# Biodiesel vs. ethanol, UE vs. US biofuels: So different in terms of LUC impact?

Forslund A.*, Gohin A.**, Le Mouël C.**, Levert F.**
*UAR 519, INRA, département SAE2, 35 000 Rennes, France
** UMR 1302, INRA, SMART, 35 000 Rennes, France

Corresponding author : C. Le Mouël, Chantal.Lemouel@rennes.inra.fr

**Abstract**

Available estimates of biofuel-induced LUC and corresponding GHG emissions vary on a wide range while estimations obtained from each model are highly sensitive to certain assumptions and key parameter values. Available studies often suggest that biodiesel and ethanol and/or EU and US biofuels would lead to different LUC and GHG emissions but they don't agree on the type and/or the origin of the biofuel which would induce the least LUC and GHG emissions. In this paper we investigate the reasons behind this feature. We show that the Armington modeling of trade flows, which is currently used in models, contributes to this pattern. Using both observed data and the partial equilibrium model MATSIM-LUCA, we show that LUC stemming from the development of biofuels is highly dependent on assumptions made on trade: the Integrated World Market (IWM) approach, which relies on the homogenous product assumption, tends to erase differences in estimates of induced LUC from biodiesel and ethanol and from EU and US biofuels as compared to the Armington approach, that postulates that product are differentiated according to their origin and thus less substitutable.

**Keywords** : Biofuel, LUC, model, Armington

## 1. Introduction

Originally, biofuels were perceived as positive contributors to the mitigation of greenhouse gas (GHG) emissions and their development was encouraged all over the world, especially through mandate and special tax system policies. Such perception was based on standard life cycle assessments (LCAs) which emphasized the potential benefits of biofuels relative to fossil fuels regarding GHG emissions. However, later analysis raised concerns about the implications of biofuels production and consumption on land use change (LUC) and the potentially related GHG emissions (Searchinger et al., 2008; Fargione et al., 2008). Then the concept of LUC started to question the initial statement while initiating fierce debates in the scientific (e.g., Plevin et al., 2010; Edwards et al., 2010; Dumortier et al., 2011; De Cara et al., 2012; Broch et al., 2013) and policy (e.g., California air resource board, 2009; European Commission, 2012) communities.

Eliciting the LUC impacts of biofuels requires to use a market and trade model allowing to disentangle the own effect of biofuels from the interrelated effects of numerous other economic and non-economic factors. However, the simulated LUC resulting from a set of biofuel policies depends closely on model structure, specification and parameter values. This explains that available estimates of biofuel-induced LUC and corresponding GHG emissions vary on a wide range (see, e.g., De Cara et al., 2012) while estimations obtained from each model are highly sensitive to certain assumptions and key parameter values (see, e.g., Dumortier et al., 2011; Golub and Hertel, 2012; Gohin, 2013; Broch et al., 2013).

In addition to this lack of consensus on the extent of biofuel-induced LUC and related GHG emissions, available results also disagree on the type of biofuel (i.e., biodiesel or ethanol) and the country of origin (i.e., mainly, European Union or the US) which would rank better regarding LUC and corresponding GHG emissions (Edwards et al., 2010; Laborde, 2011; De Cara et al., 2012’s meta-analysis results). In other words, available studies often suggest that biodiesel and ethanol and/or EU and US biofuels would lead to different LUC and GHG emissions but they don’t agree on the type and/or the origin of the biofuel which would induce the least LUC and GHG emissions.

In this paper we investigate the reasons behind this feature. We focus on available results in terms of LUC induced by biofuels.[1] In line with existing sensitivity analyses of induced LUC results, we suspect some models’ assumptions and/or parameters to be responsible for this pattern in existing results. Following Golub and Hertel (2012) we suspect the Armington modeling of trade flows, which is currently used in models (especially in CGE models), to lead, at least partly, to this pattern.

[1] As is well-known, the conversion of LUC into GHG emissions is an additional source of variability across results (e.g., Broch et al., 2013). Hence considering LUC results eliminates this source of variability.

The intuition is the following. Based on observed physical data, even if the area required for producing 1 tonne of oil equivalent (toe) varies according to the considered biofuel and both the agricultural commodity used as feedstock and the origin of this feedstock, there is not so great discrepancy between the area required for biodiesel and for ethanol when comparing major producing countries and major used agricultural commodities. In addition, there is not so great discrepancy between the area required to produce 1toe from EU and from US biofuels. Hence under product homogeneity and free trade assumptions, substitution possibilities across feedstocks and across origins of trade flows should make the areas required for producing 1toe from the various agricultural feedstocks from the various origins to get relatively close. Accordingly the induced LUC from biodiesel and ethanol on the one hand, the induced LUC from the EU and the US biofuels on the other hand should also get relatively close.[2] At reverse, because the Armington assumption reduces the substitution possibilities across trade flows, hence across feedstocks and their origins, it contributes to create gaps between induced LUC from biofuels from different origins, so from biodiesel and ethanol as well as from EU and US biofuels. We illustrate our intuition using a partial equilibrium model of the world arable crop markets (MATSIM-LUCA), specifically developed for assessing the LUC induced from biofuel development.[3]

