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The land use changes of European biodiesel: sensitivity to crop yield evolutions

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Abstract

The European public policy in favor of the biodiesel consumption is highly debated. Available estimates of the induced land use changes conclude that this policy is inefficient to reduce emissions of GreenHouse Gas. We show that the crop yield evolutions in these estimates are significantly lower than the observed and expected evolutions. This difference is directly related to biased calibration choice of behavioral parameters. We show using the GTAP-BIO framework that a consistent calibration of these parameters leads to a strong reduction (by around 80% in the long run) of the land use changes and induced emissions.

Keywords: Biofuel, Europe, land use changes

JEL classifications: Q11, Q15, Q48

Le changement d'affectation des sols induit par la consommation européenne de biodiesel : une analyse de sensibilité aux évolutions des rendements agricoles

Résumé

L'action publique européenne sur le biodiesel est aujourd'hui contestée. Les estimations du changement induit d'affectation des sols concluent à son inefficacité pour réduire les émissions de gaz à effet de serre. Nous montrons que les évolutions de rendements agricoles dans ces estimations sont très faibles par rapport aux évolutions observées et aux projections actuelles. Ces résultats découlent de choix contestables de calibrage des paramètres comportementaux. Nous montrons, avec le cadre GTAP-BIO, qu'un calibrage plus consistent de ces paramètres conduit à une forte diminution (de l'ordre de 80% à long terme) du changement d'affectation des sols et des émissions associées.

Mots-clés : Biocarburants, politique européenne, changement d'affectation des sols

Classification JEL : Q11, Q15, Q48

The land use changes of European biodiesel: sensitivity to crop yield evolutions

1. Motivations

The European public action supporting biofuel consumption really started in 1992 during the first Common Agricultural Policy reform. At the time, Europe required its farmers to set-aside a portion of the acreage in order to limit its excess farming production. Fallowed acreage could nevertheless be used for non-food production, including biofuels. This public action was later increased first in 2003 and then in 2009 through European directives promoting renewable energies and fuel quality. These directives set-forth in particular the blending targets for biofuels in the land transportation sector, Member States being required to implement policy incentives to reach these targets. At the same time, they defined sustainability criteria, in particular criteria regarding the reduction in greenhouse gas emissions (GHGs)

Nevertheless, this European public action is now extremely controversial and its future rather uncertain, at least regarding biodiesel and to a lesser extent bioethanol. The first criticism is that following the global food crisis in 2007, it contributed to the steep rise in the global prices of many agricultural products, including vegetable oils. It is currently questioned because of its low efficiency, and even its inefficiency, in connection with the reduction in net GHG emissions. Even if emissions that are directly linked to the consumption of biofuels are not known with certainty, it is in particular the scope of the emissions linked to land use change (LUC) with an expansion of croplands on carbon-rich soils that is controversial. Thus, the European public action really began within the context of the availability of croplands in Europe, and is now questioned because of a lack of availability of these lands at the global level that has led to a potential reversal of carbon-rich soils (grasslands, forests, peatlands).

This LUC is caused by the fact that additional consumption of biofuels is indeed likely to lead to additional acreage being planted in the corresponding crop (in this instance oilseeds producing oils for biodiesel). But the amount of additional acreage actually planted (in oilseeds) will depend on the likelihood of other demands being reduced (demand in human-consumed oil), of an increase in acreage already attributed to these productions or even the value-enhancement of coproducts (meal from oilseed production). Furthermore, the total amount of additional acreage planted will also depend on the repercussion on other agricultural product markets and dedicated acreages (for example, grain or sugar acreages).

LUC induced by the growth of biofuels therefore results from the interaction of several

economic mechanisms. It cannot be directly calculated from observing the size of global croplands for the simple reason that the size of these lands changes under the influence of multiple other factors (such as changes in food demand, and in farming technologies, etc.). This is why many modeling studies of the global agricultural product markets, quantifying the previously identified economic mechanisms, have been conducted over recent years. A number of these studies focuses on measuring LUC induced by U.S. biofuels policy, while a lesser number of these studies focuses on the effects of LUC induced by European policy (recent reviews are supplied in De Cara *et al*., 2012 and Broch *et al.*, 2013).
All these modeling studies rely by definition on assumptions that have generally been tested to validate the strength of the main results. The overall goal of this paper is to test the sensitivity of available LUC evaluations and associated GHG emissions induced by European biodiesel consumption to yields assumptions.

