for biofuels, but for other purposes, typically for animal feeding, e.g. soy bean and rape seed cakes.[7] Different studies reveal that when by-products are taken into account it may reduce the estimated land requirement by approximately 23–94 per cent.[8] If taken into account, the approach of doing so matters, too. An increase in rape seed biofuel production for example can lead to a net expansion or net reduction in cropland, just based on different assumptions in the models regarding the market response to the by-product of rape seed production.[9]

Overall, we observe that the ILUC effect will differ case by case depending on a wide range of circumstances, of which the feedstock is just one small component. Assigning a single ILUC factor to individual feedstocks has therefore no scientific basis.

---

3 IIASA et al. 2015, Annex V.2 Sensitivity and uncertainty analysis, detailed results per scenario, page 225ff, and Wageningen et al. 2017, table 9. This study applies the GLOBIOM model.
4 OECD 2009 as discussed in JRC 2010
5 E.g. IIASA et al. 2015
6 While all assumptions are within reasonable.
7 Wageningen et al. (2017) page 76
8 DG Energy 2010, page 15
9 See chapter 2.2

CHAPTER 1

BACKGROUND AND CONTEXT

1.1 WHAT IS ILUC AND WHY DOES IT MATTER?

Back in 2003, the European Parliament started promoting the use of biofuels in their Biofuel Directive[10] to facilitate a more sustainable development in Europe in compliance with the Kyoto Protocol. The ultimate goal was to reduce the use of and dependency on fossil fuels and therewith to reduce emissions in the transport sector.

In the following years however, the production of biofuel crops has sometimes been associated with pressure on food production (the “fuel vs. food” debate), as well as pressure on land, leading to the conversion of carbon rich land (e.g. deforestation). The latter reflects the concern that biofuels may not really be carbon neutral, since they can lead to land use change which causes emissions – and a discussion evolved around whether and to which extent biofuels should be “penalised” for giving rise to land use change.

Typically, a distinction is made between direct land use change (DLUC) and indirect land use change (ILUC). **Direct land use change** is when cropland is expanded for biofuel feedstock production, e.g. when a forest in Europe is cut down in order to grow wheat there, which is then processed into bioethanol. **Indirect land use change** also describes the conversion of land to cropland, but caused indirectly through displacement of other production. If e.g. European wheat has been used for food production before, but is now used for bioethanol instead, this could give rise to wheat production elsewhere in the world due to increasing wheat prices. The land that is converted to cropland for this purpose is the indirect land use change effect of the wheat-based ethanol.

While the difference between DLUC and ILUC may be arbitrary, the distinction holds important implications for regulators who want to affect land use change. Direct land use change is observable and can be monitored and enforced. ILUC, on the other hand, cannot be observed and instead can only be estimated based on complex economic models.

1.2 ILUC IS BACK ON THE POLITICAL AGENDA

The European Union (EU) has published a recast of the Renewable Energy Directive to 2030 (RED II), which brought the ILUC effect of biofuels back into the focus of the political discussion. This recast includes an increased target for renewable energy used in transport of 14%. Due to concerns about ILUC however, the contribution of food or feed-based biofuels to the renewable energy target in transport is capped at 7% of road and rail transport energy or limited to 2020 consumption levels in each Member State, whichever is lower.[11]

The RED II includes a further restriction for so-called “high ILUC risk biofuels”; their contribution toward the target is capped to 2019 consumption levels to start with, and starting on 31 December 2023, it will be phased out completely by 2030.[12] The EU Commission has not yet defined clearly what high as compared to low ILUC risk biofuels are, but is required to set criteria for classifying

10 Directive 2003/30/EC
11 icct (2018a) page 2 and icct (2018b) page 1
12 icct (2018) page 2

this in 2019. A Delegated Act is being prepared that would set out the Commission's methodology for this classification.

CHAPTER 2

ILUC NOT A GOOD BASIS FOR DEFINING INDIVIDUAL BIOFUEL RISKINESS

Indirect land use change effects and the greenhouse gas emissions caused by it cannot be measured or observed, and therefore must be estimated by applying complex global models. The outcome of those models is the so-called ILUC factor (or ILUC effect), a term for the estimated emissions due to indirect land use change expressed in grams of CO2 equivalents per megajoule of biofuel (g CO2 equ./MJ biofuel). A negative ILUC factor therewith means that the production of the biofuel entails an overall net reduction in greenhouse gas emissions; positive ILUC factors mean positive net emissions, but those can still be lower than for fossil fuels. The fossil fuel comparator as determined by the Commission in RED II for the transport sector is 94 g CO2eq/MJ;[13] this means that the use of biofuels with a lower (higher) ILUC factor will entail a net decrease (increase) in emissions.