The paper is organized as follows. Section 2 sets the scene. First we emphasize the different rankings among biofuels of different types and of different origins that emerge from available estimates of biofuel-induced LUC. Then, based on observed data, we compute the area required for producing 1toe derived from each type of biofuels (i.e., biodiesel from various vegetal oils and ethanol from cereals, beets and cane) and then show how such required areas vary according to the origin of the feedstock used. Section 3 tries to point fingers. We emphasize the role of the Armington approach regarding the propagation of a biofuel production/consumption increase in one country all over the world and we explain how this approach may contribute to generate gaps between the estimates of LUC impacts of biodiesel and ethanol and of EU and US biofuels. In section 4, using MATSIM-LUCA, we illustrate how biofuel-induced LUC estimates vary when the integrated world market (IWM) assumption is progressively replaced by an Armington-like approach. Finally section 5 concludes.

## 2. Setting the scene

As a support study to the preparation of the EU policy proposal on the assessment of the indirect LUC (iLUC) effect and how to address iLUC emissions in legislation, Edwards et al. (2010) proposed a comparison of the LUC induced by 1 toe extra demand of biofuels of

[2] Provided that the land area saved following the use (mostly in animal feed) of by-products resulting from biofuel production do not differ much according to the type and the origin of biofuels, as it is discussed later.

[3] Market And Trade Simulation Model for Land Use Change Analysis. For more details on the model, see Forslund et al. (2013a, 3013b, 2013c).

different types in the EU or in the US.[4] Several scenarios were considered allocating the extra biofuel demand alternatively to biodiesel and ethanol on the one hand or to biodiesel from specific feedstocks and ethanol from specific feedstocks on the other hand. Table 1 reports Edwards et al. (2010)'s results. We added results from Laborde's study (2011) which was also commissioned by the EU.

**Table 1. LUC induced by various types of EU or US biofuels simulated by different models**

| | **Biodiesel** | | | **Ethanol** | |
|---|---|---|---|---|---|
| Model | ha/toe | Feedstock and/or origin | Model | ha/toe | Feedstock and/or origin |
| *Edwards et al. 2010 :* | | | | | |
| LEITAP | 1.93 | Biod EU | LEITAP | 0.73 | Wheat EU-France |
| | | | LEITAP | 0.86 | Corn US |
| FAPRI | 0.44 | Biod EU | FAPRI | 0.39 | Eth EU |
| AGLINK | 0.23 | Biod EU | AGLINK | 0.57 | Eth EU |
| AGLINK | 0.24 | Biod US | AGLINK | 0.51 | Corn US |
| GTAP | 0.38 | Biod EU | GTAP | 0.79 | Eth EU |
| | | | GTAP | 0.17 | Corn US |
| *Laborde 2011 :* | | | | | |
| Mirage | 0.08 | Palm | Mirage | 0.02 | Beet |
| Mirage | 0.16 | Rape-Soya | Mirage | 0.04 | Corn |
| Mirage | 0.21 | Sunflower | Mirage | 0.06 | Cane-wheat |

Source: Edwards et al. (2010); Laborde (2011)

Table 1 provides for each considered type of EU and US biofuel, the number of hectares that would be converted from non-crop to crop use by toe. For instance, simulations performed with the GTAP model suggest that one toe from EU biodiesel induces 0.38 hectare converted from non-crop to crop use, while the same toe from US corn ethanol would displace only 0.17 hectare.

Three main features emerge from Table 1. First of all induced LUC estimates differ according to the type of biofuel considered and according to the feedstock used: for example, simulations performed with the OECD/FAO model AGLINK/COSIMO suggest that biodiesel extra demand in the EU would displace 0.23 ha per toe while ethanol extra demand in the EU would displace 0.57 ha per toe; simulations performed with MIRAGE show that biodiesel would displace different land areas whether it is made exclusively from palm (0.08 ha per toe) rape or soya (0.16 ha per toe) or sunflower (0.21 ha per toe) oils. Secondly, induced LUC estimates differ according to the origin of the extra demand: for instance, results from both GTAP and LEITAP show that ethanol extra demand leads to different area converted whether the extra demand takes place in the EU or in the US.[5] Thirdly available results do not

[4] In this paper we use LUC and we generally don't use iLUC. Usually the LUC we deal with here is the total net land area which is converted (or displaced) from non-crop uses (mainly pasture and forests) to crop use due to the development of biofuels. This does not correspond exactly to the strict definition of iLUC (see, e.g., De Cara et al., 2012).

[5] Of course part of the variability according to the origin of the extra demand relates to the variability according to the feedstock used since the EU and the US don't use the different feedstocks in the same proportions to

converge towards a definite ranking of the different types of biofuels from both origins regarding the converted area per toe: as an example FAPRI estimates that EU biodiesel would displace slightly more area per toe than EU ethanol while AGLINK/COSIMO suggest that EU biodiesel would displace significantly less area than EU ethanol; LEITAP shows that EU ethanol would displace less area per toe than US ethanol, while AGLINK/COSIMO suggests that EU ethanol would displace slightly more area per toe than US ethanol and GTAP results indicate that EU ethanol would displace significantly larger area per toe than US ethanol.