We have focused our analysis on European biodiesel consumption for two main reasons. First, this is the main biofuel consumed today in Europe and will most likely remain so in the near future. European automobiles are mostly diesel powered and the potential shift towards gasoline engines will only be gradual. Second, the review of the literature carried out by the European Commission (EC, 2012) shows that evaluations deemed relevant to the effects of LUC and associated GHG emissions are clearly more convergent for biodiesel than for bioethanol.[1] Thus, these induced emissions vary (approximately) between 50 and 100 gCO2eq/MJ for biodiesel, the majority of these evaluations being centered around 55 gCO2eq/MJ. On the other hand, the evaluations for bioethanol are relatively spread out between 0 and 200 gCO2eq/MJ. This implies that the results of an analysis of the sensitivity to the yield change assumptions are less likely to depend on the modeling framework retained in the case of biodiesel.

Two main reasons also justify our focus on assumptions relating to yield changes. First, sensitivity analyses concerning the evaluation of U.S. biofuels policy indicate that the results are mainly dependent on these assumptions with respect to yield changes (Dumortier *et al.*, 2011, Golub and Hertel, 2012). Second, among all the economic mechanisms mentioned above that influence the quantification of LUC effects and associated GHG emissions, yield changes are not the most difficult to validate. Indeed, observations regarding acreage, productions and yields of the main crops in the major producing countries are in general

[1] 1. More precisely, see Figure 3 of page 13 in the Impact Statement that is included in the proposal for the revision of the European directive on biofuels (EC, 2012).

clearly more abundant and considered more reliable than the observations on the level of food and feed demand for example.The latter are only generally available for certain productions (data for fodder consumption in grazing animal feed is rarely available) and moreover the level of these demands is mostly calculated from the balance in market assessments (accumulating thereby potential errors in the other balance sheet entries such as variations in inventory). In other words, even though it is also possible and desirable to improve them, measuring changes in yields is relatively easier than measuring other economic mechanisms impacting the quantification of LUC effects.

This paper is divided into two sections. In the first section, we will conduct a new review of the literature focused on changes in yields assumed or obtained in the evaluations of the LUC effects induced by European biodiesel consumption. This literature review will naturally include the IFPRI study and the underlying model MIRAGE-BioF (Laborde, 2011). This is indeed the one chosen by the EC to justify its proposals for revising the European biofuels directives. We will show in the first section that the change in yields obtained in these studies are generally very low with respect to the change in yields observed over the long term and also with respect to projected trends for these yields. We will also show that this is the consequence of questionable choices in the calibration of these parameters. In the second section, we will test the impact on LUCs and associated emissions of a more consistent change of the yield effects. This sensitivity analysis is conducted with the GTAP-BIO model, which was used in particular to measure the effects of U.S. biofuels policy by the California Air and Resource Board (CARB, 2010). Even though this is not the modeling framework chosen by the EC, its structure and results are close to those obtained with the MIRAGE-BioF framework. Above all it has the advantage of being openly available, which allows the analysis of sensitivity of these results to be subject to various assumptions. We will then show that a more consistent calibration of the parameters that directly determine the yield changes leads to a strong decrease in the LUC effects and associated GHG emissions induced by European biofuels consumption.

2. European biodiesel and yield changes: A review of the literature

Over the past few years, the market for biofuels has gone from marginal to significant for some global farming markets, such as corn (mainly because of U.S. consumption of bioethanol) or rapeseed (mainly because of European biodiesel consumption). Since then various economic models of agricultural markets have gradually integrated these new

demands in their balances, initially to measure the implications in terms of price trends (and their contribution to food crises) and subsequently to measure the effects on croplands and associated GHG emissions.
Many modeling teams have been sollicited to supply estimates of the LUC effects related to European biofuels consumption (Edwards *et al.*, 2010). It appears that, even though they incorporated the biofuels markets, some models are really inadequate to measure these LUC effects and associated GHG emissions. This is the case in particular with models initially focused on Europe with a rather rough representation of non-European regions. These are in particular the partial equilibrium models CAPRI and ESIM that the services of the EC have mobilized in order to quantify European effects (Blanco Fonseca *et al.*, 2010). This is also the case with models that do not have an explicit representation of coproduct markets, such as the general equilibrium LEITAP model, or the land market, such as the general equilibrium DART model (see Edwards *et al.* 2010). If moreover, we exclude models that do not give an analysis of the biodiesel sector and only focus on bioethanol (such as the IMPACT model of IFPRI), our review of the literature is limited therefore to the results given by 4 modeling frameworks. It includes two partial equilibrium frameworks with the FAPRI model of the University of Iowa and the AGLINK COSIMO model jointly developed by the OECD and FAO. It also includes two general equilibrium frameworks with the GTAP-BIO model developed by the University of Purdue and the MIRAGE-BioF model developed by IFPRI.