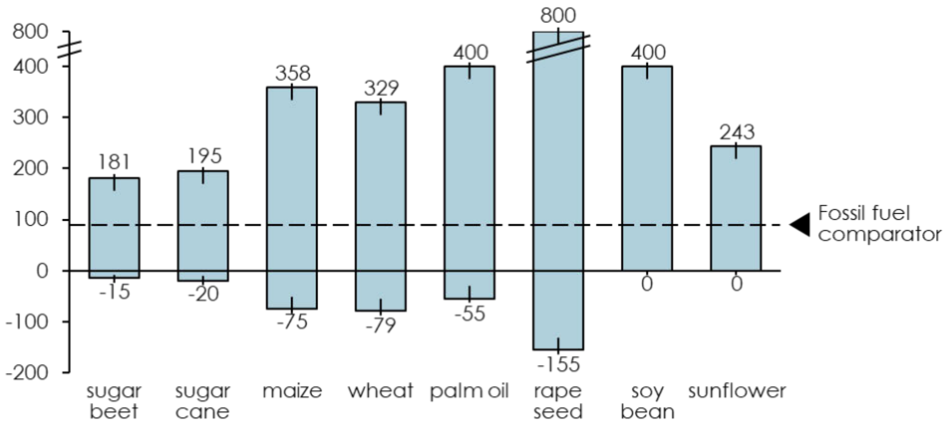
We observe that the estimated ILUC factors vary greatly (section 2.1), which can be explained by a number of uncertainties in the models (section 2.2).

2.1 THE ESTIMATES VARY GREATLY

We are currently far away from a consensus about the ILUC effects of different biofuels. The ILUC estimates provided by different studies vary enormously. Estimates vary not only between feedstocks, but also largely between studies and models for the same feedstocks. The predicted ILUC factor across models for wheat-based bioethanol for example ranges from -79 to 329 g CO2 equ./MJ biofuel, and the factor for rape seed based biodiesel ranges from -155 to 800 g CO2 equ./MJ biofuel, see Figure 2.

[13] See European Commission (2017), Annex V part C, point 19.

Figure 2
Variance in ILUC estimates per feedstock across studies
g CO2 eq./MJ biofuel



Note: Break in continuity in the y-axis
Source: European Commission (2017) and Copenhagen Economics (2014)

The fossil fuel comparator as determined by the Commission in RED II for the transport sector is 94 gCO2eq/MJ.[14] This means that using maize-based bioethanol for example can mean an emission reduction by 180 per cent (ILUC factor of -75) or an emission increase by 280 per cent (ILUC factor of 358) compared to using fossil fuels, or anything in between those extremes.

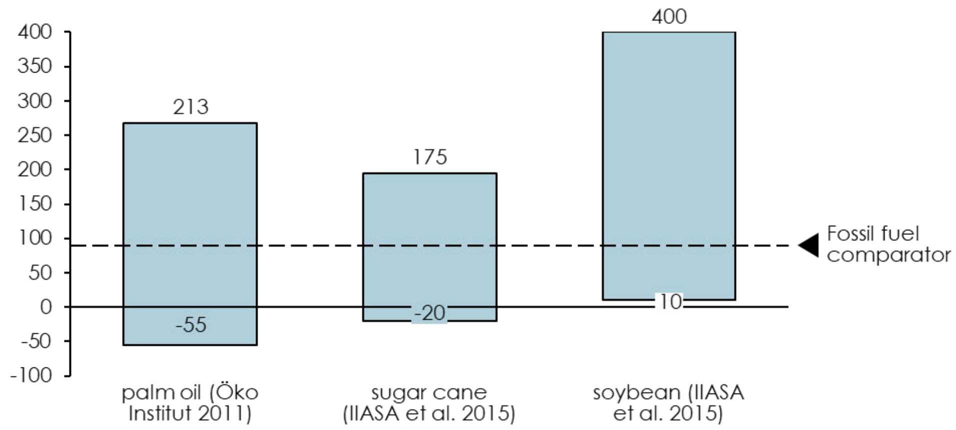
Especially prior to 2012, there have been numerous efforts to quantify ILUC, and many studies with estimates have been published. Around that time, the existence of ILUC effects and the necessity to understand them better was recognised, and research towards modelling ILUC experienced a large push forward. The models however predicted ILUC estimates that varied strongly. Since 2012, there have been attempts to improve ILUC estimates, but with little success; There is still no consensus regarding which modelling approach is the best one, and no convergence of ILUC estimates. In fact, the opposite is the case. For most feedstocks, the ILUC estimates of more recent studies have increased the variance; this holds true for sugar beet, sugar cane, maize, palm oil, rape seed and soy bean. Wheat is the only feedstock where the range of estimates has not increased, but it is also the feedstock that has been analysed least in recent studies.