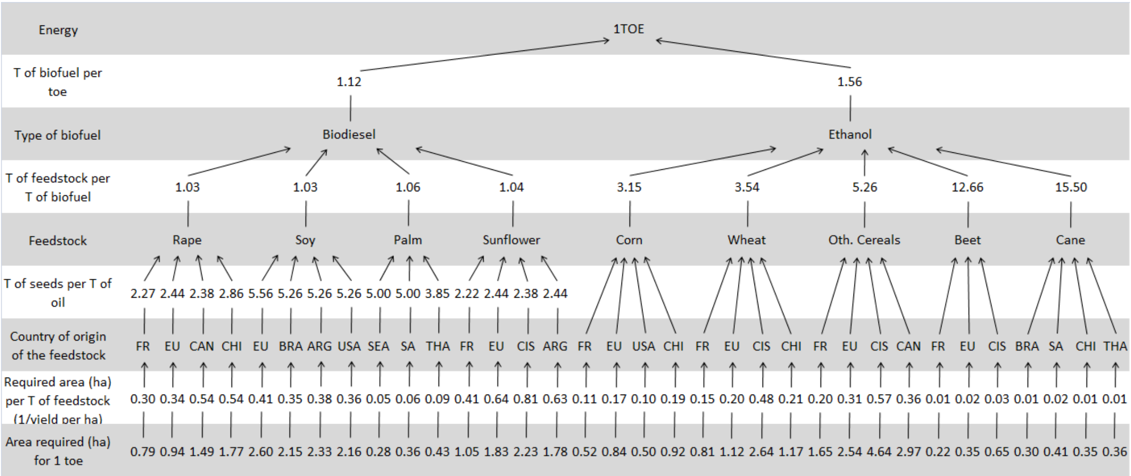
Figure 1 below indicates that part of this variability in displaced area per toe according to the type of biofuel and to the origin of the extra biofuel demand is due to the variability in the technical performance of the various feedstocks from various origins. Indeed Figure 1 relies on 2007-2009 average observed data and provides, given the technical transformation coefficients and the observed yield per hectare, the area required for producing one toe from different feedstocks from various origins.

Figure 1 shows clearly that due to discrepancies across technical performances (especially across yields per ha), the area required for producing one toe differs widely according to the feedstock used and according to the origin of these feedstocks. Among biodiesel feedstocks, palm oil is the most land saving while soya and sunflower are the most land using. South-East Asian palm oil seems to be the best performer as regards area required for producing one toe: 1 toe of biodiesel from palm oil in South East Asia only “costs” 0.28 ha, while the same toe from soy oil requires more than 2 ha. French and, to a lesser extent, EU rape oil also exhibit quite good performances: 1 toe biodiesel from rape oil requires 0.79 ha in France. Regarding ethanol, sugar beet (except the CIS origin) and sugar cane appear as the most land saving feedstocks (0.22 ha required for ethanol from sugarbeet in France, 0.30 ha for ethanol from cane in Brazil), wheat and other cereals as the most land using (especially in the CIS countries: 2.64 and 4.64 ha/toe respectively). French beet and Brazilian cane rank first as regards the area required per toe. French and US corn also exhibit good performances (around 0.50 ha/toe). EU beet and almost EU corn clearly rank behind their French counterpart (0.35 and 0.84 ha/toe respectively).

Obviously these differences in technical performances may partly explain why LUC estimates differ according to the type of biofuel considered and to the origin of the biofuel extra demand. However this is not the most important factor. First, Figure 1 shows that choosing the least land using feedstocks for both biodiesel and ethanol (i.e., respectively palm oil and beet/cane), the area required for producing one toe would not differ much between biodiesel and ethanol (0.28 ha/toe for South East Asian palm oil biodiesel, 0.22 for French beet ethanol and 0.30 for Brazilian cane ethanol). Second, considering the best performers for producing ethanol in both the EU and the US (i.e., respectively beet and corn), the area required per toe would not be so different neither between EU and US ethanol (0.35 versus 0.50 ha/toe).

produce ethanol: US ethanol is made mostly with corn while EU ethanol is made with both wheat, corn and sugar beet.

**Figure 1. Variability in technical performances of the different feedstocks from various origins**




Note : FR=France; CAN=Canada; CHI=China; BRA=Brazil; ARG=Argentina; SEA=South-East Asia; SA=South Asia; THA=Thailand; CIS=Former USSR

Source: calculated from 2007-2009 observed data

In addition and most importantly, Figure 1 is a static picture of the technical performances of the different feedstocks of various origins at one point in time[6]. Hence areas required per toe reported in Figure 1 are quite different from the LUC estimates issued from models, which account for market and price adjustments and for land saving from the use of biofuel by-products in animal feed. Our intuition here is that the discrepancies among simulation results that we observe between LUC estimates of the various types of EU and US biofuels is not principally due to differences in technical performances but to the substitution possibilities that are allowed between feedstocks and country origins in used model.