We describe below, for each of the modeling frameworks, the main assumptions relating to yield specifications and then analyse their main results (in particular from the simulations of comparisons reported in Edwards *et al.* 2010).

2.1. The FAPRI framework

This is the partial equilibrium framework developed in part by the CARD team at the University of Iowa. This model is regularly used to make projections on global agricultural market products and analyze agricultural policy reforms. In particular it was used on several occasions to quantify the effects of U.S. biofuels policy and at the request of the services of the EC to quantify the effects of European biofuels policy.

Production specifications, acreages and yields vary greatly depending on the regions and crops and moreover have changed with the various versions of the model (Elobeid *et al.*, 2012). The initial versions assumed that yields would change in an exogenous manner and therefore that prices had no impact with the exception of the United States. In this country, yields depended negatively on the acreage allotted to crops, while acreages changing under the influence of prices. On the other hand, the direct positive effect of prices on incentives to change yields, by adjusting input variables for example, was absent. By definition, an increase in price of a single crop automatically led to a drop in its yield, because of the increase in U.S. acreage allocated to the crop.

Specifications for yields have been revised in recent versions quantifying the effects of biofuel policies with, on the one hand the introduction of positive price effects and the other, the generalization of negative acreage effects in all regions (Edwards *et al.*, 2010). Elasticities effectively imposed are not indicated therefore we cannot appreciate the *ex-ante* effects of the introduced yield specification.

The simulation of a biodiesel consumption shock in Europe resulted in a global LUC of 437 thousand hectares for each million tons of oil equivalent (toe), i.e., 0.44 ha/toe. The majority of additional croplands come from India and rather marginally from Europe. At the global level, additional croplands led to an increase in total cropland production but a very modest decrease in global yields. Indeed these diminished by 0.008% whereas global croplands increased by around 0.05%.[2] This decrease in global yields is explained essentially by the shift in the global production of crops towards areas of low initial yields (India). At the level of each area, yields change marginally, or are even stable for rapeseed crops which are the most impacted by the shock. For yields of this crop, the negative effect of an increase in acreage is therefore barely compensated by the positive effect of the change in prices.

These divergent trends in acreage and yields at the global level in connection with European biodiesel consumption are in sharp contrast with projections established by FAPRI at the 2020 horizon. All cropland production included, projections are indeed that between 2010 and 2020 there will be an increase in global croplands of 3.1% as well as 7.9% in yields. In other words, 70% of additional production of croplands projected on a 10-year horizon will be obtained thanks to an increase in yields and only at the level of 30% through additional acreage. These proportions vary depending on the crops, for example shares linked to yields of around 82% for wheat and 45% for soybeans.

These variations are explained by the fact that yields change for a large part independently under the effect of exogenous technical progress in the projection whereas this exogenous technical progress is absent from the policy simulation. Only the induced effects on prices of

[2] 2. The FAPRI projections established in 2010 for 2020 indicate global croplands of 862 754 thousand hectares.

yields are taken into account and appear very limited in the simulation. Thisraises the question of the exact origin of technical progress in the projection phase and also of its absence when the long term effects of biofuels policies are quantified.

Even though they do not cover the case of European biodiesel, it is interesting to compare the results of the analysis of sensitivity carried out by Dumortier *et al.* (2010) on U.S. bioethanol with this FARPI framework. These authors compare the LUC effects and associated GHG emissions with and without taking into account the price effects in yield changes. As previously mentioned, the initial version of the FAPRI model excluded yield effects (as in the analysis carried out by Searchinger *et al.*, 2008 that launched the LUC debate). In an alternate version, these authors introduce specific price elasticities in yields of around 0.15 depending on crops and regions. These authors thereby show that estimates of LUC and associated GHG emissions are very sensitive to these elasticities. Thus, emissions depreciated over 30 years drop from 107 gCO2eq/MJ to only 14 gCO2eq/MJ when yields can adjust with prices. These authors conclude that the efficiency of the U.S. biofuels policy in terms of GHG emissions reduction could be improved by additional efforts in research and development on farming yields.