We do not only observe substantial variance in estimates between, but even within, models. A study undertaken for the European Parliament for example predicts the ILUC factor of palm oil to be between -55 and 213[15], and another study[16] yields ILUC factors between -20 and 175 for sugar cane, and between 10 and over 400 for soybean, see Figure 3.[17] This means that all three biofuels could lie well below or well above the fossil fuel comparator of 94 g CO2/MJ.

---

14 See European Commission (2017), Annex V part C, point 19.
15 Öko Institut 2011, table 9 page 38.
16 IIASA et al. 2015, Annex V.2 Sensitivity and uncertainty analysis, detailed results per scenario, page 225ff, and Wageningen et al. 2017, table 9. This study applies the GLOBIOM model.
17 All those studies are also included in Figure 2.

Figure 3
Examples for large variance in ILUC estimates within models
g CO2 eq/MJ biofuel



Note: Comparison within models: each bar shows the range of results from a single model
Source: Öko Institut 2011 table 9 page 38 IIASA et al. 2015 IIASA et al. 2015 Annex V.2 Sensitivity and uncertainty analysis detailed results per scenario page 225ff and Wageningen et al. 2017 table 9

As a consequence of the substantial uncertainty about the absolute size of ILUC effects, there is also no consensus on which biofuel feedstock gives rise to the highest ILUC emissions in relative terms. In a study by IFPRI in 2011 for example, oil-based crops (which are used to produce biodiesel) are given an ILUC factor 4-5 times higher than cereal- and sugar-based crops (which are used to produce bioethanol). However, many other studies come to very different conclusions. In the OECD's dynamic supply-demand model of world agriculture AGLINK-COSIMO for example, biodiesels based on rape seed and soy bean are estimated to have a smaller ILUC impact than bioethanol based on wheat or maize, see Table 1. Also, a study by the Öko Institut (2010) ranks the feedstocks palm oil and rape seed better than wheat, contrary to IFPRI. In more recent studies, there seems to be a tendency that biodiesel (i.e. oil-based crops) on average have a larger ILUC factor than bioethanol (i.e. cereal- and sugar-based crops),[18] but there is still no consensus about the precise ranking.

[18] See European Commission 2014, 2015a, 2015b, 2017.

Table 1
Ranking of feedstocks based on the median ILUC estimates

FEEDSTOCK	BIOFUEL TYPE	IFPRI 2011 Model: MIRAGE	OECD 2009* Model: AGLINK-COSIMO	ÖKO INSTITUT 2010 Model: GEMIS	CARB 2014 Model: AEZ-EF GTAP	IFPRI 2014 Model: MIRAGE	PBL, JRC ET AL. 2015 Empirical approach	IIASA ET AL. 2015 Model: GLOBIOM
Sugar beet	bioethanol	1				1	2	2
Sugar cane	bioethanol	4	1	1	2	3	2	3
Maize	bioethanol	2	4		3	2	1	1
Wheat	bioethanol	3	5	4			4	4
Palm oil	biodiesel	6		2	5	5	5	8
Rape seed	biodiesel	7	2	3	1**	5	6	6
Soybean	biodiesel	8	3	5	4	7	8	7
Sunflower	biodiesel	5				4	7	5

Note: A high ranking (small figure) means a low ILUC factor in the respective model. The Öko Institut study provides several estimates per feedstock for different sensitivities the shown ranking is based on average values.
* as discussed in JRC 2010
** US only.

Source: The studies shown in the table.

2.2 COMPLEX MODELLING BASED ON UNCERTAIN ASSUMPTIONS EXPLAINS THE VARIANCE

Given the complexity and need to take many in reality arbitrary choices on parameters and modelling approaches, it is of no surprise that the estimates vary so considerably.

To illustrate this point, consider the following example of eight steps that need to be modelled to arrive at an ILUC estimate. Those steps are simplified and present just a small fraction of the complete modelling exercise. The following paragraphs shed light on the uncertainties involved and assumptions to be made in each of the steps.