## 3. Pointing fingers

Let's try, starting from Figure 1, to explain further this intuition. Suppose we register an increase in the EU biodiesel demand. This extra demand may be covered either by increasing domestic biodiesel production or by importing biodiesel, both domestic and foreign production looking for the most profitable feedstocks from the various origins. Under the Armington assumption (used in GTAP and Mirage for instance) the substitution possibilities between domestic and foreign production are limited so that it is likely that the land conversions will be concentrated in the EU and concern rape. In the same way, substitution possibilities between origins of trade flows are also limited so that it is likely that the EU will continue to trade with its traditional partner countries, which are not always the most productive in terms of per hectare yields and thus in terms of area required per toe. The

[6] It is also a partial picture, as only the main technologies are represented. Other feedstocks (cotton oil, coprah oil, manioc, etc.) can also be used for biodiesel and ethanol production.

story is the same if the extra demand focus on ethanol and is registered in the US: the land conversions are likely to take place mainly in the US and concern corn.

At reverse, under the integrated world markets (IWM) assumption, substitution possibilities between domestic and foreign production as well as among origins of trade flows are far more important so that the extra biodiesel demand in the EU is likely to provoke LUC not only (even not principally) in the EU but also in many other countries in the world and concern more feedstocks than rape. Similarly, under IWM, an extra ethanol demand in the US is likely to provoke LUC all over the world, the domestically produced corn ethanol being more easily substitutable by cane ethanol imports from Brazil, all other things being equal.

Hence it is clear that the Armington assumption contributes to create gaps between induced LUC estimates for the various types of biofuels and according to the origin of the considered extra demand. At reverse, the IWM assumption tends to erase these gaps. In other words, without the Armington assumption, which is used in numerous models, biodiesel and ethanol on the one hand, EU and US biofuels on the other hand are likely to exhibit closer performances in terms of induced LUC.

This statement is consistent with Table 1 where the FAPRI model, which is the only model not relying on the Armington assumption[7], is also the only one providing rather similar LUC estimates for biodiesel and ethanol in the EU. This statement is also confirmed by Golub and Hertel (2012). They show that with the Armington approach land conversions resulting from an extra demand of ethanol in the US are concentrated in the US and its main export competitors in Europe. While when shifting towards the IWM assumption, the impacts of expanding US ethanol is distributed more evenly across the world. Golub and Hertel (2012) also show that shifting from the Armington to the IWM assumption may increase or decrease the total area displaced by toe, depending on the relative yields per hectare of US ethanol feedstocks as regards its partner countries.

Because the Armington approach allows to capture stylized facts such as imperfect transmission of world prices changes to domestic prices, incomplete specialization and two-way trade, it has been widely used in market and trade models (mainly CGE models). However, this approach suffers from an important drawback: it tends to stiffen trade flows. This drawback implies important limitation when dealing with scenarios implying strong changes on several or all markets. Some authors have shown for instance that under the Armington approach import (export) shares in domestic consumption (production) which are initially very small will remain small even after global market liberalization scenarios (e.g., Gohin et al., 2006). At reverse, the IWM approach does allow for perfect substitutability between domestic and foreign commodities, leading to very flexible adjustments in trade. Such an assumption is probably more appropriate when dealing with a rather long term horizon.

[7] Although the AGLINK/COSIMO model does not formally use the Armington assumption, its world to domestic price transmission equations result in adjustment patterns of domestic relative to world prices which are similar to the patterns that would be observed under the Armington modeling of trade flows.

Biofuel markets (either in France or elsewhere) have been evolving rapidly over the last 10 years and it is likely that the Armington approach used in a lot of models is too restrictive in such a case. In such an environment, where domestic markets and trade flows are changing dramatically, the IWM approach may be more appropriate even if one must admit that the reality clearly deviates from the product homogeneity assumption.

## 4. Sensitivity Analysis of Land-Use Change estimates relative to trade assumptions

Our objective here is to illustrate our above described intuition. For that purpose, using MATSIM-LUCA we illustrate how biofuel-induced LUC estimates vary when the IWM assumption is progressively replaced by an Armington-like approach.

MATSIM-LUCA is a partial equilibrium model of the world arable crop markets, specifically developed for assessing the LUC induced by biofuel development. MATSIM-LUCA relies on the IWM approach and thus an extra demand of biofuel in one country or zone is very easily transmitted to the world markets and to the other countries or zones. We emphasize however that MATSUM-LUCA does not rely on the free trade assumption and accounts for the main agricultural policy and trade measures applied in considered countries and zones. Specification, data and some simulation results of MATSIM-LUCA are detailed in Forslund et al. (2013a, 2013b and 2013c).

As shifting from the IWM to the Armington assumption would require to rewrite the model and integrate consistent bilateral trade flows, we propose to mimic the Armington specification by restricting the substitution possibilities between some trade flows. The trade flows which are alternatively restricted are chosen according to the energy content in hectares of the different feedstocks of various origins as reported in Figure 1. Indeed one may keep in mind that the global land displaced following an extra demand of biofuel in one country highly depends on whether its trade partners are more or less efficient in terms of biofuel production.

In the various scenarios simulated and discussed below, we impose a 1 million ton of oil equivalent extra demand of either ethanol or biodiesel in either the EU or the US. The base year is 2009. The considered scenarios are differentiated according to the EU or the US partners which are allowed to adjust their trade following the initial extra demand shock.