2.2. The AGLINK-COSIMO framework

This is also a partial equilibrium framework developed in cooperation between OECD and FAO. This model is also regularly used to make projections on global agricultural market products and analyze agricultural policy reforms. The EC services have access to this model and can use it for policy projections and simulations. Blanco Fonseca *et al.* (2010) have for example used it to test biofuel simulations in Europe.

Contrary to the FAPRI framework, product specifications, acreages and yields have not been specially modified to analyze biofuel policies. Acreages as well as yields are specified through reduced forms. Yields are either exogenous (marginal crops), or determined by iso-elastic functions of anticipated prices for corresponding crops (theses anticipated prices being assumed to be the prices of the previous year) and of a trend capturing exogenous technical progress. On the other hand, there is no negative effect for acreages as in the FAPRI framework. This does not exclude that at the global level, the yield effects can be negative if production shifts to areas with low initial yields.

The simulation of a biodiesel consumption shock in Europe resulted in a global LUC of 230 thousand hectares for each million toe (this figure takes into account acreages for palm oil crops), i.e., again 0.23 ha/toe. The majority of additional croplands come from Europe, followed by Argentina and India. This corresponds to a 0.025% increase in global croplands, i.e., half the FAPRI estimate. The difference is essentially explained by the yield increases obtained within the AGLINK-COSIMO framework at the aggregate level. These increase by 0.004%, essentially caused by an increase in cereal yields. Oilseed crop yields have decreased modestly (0.001%), again due to an extension of acreage in India.

Edwards *et al*. (2010) have also calculated the *ex-post* elasticities of acreages, yields and productions linked to this shock. Results are respectively of 0.25, 0.04 and 0.29. Therefore, 12% of the increase in production required to meet new demand is obtained by an increase in yields, the rest by an increase in acreage. This proportion is again in strong contrast with projection established in 2010 by OECD-FAO for 2021. All crop productions included, the projection indicates between 2010 and 2021 a global increase in croplands of 7.3% and in yields of 14.7%. In other words, 64% of additional production of croplands projected on a 10-year horizon will be obtained thanks to an increase in yields and only at the level of 36% through additional acreage. These proportions vary depending on the crops, for example shares of yields of around 80% for oilseeds and 47% for beats.

These variations are again explained by the fact that yields change for a large part independently under the effect of exogenous technical progress in the projection whereas this exogenous technical progress is absent from the policy simulation.

It is again relevant to report results of the sensitivity analysis carried out by Blanco Fonseca *et al*. (2010) with this AGLINK-COSIMO framework. These authors simulate the entire European biofuels policy (i.e., an increase in consumption of bioethanol and biodiesel, respectively of 7.3 and 14.9 million toe). They have obtained with the standard AGLINK-COSIMO version an increase in global croplands of 5.2 million hectares, which corresponds to an increase of 0.23 ha/toe (i.e., the same figure reported by Edwards *et al.*, 2010). These authors then test the effects of a permanent acceleration in farming yields that is motivated by the favorable prospects offered by European biofuels policies. The *ad hoc* assumption here is an increase in yields of around 3 to 3.4%. In this instance, an increase in global croplands induced by an expansion of biofuels is now only 0.187 million hectares (i.e., less than 0.01 ha/toe).

This variation shows the extreme sensitivity of the results to the assumptions regarding yield increases. However, this variation results at the same time in a decrease in crop prices. The question is therefore raised here of the origin of the yield increases because the margin per hectare and farming profits diminish after this shock. The authors of this study also reflect on this outcome and unfortunately do not further explore these variations. Specifying acreages and yields through reduced forms does not help with the consistency of the data, contrary to structural approaches such as those developed in the computable general equilibrium models that we will now examine.

2.3. The GTAP-BIO framework

The GTAP-BIO framework proceeded from the GTAP framework that combines a unique global database (of social accounting matrices coherent among countries) and a computable general equilibrium model adopting the neoclassical theory formalized by Arrow Debreu. The GTAP framework is mostly used to study issues of trade, poverty, energy and the environment (climate change in particular).

Several changes were made to this framework to allow for a relevant analysis of biofuels policies (essentially U.S. policy). These changes concern both the databases (with the introduction of coproducts for example) and the behavioral function specifications (with the introduction of multi-product technologies for example). These various improvements are described in Golub and Hertel (2012).