1. Model which types of biofuels will see an increase in demand
2. Model the effect on the supply of non-biofuel crops
3. Model the price effect
4. Model the location and magnitude of increased production of the crop
5. Model a particular previous land use
6. Model the carbon content of the land
7. Model the market effects of increased supply of by-products
8. Model second-round market effects

Step 1: Establish which types of biofuel are likely to see an increase in demand in the future. This involves determining the substitutability between the different fuels, as well as knowledge and predictions regarding technical questions such as whether engines can run equally efficient and damage-free on the different fuel types.

Step 2: The increased use of a crop (e.g. palm oil) for biofuel can lead to a reduced supply (and production) of that crop for other, non-biofuel uses, which means less land is used for producing the latter. The first challenge is to define the magnitude and functional form of this substitution elasticity. The second challenge is to decide to which extent emission reductions from this consumption effect should be counted into the ILUC of biofuels. Currently, there is no consensus about that,[19] but estimates show that the potential effect is significant – a decrease in demand for non-biofuel crops can reduce the ILUC factor of biofuels by one third or even half.[20]

Step 3: An increased demand for palm oil based biodiesel will most likely raise the price of palm oil – but how much? This depends on the magnitude and functional form of the price elasticity, and as of today, there is no clear consensus around the question of how prices are affected by biofuel demand[21]

Step 4: A price increase of palm oil will most likely lead to an increase in production of palm oil – but where in the world will this take place, and how much land will be used for it? Modelling this requires a range of assumptions, for example regarding future land availability, flexibility of farmers and intensification of agriculture. Yield elasticities in the model determine how yields react to e.g. increased fertilizer use, and are typically very small short term, but larger long term.[22] Many of those assumptions depend on other underlying factors that also are uncertain, which makes projections challenging. The future land availability for example depends on the future agricultural production in this region, which in turn depends on factors like future transportation costs and water availability in the region.

The price increase of palm oil can also cause an increase in the production of substitutes, e.g. rape seed oil for use in bakery products. At the same time, the size of the price increase is determined (or capped) by the ability to produce substitutes. Those effects are modelled using substitution elasticities, which can differ in the short- and long-term.

Step 5: Having determined where in the world how much land will be converted to compensate increased palm oil production (or the crop replacing palm oil in final production), the next step is to determine what this piece of land has been used for before. This has a potentially large effect on the ILUC estimates. The Öko Institut[23] for example estimated the ILUC factor of palm oil based biofuel to be -55 if the previous land use was degraded land, 48 if it was grassland and 213 if it was tropical rain forest.

---

19 See for example Searchinger et al. (2015) and Malins et al. (2014) as cited in Wageningen et al. (2017)

20 See also Wageningen et al. (2017) page 11. Schmidt et al. (2015) argues that agricultural supply in the long term is almost perfectly elastic, and that for this reason, the emission effects through reduced consumption of non-biofuel crops should not be included.

21 Persson (2015) as cited in Wageningen et al. (2017)

22 Wageningen et al. (2017) page 11

23 Öko Institut (2010), tabel A-4, page 55.