### 4.1. Comparison of ethanol and biodiesel scenarios in Europe

#### i. Ethanol

The EU is one of the most efficient ethanol producing zone in terms of land use. In 2009, half of the European ethanol production came from beets, the other half was shared between wheat, corn and other cereals. According to Figure 1, in 2007-2009 the EU needed 0.35 hectare of beets to produce 1 toe of ethanol, 0.84 ha of corn or 2.54 ha of other cereals. Meanwhile, the USA used 0.50 ha of corn and Brazil used 0.30 ha of sugarcane. Let us keep in mind that these figures do not account for by-products resulting from the production of ethanol (especially from cereals), and which can be used in replacement to other feeds (like oilcakes and cereals) in feed rations. These by-products and their LUC effects are of course fully accounted for in MATSIM-LUCA.

**Erreur ! Source du renvoi introuvable.** illustrates the impact of the different assumptions regarding EU trade partners on the simulated LUC impacts of a 1Mtoe extra ethanol demand in the EU.

**Table 2. LUC induced by 1 Mtoe extra ethanol demand in the EU under different trade schemes**

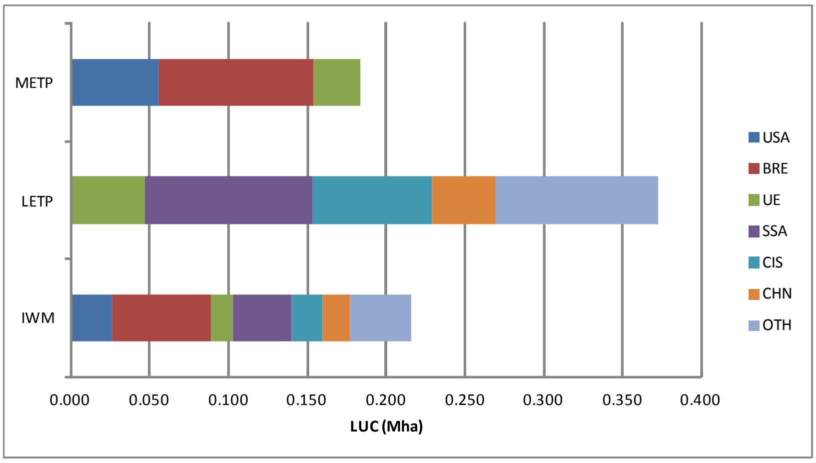
| | IWM | METP | LETP |
|---|---|---|---|
| Trade limited to : | - | USA and BRAZIL | All except USA and BRAZIL |
| LUC, ha/toe | 0.217 | 0.183 | 0.373 |
| Change relative to IWM, % | - | -15.7% | +71.9% |

When using the standard version of MATSIM-LUCA (IWM scenario), the 1 Mtoe extra ethanol demand in the EU leads to 217 kha displaced from non-crop to crop use in the world, that is 0.217 hectare per toe. In this scenario, only a small share of the total LUC takes place in Europe (6%), the bulk part of the land conversions comes from Brazil (29%) and Sub-Saharan Africa (17%).

When we simulate the same shock but with trade adjustments limited to the most efficient partners countries of the EU regarding ethanol production (i.e., USA with corn feedstock and Brazil with cane feedstock) (METP –more efficient trading partners- scenario), the induced LUC is, as expected, reduced to 183 kha or 0.183 ha/toe (i.e., -16% relative to the IWM scenario). As other countries are excluded from trade adjustments and do not register the price change occurring on the world market, LUC takes place only in Europe and in these 2 countries: the conversion of land that takes place in Europe increases (to 16%) compared to the IWM scenario, but Brazil still accounts for the largest share (53%), followed by the USA.

At reverse, in the LETP (less efficient trading partners) scenario, when trade adjustments are allowed in all countries but Brazil and the USA (that is in ethanol producing countries which are less efficient than the UE in terms of land used), the LUC increases, also as expected, to 373 kha, or 0.373 ha/toe (i.e., +72% relative to the IWM scenario). In this scenario, the bulk part of the land conversions takes place in Sub Saharan Africa (28%) and in the CIS countries (20%), where the initial shock has much higher LUC impacts due to lower yields relative to the EU. The LUC arising in the EU increases in scenario LETP compared to the two other scenarios, but only accounts for 13% of total LUC. Finally, between the METP and the LETP scenarios, the LUC impact of 1 Mtoe extra ethanol demand in the EU more than doubled.

**Figure 2. LUC induced by 1 Mtoe extra ethanol demand in the EU, by country, under different trade schemes**




### ii. Biodiesel

When it comes to the production of biodiesel, Figure 1 indicates that palm oil is by far the most efficient feedstock as regards the area required per toe, as of its very high yield per ha compared to other oilseeds. In Europe, where rape is the most commonly used feedstock, 0.94 ha is required to produce 1 toe of biodiesel, when in South-East Asia, only 0.28 ha is needed, that is more than three times less land than in Europe to produce the same amount of biofuel. On the contrary, soy is the least efficient biodiesel feedstock, as the oil yield of soy is very low compared to other oilseeds. Hence 2 hectares or more must be utilized in the US, Brazil or Argentina and 2.60 ha in Europe for producing 1 toe.