The specification of the supply, acreage and yield functions is very different from the previous ones because it is structural. Indeed, within a general equilibrium framework, producer decisions are modeled in terms of use of the various inputs need for production. These inputs are distinguished among variable inputs (chemical products, seeds, energy products for example) and production factors (labor, capital and land). Producers maximize their profit by combining these inputs in an optimal manner. They must meet technological constraints that are represented by functions of the CES (Constant Elasticity of Substitution) type. It is essentially through the parameters of these CES functions (in particular the elasticity of substitution among inputs) and through parameters of the supply of production factors (their mobility elasticity) that increases in acreage, other inputs and therefore yields are managed in this type of model.

Since we will be using this framework in the second section of our paper for the sensitivity analysis and that it is relatively close to the MIRAGE-BioF framework chosen by the EC to justify its proposals, we list in more detail below these specifications for acreage, yield and production equations (they are fully described in Keeney and Hertel, 2009).

This framework distinguishes 5 major types of inputs: labor, capital, land, energy products and other inputs. This implies that in theory, for each agricultural sector in each region, 10 elasticities of substitution can be specified to decide substitutions among these inputs (the other elasticities are determined by theoretical conditions of symmetry and homogeneity). In practice, only 2 elasticities of substitution are specified because of limited knowledge about them. Separabilities are then imposed among inputs and a structure by stages of the production function. At the lowest level of the structure, a CES function rules substitutions among capital and energy products. At the intermediate stage, a second CES function rules substitutions among labor, land and an aggregate composed of capital and energy products. Finally, at the top stage, a third CES function rules substitutions among the other variable inputs and an aggregate composed of the added value. Furthermore, the assumption is that the second and third CES functions share the same elasticity of substitution.

The value of the parameters for the supply of production factors, which are also major parameters in the increase in acreage and yields, vary respectively depending on the simulated timeframe being considered. Over the long term, supply factors are assumed to be completely elastic except for land. The latter is on the contrary fixed and moreover in variable quality. Also, its mobility among various farming activity sectors is not perfect (in practice not all lands are adequate for wine and cereal production for example). This mobility is specified through CET (Constant Elasticity of Transformation) functions.

These various assumptions within the GTAP-BIO imply the following equations for acreage and productions for a given crop in a given region (the indices are not introduced in order not to burden the equations unnecessarily):

$$l = q + \sigma\left(p_q - p_l\right) \quad (1)$$

$$p_q = s_l p_l \quad (2)$$

$$l = \varepsilon_{p_l}^{l} p_l \quad (3)$$

where q, l, p_q, p_l are respectively variations in percentage of production, acreage, production price and (annual) return on the land, $\sigma, \varepsilon_{p_l}^{l}$ are respectively the elasticity of substitution (which is shared by the two CES functions) and the elasticity of the supply of land and finally

s_l the initial portion of the return on the land in the cost of production. Equation (1) states the demand derived from land, equation (2) the condition of zero profit over the long term and finally equation (3) the supply of land. These equations simply reproduce those of Keeney and Hertel (2009).

From these equations, we can infer the calibrated values of the elasticity of supply, acreage and yield following a variation in the price of the product:

$$\varepsilon_{p_q}^{q} = \sigma\left(\frac{1}{s_l} - 1\right) + \frac{\varepsilon_{p_l}^{l}}{s_l} \qquad (4)$$

$$\varepsilon_{p_q}^{l} = \frac{\varepsilon_{p_l}^{l}}{s_l} \qquad (5)$$

$$\varepsilon_{p_q}^{y} = \sigma\left(\frac{1}{s_l} - 1\right) \qquad (6)$$

Not surprisingly, the elasticity of price supply is composed of two components, acreage elasticity and yield elasticity. The latter only depends on the elasticity of substitution (equation 6) and on the initial portion of the return on the land in the cost of production. It is therefore through this elasticity of substitution that the GTAP-BIO framework calibrates its yield effects. These equations also show that the calibration of the yield elasticities is conducted independently from the calibration of the elasticity of the acreage and supply. If the elasticity of the supply of land is high or the share of land in the cost of production low, then the acreage and supply elasticities will be high relatively to the yield elasticity (equation 5). In such a case, the increase in production required to meet demand tied to biofuels is essentially obtained by an increase in acreage and marginally by an increase in yields.