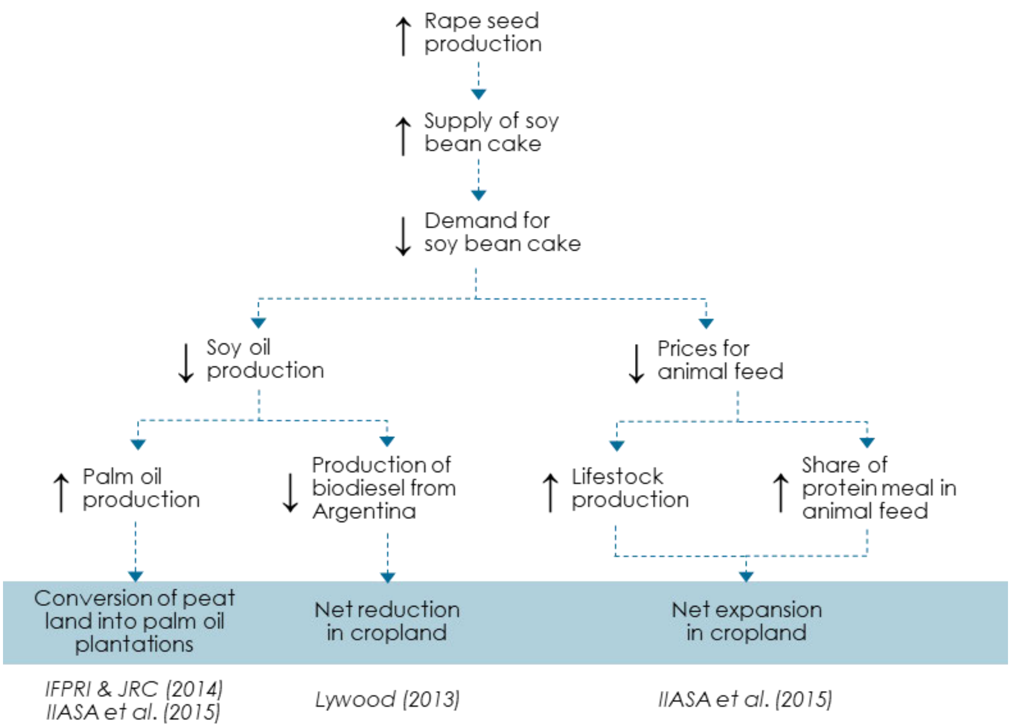
Step 6: ILUC depends highly on the carbon content of the converted land. Having determined the previous land use, the next step is therefore to make assumptions regarding how much greenhouse gas will be emitted by using this land for e.g. palm oil production instead. Even within land types, the carbon content varies considerably, which makes it difficult to make meaningful assumptions about. Estimates for the carbon stock value of boreal forest in Canada for example range from 71 to 1085 t CO_2/ha, and similarly from 172 to 1077 t CO_2/ha for temperate forests in Europe; the estimate for tropical rain forests in Brazil and South East Asia range from 359 t CO_2/ha to 2572 t CO_2/ha.[24]

Step 7: The increased production of biofuel feedstocks will also entail an increase in supply of their by-products, and modelling the consequences of that is the next challenge. By-products are parts of the harvest that cannot be used for biofuels, but for other purposes, typically for animal feeding. The by-products of soy bean and rape seed are protein-rich soy bean and rape seed cakes, and maize and wheat by-products are dried distillers grains with solubles (DDGS).[25]

Different studies reveal that taking by-products into account has a large effect on the ILUC estimate: it can reduce the estimated land requirement by approximately 23–94 per cent.[26] Most ILUC models do take by-products of biofuels into account but differ in their approach to how (and how sophisticatedly) they do, which leads to fundamental differences in the resulting ILUC estimates. Consider for example an increase in rape seed biofuel production; depending on the assumptions made in the model, this can lead to the conversion of peat land into oil palm plantations, to a net expansion in cropland area on different land types, or to a net reduction in land area mainly in South America, see Figure 4.

[24] DG Energy (2010), page 25
[25] Wageningen et al. (2017) page 76
[26] DG Energy 2010, page 15

Figure 4
Different consequences of an increase in rape seed production in different models



Note: Upward facing arrows indicate an increase downward facing arrows a decrease.
Source: Wageningen et al. (2017) referering to IFPRI & JRC (2014) IIASA et al. (2015) and Lywood (2013)

Step 7: Lastly, the model needs to account for second-round market responses. This means that any production and price effects e.g. for substitutes of the feedstock that saw the initial increase in demand, will trigger their own market response. An increase in rape seed oil production as a consequence of a higher palm oil price for example (see step 4) will in have a cascade of consequences; the model starts over at step 3 with the trigger "increased demand for rape seed oil".

Important to note is that the models used to estimate ILUC effects differ significantly in their structure and approach, and that is an additional driver of differences in the ILUC results. *Firstly*, models differ in how sophisticated and complex they are, or in other words in *how much* they simplify. More advanced models may be able to account for more complex relationships, but also rely on a larger number of assumptions regarding both exogenous variables and endogenous parameters. Simpler models abstract more from the highly complex relationships of the real world, which is also an important source of uncertainty. *Secondly*, models differ – also when being similarly complex – in their structure, meaning in *how* they simplify. An example for such differences is to what extent future developments such as trade patterns rely on historical patterns, or which variables are exogenous and which ones endogenous to the model.

There is no consensus about which modelling approach is the best one. In recent years, five different models have been used to quantify ILUC effects, each of them having different approaches and different sources of uncertainties, see Table 2.