As of these differences, allowing trade with or without countries specialized in one or the other of these feedstocks makes great differences as regards the land area required to produce the same amount of biofuel. This is illustrated in **Erreur ! Source du renvoi introuvable.**.

**Table 3. LUC induced by 1 Mtoe extra biodiesel demand in the EU under different trade schemes**

| | IWM | Palm-METP | Palm-LETP | Soya-METP | Soya-LETP |
|---|---|---|---|---|---|
| Trade limited to : | - | South-East Asia (SEA) | All except SEA | ARG, BRA and USA | All except ARG, BRA and USA |
| LUC, ha/toe | 0.260 | 0.164 | 0.318 | 0.316 | 0.251 |
| Change relative to IWM, % | - | -36.9% | +22.3% | +21.5% | -3.5% |

In the IWM scenario, the 1Mtoe increase in the EU biodiesel demand would lead to a total 260 kha displaced area in the world, equivalent to 0.26 ha/toe. As in the ethanol case, the greatest share of land conversions would take place outside Europe (converted land from non-crop to crop use in the EU would account for 10% only of the total LUC).

Under an extreme scenario where trade adjustments would be allowed between Europe and South-East Asia only, (Palm-METP scenario), the extra biodiesel demand in the EU would induce a total LUC of “only” 164 kha[8], equivalent to 0.164 ha/toe, a 37% decrease compared to the IWM scenario. Land conversions would be concentrated in these two zones, and much more land than in the IWM scenario would now be converted in Europe (see Figure 3).

At reverse, if the EU’s most efficient palm oil trade partner is excluded from trade adjustments (Palm-LETP scenario), the induced LUC would instead increase to 318 kha, or 0.318 ha/toe, 22% more than in the IWM scenario. This result illustrates the very high contribution of South-East Asia on (the sparing of) land, especially when considering the very small share of global LUC that takes place in this region under the IWM scenario (1%). The largest land conversions would now take place in the CIS countries (15%), Sub-Saharan Africa (15%) and Brazil (13%), the European share of global LUC would account for 11%.

When instead allowing trade only with partners that are efficient in the production of soya (Soya-METP scenario): USA, Brazil and Argentina, the 1 Mtoe increase in the European biodiesel consumption would lead to global LUC of 316 kha, or 0.316 ha/toe. This is more than in the IWM scenario (260 kha). This is due to the fact that, when restraining the EU trade partners to those specialized in soy production, even if these are the most efficient ones, the additional biodiesel demand has larger impact on LUC due to the relatively lower yields of soy relative to other biodiesel feedstocks like rape or palm oil.

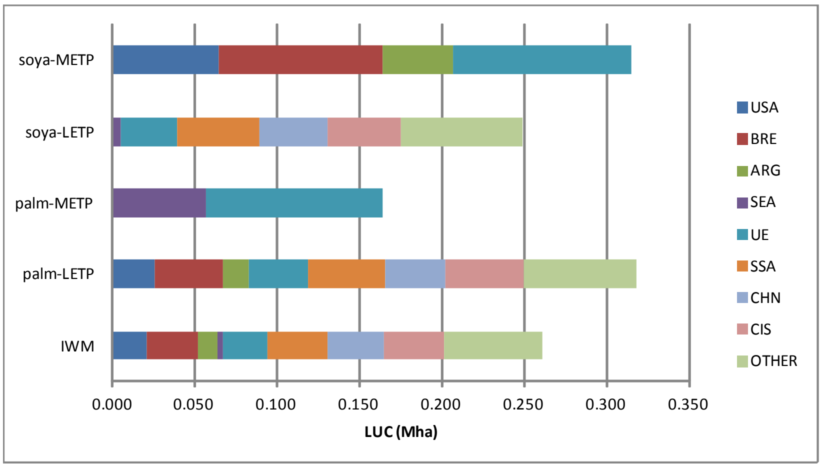
In this Soya-METP scenario, the LUC that takes place in Europe where the shock originates increases a lot compared to the IWM approach, and would represent the largest share of the total converted land (>1/3 of the global LUC would take place in Europe).

When we instead allow for trade with only less efficient partners than USA, Brazil and Argentina in soya products, the global LUC decreases, very slightly, to 251 kha, or 0.25 ha/toe, which is less than the LUC in the IWM scenario. As the biggest producers of soy are excluded from the world market, use of other, more productive, feedstocks increases so the induced LUC decreases.

Once again, these results can be explained by the differences in Europe’s trade partners’ efficiency in biodiesel production, these differences originating mainly from gaps between their yields in feedstocks per hectare.

[8] Here one must keep in mind that we only talk about induced LUC in terms of displaced hectares and not about the greenhouse gas emissions related to the LUC which are expected to be very large in this region as converted land often comes from carbon-rich rainforests.