We indicate in Table 1 below the elasticity values for the production of oilseeds in the main producing countries. We also calculated these elasticity values at the global level by weighing each regional value by its size in global production/acreage. These various values are obtained under the assumption adopted generally under the GTAP-BIO framework of an elasticity of the price of yields of 0.25. To calculate the elasticity of the supply of land, we also used a standard value of the mobility of land of 0.5. The elasticity of the price of the supply of land is indeed equal to the weighted elasticity by the share, in value, of lands planted with oilseeds in all the croplands. Our calculations also rely on the portions of returns on the land in the costs of production for each arable crop.

In the following Table 1, we also supply the values for elasticities of substitution that are calibrated in this framework (via equation 6). These values are modified in the second section of our paper when we perform our sensitivity analysis. Finally, the Table 1 shows the portion of the yield elasticities representing supply elasticities.

Table 1: Substitution elasticities, own price elasticities of supply, acreage and yields for oilseed crops in the GTAP-BIO framework

	US	Europe	Brazil	China	India	South East Asia	World
Substitution	0,06	0,02	0,03	0,09	0,14	0,18	0,08
Supply	2,45	5,73	4,33	2,12	1,41	1,38	2,95
Acreage	2,20	5,48	4,08	1,87	1,16	1,13	2,79
Yields	0,25	0,25	0,25	0,25	0,25	0,25	0,15
Yield share (%)	10,22	4,36	5,78	11,77	17,79	18,13	5,24

We find that for all areas, price elasticities for yields are largely inferior to acreage elasticities (and supplies). For example, these elasticities imply that in Europe, if the price of oilseeds increases by 1%, production increases by 5.73%, most of the increase is caused by an increase in dedicated acreage (5.48%) and marginally by an increase in the yield effects (0.25%). In other words, this calibration requires that at the starting point, the increase in yields can only explain a 4.36% increase in production. At the global level, the contribution reaches 5.24%.
Again, this is quite different from increases observed over the past few years. Thus, over the last decade (2000-2010), the contribution of yields in the increase in global production is of around 20% for soybeans, 40% for rapeseed and above 100% for sunflowers, peanuts and cotton (calculated from FAPRI data). Even if statistics on the exact levels of acreage in palm oil are more controversial, yields appears to have contributed to an increase in production over the past ten years. According to FAO statistics, they contributed by 25% in the increase in the global production of palm oil.

The calibration of the parameters within the GTAP-BIO framework is such that for marginal shocks, the majority of increases in production are obtained by an increase in acreage and very modestly by an increase in yields. This does not mean that at the end of the simulation, the effects are strictly given by these initial elasticities. Indeed, equations (4) to (6) show clearly that these elasticities do not depend only on fixed parameters (elasticities of substitution and elasticities in land mobility). The values of land returns and their shares in the cost of production can also change. Furthermore, previous calculations were carried out under the assumption that only the price of oilseeds changed whereas there can be interactions with prices of other crops. It remains however that with these calibration assumptions, a marginal increase in production is essentially obtained by an increase in acreage and a very modest increase in yields.

The simulation of a biodiesel consumption shock in Europe resulted in a global LUC of 377 thousand hectares for each million toe (i.e., 0.38 ha/toe) when European importations of biodiesel (in particular from palm oil) are frozen. The majority of additional croplands come from Europe. Acreage also expands in Sub-Saharan Africa where yields are lower and where yield elasticities are, relatively to supply elasticities, very low (respectively 0.25 and 4.70). The factorizing of the production effects indicated by Edwards *et al*. (2010) shows that yields decrease, which contributes to an increase in acreage needed of around 171 thousand hectares. The results are therefore very close to FAPRI's. Roughly, if yields had not decreased, additional acreage would have represented around 200 thousand hectares, which is very close to the AGLINK-COSIMO results.

A variant is suggested in Edwards *et al.* (2010) in which it is assumed that the increase in European consumption of biodiesel can only be satisfied by imported palm oil. LUC in this variant reaches 82 thousand hectares (i.e., 0.08ha/toe). Additional acreage is essentially located in South East Asia (Indonesia/Malaysia), implying a conversion of soils that are richer in carbon (peatlands). The decomposition of the production effects indicates here that yields increase. Thanks to these yield increases, acreages have increased less (of around 550 thousand hectares). These results do not appear surprising to us because we show in Table 1 that yield elasticities are, relatively to supply elasticities, more important in this region (respectively 0.25 and 1.38).