Table 2
Differences in models used to quantify ILUC effects

MODEL	APPROACH	MAIN SOURCES OF UNCERTAINTY
Partial Equilibrium Models (PE)	Based on the concept of "economic equilibrium" i.e. supply and demand are equilibrated through price adjustments. Econometric analysis dictates this behaviour.	The models tend to take a regional or global perspective and suffer from uncertainties arising from aggregation: - Crop yields particularly marginal crop yields. Indirect effects on food consumption. -Broader indirect effects on the overall economy. Especially food consumption - Land use change emission factors.
General Equilibrium Model (GE)	Similar to PEs but accounting for the entire economy. Thus include further economic feedbacks ignored by PEs. These are based on input-output tables (i.e. social accounting matrices) with flows usually measured in monetary terms.	Similar to PEs except that since CGEs include the broader economy: - Their characterisation of agricultural and energy systems is even more aggregate. - Substitution based on elasticities (CET). - Parameterisation very uncertain. - Land constraints and land aggregation methods.
Integrated Assessment Models (IAM)	Aim to account for the long term and global interactions between human and natural systems by adopting a systems-dynamic approach combining land-use energy nutrient societal and climate systems. No standard methodology usually a combination PE CGE CD and LCA methods.	- As these models aim to show long-term dynamics uncertainties include the future development of key drivers (population economic growth etc.). - Uncertainties due to increased aggregation.
Causal Descriptive Models (CD)	Extrapolations of observed trends and assumptions of future trade patterns displacement ratios and incremental land use. These methods were developed in order to simplify data intense and complex economic models.	Key assumption is that current patterns are an adequate proxy for potential future ILUC. Thus they do not account for economic feedbacks which may arise.
Hybrid Life Cycle Assessment (LCA)	Contains detailed information on techno-economic parameterisation. Limited understanding of land use change dynamics.	Typically LCAs ignore indirect effects. Some studies overcome this by combining them with economic modelling (Hybrid LCA).

Note: Combinations of models can be possible.
Source: Wageningen et al. (2017) page 26ff

We conclude that ILUC estimates vary too substantially to be an appropriate foundation for regulation. As shown in chapter 2, estimates for the ILUC factors of different feedstocks vary considerably, both between studies and within models. The reason for this is that ILUC effects depend on several different things – for example the exact piece of land that is converted to cropland and its carbon content – that all are uncertain and can only to a limited extent be predicted or assigned to a particular biofuel feedstock. Regulation based on feedstock-level is therefore likely to give a biased result and to punish single producers inadequately.

Proponents of ILUC modelling sometimes put forward that all economic modelling is uncertain, and that society continues to rely on complex general equilibrium models to inform several aspects and decisions. However, there are a number of big differences to how ILUC modelling is suggested to be applied. As far as we know, there is nowhere that general equilibrium models are used to estimate product-specific penalties even distinguishing between different product variants. Such models are instead used to provide broader levels of information such as overall economic growth rates, benefits from reducing trade barriers etc. Not to assign precise values/penalties to specific products.

REFERENCES

CARB (2014) Low Carbon Fuel Standard Re-Adoption Indirect Land Use Change (iLUC) Analysis. Staff report by the California Environmental Protection Agency, Air Resources Board.

European Commission (2017) Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast) [RED II] and Annexes.

icct (2018a) Analysis of high and low indirect land-use change definitions in European Union renewable fuel policy. Working paper.

icct (2018b) Defining low and high indirect land-use change biofuels in European Union policy. Fact sheet: Europe.

IFPRI (2011) Assessing the Land Use Change Consequences of European Biofuel Policies. Study for the European Commission.

IFPRI & JRC (2014) Progress in estimates of ILUC with MIRAGE model. Study for the European Commission.

IIASA, ECOFYS & E4tech (2015) The land use change impact of biofuels consumed in the EU. Quantification of area and greenhouse gas impacts. Study for the European Commission.

JRC, PBL & Koen Overmars Consultancey (2015) Estimates of indirect land use change from biofuels based on historical data. Study for the European Commission.

Lywood (2013) Estimate of ILUC impact of EU rapeseed biodiesel based on historic data. Study for the European Oilseed Alliance

Öko Institut (2011) Indirect Land Use Change and Biofuels. Study for the European Parliament.

Öko Institut (2010) The "iLUC Factor" as a Means to Hedge Risks of GHG Emissions from Indirect Land Use Change

Persson (2015) The Impact of Biofuel Demand on Agricultural Commodity Prices: A Systematic Review. WIREs Energy and Environment, Volume 4, Issue 5.

Wageningen Economic Research, PBL, Wageningen Environmental Research & CENER (2017) Study report on reporting requirements on biofuels and bioliquids stemming from the Directive (EU) 2015/1513. Study for the European Commission.