**Figure 3. LUC induced by 1Mtoe extra biodiesel demand in the EU, by country, under different trade schemes**




The comparison of the results from the European ethanol and biodiesel scenarios reveals that:

i/ our IWM scenarios result in LUC of 0.217 ha/toe for ethanol and 0.26 ha/toe for biodiesel, confirming that the IWM approach tends to erase differences in induced LUC from biodiesel and ethanol;

ii/ the results obtained from the different scenarios confirm that land use change stemming from the development of biofuels is highly dependent on assumptions made on trade;

iii/ in our scenarios, and under different trade assumptions, the EU ethanol shock induces global LUC between 0.183 and 0.373 ha/toe whilst the biodiesel shock results in global LUC between 0.16 and 0.318 ha /toe; compared to the IWM scenarios, trade assumptions seem to have greatest impact on ethanol for increased LUC (+72% compared to IWM when trading with least efficient partners) and on biodiesel for decreased LUC (-37% compared to IWM when allowing trade only with the most efficient partner).

### 4.2. Comparison of ethanol scenarios in the US

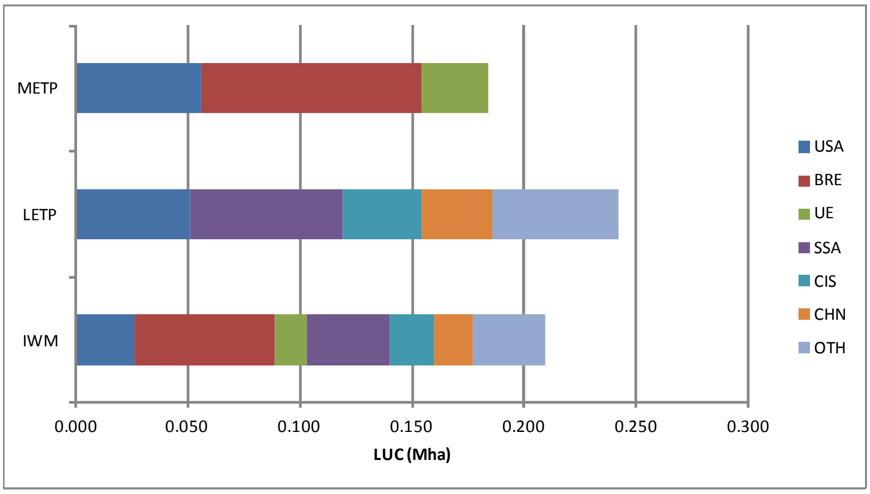
We now simulate a 1 Mtoe extra ethanol demand in the US keeping the same trade schemes as in previous EU scenarios.

**Table 4. LUC induced by 1Mtoe ethanol extra demand in the US under different trade schemes**

| | IWM | METP | LETP |
|---|---|---|---|
| Trade limited to : | - | UE and BRA | All except UE and BRA |
| LUC, ha/Toe | 0.217 | 0.183 | 0.254 |
| Change relative to IWM, % | - | -15.7% | +17.05% |

LUC induced from an increase in US ethanol demand is equivalent to 0.217 ha/toe when using the IWM approach, which is exactly the same impact as when the shock was applied to European ethanol. When we restrict trade adjustments to the most efficient US partners as regards ethanol production (Europe and Brazil), the LUC decreases to 0.183 ha/toe, -16% compared to the IWM scenario, and is again exactly the same figure as in the corresponding European scenario. However, when restraining trade adjustments to less efficient partners, LUC increases to 0.254 ha/toe, +17% compared to the IWM scenario and much less than corresponding EU scenario (which induced greater LUC especially in SSA and the CIS countries). It seems then that US ethanol industry would perform better that its EU counterpart as regards the land area required par toe. Indeed US ethanol is quite entirely produced with maize while UE ethanol uses more diversified feedstocks, including sugar beet that technically needs less land than maize per toe (as shown by Figure 1) but which also produces less by-products.

**Figure 1: LUC induced by 1Mtoe extra ethanol demand in the US, by country, under different trade schemes**




## 5. Concluding comments

Our paper contributes to the vigorous debates which are currently going on within both the scientific community and the policy sphere on biofuel-induced LUC and corresponding GHG emissions. Fueling these debates is the wide range of available estimates of biofuel-induced LUC and corresponding GHG emissions issued from various models as well as the lack of consensus regarding the type of biofuel (i.e., biodiesel or ethanol) and the country of origin (i.e., mainly, European Union or the US) which would induce the least LUC and GHG emissions.

In line with existing sensitivity analyses, which show that estimated biofuel-induced LUC and related GHG emissions are highly sensitive to models' assumptions and/or parameters, we focus on the role of the trade modeling assumptions. Our intuition is that the Armington approach, currently used in market and trade models, contributes to create gaps between induced LUC from biofuels from different origins, so from biodiesel and ethanol as well as from EU and US biofuels.

We illustrate our intuition using both observed data and the partial equilibrium model MATSIM-LUCA. Our results show clearly that LUC stemming from the development of biofuels is highly dependent on assumptions made on trade: the IWM approach tends to erase differences in estimates of induced LUC from biodiesel and ethanol and from EU and US biofuels as compared to the Armington-like approach.

Our results also show how the initial biofuel extra demand shock is propagated differently according to the retained trade modeling assumptions. Such a result is essential as regards the estimation of GHG emissions resulting from biofuel-induced LUC: the carbon stocks in the aboveground biomass and/or in the soil varying spatially, GHG emissions differ according to the location of the induced LUC.

In other words, trade modeling assumptions are likely to be essential as regards policy recommendations that are drawn from simulation results issued from market and trade models. Modelers must be aware of this feature and justify further their choice of modeling approach. Of course, there are still controversies on the empirical relevance of the Armington vs. the IWM approaches for modeling agricultural trade. These controversies partly come from the difficulties to observe all policy instruments that apply on trade flows as well as all relevant prices and quantities. Villoria and Hertel (2011) and Reimer et al. (2012) conclude that the most relevant trade modeling approach depends on the considered countries and products. These authors also agree that in the medium to the long run, the IWM approach is more relevant. One may add that the IWM approach allows to explicitly tackle new trade flows while the latter are difficult to capture in the CES-based Armington approach. This is a valuable advantage of the IWM approach when dealing with dramatically evolving markets such those of biofuels all around the world.

## References

Broch, A., Hoekman, S.K., Unnasch, S. (2013). A review of variability in indirect land use change assessment and modeling in biofuel policy. *Environmental Science & Policy*, 29: 147-157.

California air resource board (2009). Low carbon fuel standard. http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

DeCara, S., Gousebaïl, A., Grateau, R., Levert, F., Quemener, J., Vermont, B. (2012). *Revue critique des études évaluant l'effet des changements d'affectation des ols sur les bilans environnementaux des biocarburants*. Rapport final pour l'Ademe, mars 2012.

Dumortier, J., Hayes, D., Carriquiry, M., Dong, F., Du, X., Elobeid, A., Fabiosa, J.F., Tokgoz, S. (2011). Sensitivity of Carbon Emission Estimates from Indirect Land-Use Change. *Applied Economic Perspectives and Policy* 33(3): 428-448.

Edwards, R., Mulligan, D., Marelli, L. (2010). *Indirect Land Use Change from increased biofuels demand. Comparison of models and results for marginal biofuels production from different feedstocks*. European Commission JRC. Final report of the contract n. 070307/2008/517067/C3.

European Commission (2012) COM(2012) 595 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. October 17th, 2013.

Fargione, J., Hill, J., Tilman, D., Polasky, S., Hawthorne, P. (2008). Land Clearing and the Biofuel Carbon Debt. *Science*, 319(5867): 1235-1237.

Forslund, A., Levert, F., Cuvelette, C., Le Mouël, C., Gohin, A. (2013a). *Etude complémentaire à l'analyse rétrospective des interactions du développement des biocarburants en France avec l'évolution des marchés français et mondiaux et les changements d'affectation des sols. Volet 2 : Evaluation des effets du développement des biocarburants en France sur les marchés nationaux et internationaux des grandes cultures et sur le changement d'affectation des sols : La base de données du modèle MATSIM-LUCA*. Rapport final pour l'ADEME, mars 2013.

Forslund, A., Levert, F., Gohin, A., Le Mouël, C. (2013b). *Etude complémentaire à l'analyse rétrospective des interactions du développement des biocarburants en France avec l'évolution des marchés français et mondiaux et les changements d'affectation des sols. Volet 2 : Evaluation des effets du développement des biocarburants en France sur les marchés nationaux et internationaux des grandes cultures et sur le changement d'affectation des sols : Le modèle MATSIM-LUCA*. Rapport final pour l'ADEME, mars 2013.

Forslund, A., Levert, F., Gohin, A., Le Mouël, C. (2013c). *Etude complémentaire à l'analyse rétrospective des interactions du développement des biocarburants en France avec l'évolution des marchés français et mondiaux et les changements d'affectation des sols. Volet 2 : Evaluation des effets du développement des biocarburants en France sur les marchés* *nationaux et internationaux des grandes cultures et sur le changement d'affectation des sols : Une analyse avec le modèle MATSIM-LUCA, résultats des simulations*. Rapport final pour l'ADEME, mars 2013.

Gohin, A., Guyomard, H., Le Mouël, C. (2006). Tariff protection elimination and CAP reform: Implications of change in methods of import demand modeling. *Applied Economics*, 38: 1527-1539.

Gohin, A. (2013). *Le changement d'affectation des sols induit par la consommation européenne de biodiésel : une analyse de sensibilité aux évolutions des rendements agricoles*. Working Papers SMART-LERECO, juin 2013.

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

Laborde, D. (2011). *Assessing the Land Use Change Consequences of European Biofuel Policies.* Final report for the Directorate General for Trade of the European Commission. IFPRI, October 2011.
http://trade.ec.europa.eu/doclib/docs/2011/october/tradoc_148289.pdf

Plevin, R.J., O'Hare, M., 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 and Technology*, 44(21): 8015-8021.

Reimer J.J., Zheng, X., Gehlhar, M.J. (2012). Export Demand Elasticity Estimation for Major U.S. Crops. *Journal of Agricultural and Applied Economics*, 44(4): 501-515.

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

Villoria, N. B., Hertel, T. W. (2011). Geography Matters: International Trade Patterns and the Indirect Land Use Effects of Biofuels. *American Journal of Agricultural Economics*, 93(4): 919-935.