Therefore these two simulations show the importance of yield elasticities, relatively to supply elasticities, in the quantification of LUC effects. Another illustration with respect to the same modeling framework is given by Britz and Hertel (2011). These authors examine the LUC effects and associated GHG emissions in connection with European biodiesel consumption. They found that within the GTAP-BIO framework described above (annualized) emission of GHG adjusted to the unit of energy of 50.2 gCO2eq/MJ. Then, they modified the supply and yield equations in Europe to integrate elasticities, conditional to total acreages, simulated from the CAPRI model. Thus, their elasticity matrix furnished directly the yield elasticities (specific and interactive prices). For example, specific elasticity prices of European oilseed crop yields is of 0.69 (versus 0.25 below). With this modified version, the authors have found not surprisingly that European emissions (and therefore the variations in acreage) are largely mitigated. The same European shock in consumption of biodiesel currently leads to (annualized) emissions of GHG of around 42.3 gCO2eq/MJ. In other words, the effects of GHG emissions have decreased by 16% when only European elasticities are more precise (to quote these words of the authors).

2.4. The MIRAGE-BioF framework

The MIRAGE-BioF framework proceeds from the MIRAGE framework, which also relies for a large part on the GTAP framework mentioned above. Compared with the MIRAGE framework, several changes were also made to this framework to allow for a relevant analysis of biofuels policies. These changes concern both the databases (with the introduction of coproducts for example and many agricultural products for example) and the behavioral function specifications (with sophisticated production technologies structures for example). These various improvements were described in Laborde (2011) or Laborde and Valin (2012).

The specification of the supply, acreage and yield functions are rather similar to those of the GTAP-BIO framework with an explicit modeling of input decisions by farmers. There are obviously differences, such as those related to the finer distinction of inputs and the introduction of mineral fertilizers (organic fertilizers are not, however, recorded because it is currently impossible to obtain them at the global level). Compared with the GTAP-BIO framework, the specification of farming technologies is not as rigid because an additional CES function is introduced between land and mineral fertilizers.[3] On the other hand, the substitution at the top of the tree of production between the composite aggregate of added value and the other input variables is presumed to be zero.

Regarding the factor supplies, it is however assumed a finite elasticity of non-skilled labor supply for farming sectors (captured by a mobility elasticity of this factor between farming and non-farming sectors). Cropland is again assumed to be imperfectly mobile among arable sectors; likewise mobilities are imperfect among croplands, grasslands and forests. At the level of the total supply of croplands (including managed forests but not primary forests), the assumption is that they increase when return increases (with its own price elasticity that decreases with the expansion of these acreages).

[3] 3. In fact two specifications were tested for the substitution between land and fertilizers: Either a CES function, or a logistic function. Laborde (2011) indicates that the choice of a specification does not have a real impact on the LUC calculation. Since, in the second section of our report we use the GTAP-BIO framework that only uses CES, the formulas and results reported above use the CES version.

These generalizations of the substitution schemes and mobility of the factors lead to elasticity formulas for the specific price of productions, acreages and yields that are a little more complex. Indeed, the increase in the price of a crop is not fully transmitted to an increase in the return of the allotted land (as indicated in equation 2 above). This increase is shared between the return on the land and the return for non-skilled labor (in practice that means that farmers' income increases also when the price of their productions increase). Specific price elasticities for acreages and yields are given by:

$$\varepsilon_{p_q}^{l} = \frac{\varepsilon_{p_l}^{l}}{s_l + s_n\left(\frac{\varepsilon_{p_l}^{l} + \sigma_{lf}\frac{s_f}{s_l+s_f} + \sigma_{ff}\frac{s_l}{s_l+s_f}}{\varepsilon_{p_n}^{n} + \sigma_{va}\frac{s_k}{s_n+s_k} + \sigma_{ff}\frac{s_n}{s_n+s_k}}\right)} \qquad (7)$$

$$\varepsilon_{p_q}^{y} = -\frac{\sigma_{ff}}{s_l+s_f+s_n+s_k} + \frac{\sigma_{lf}\frac{s_f}{s_l+s_f} + \sigma_{ff}\frac{s_l}{s_l+s_f}}{s_l + s_n\left(\frac{\varepsilon_{p_l}^{l} + \sigma_{lf}\frac{s_f}{s_l+s_f} + \sigma_{ff}\frac{s_l}{s_l+s_f}}{\varepsilon_{p_n}^{n} + \sigma_{va}\frac{s_k}{s_n+s_k} + \sigma_{ff}\frac{s_n}{s_n+s_k}}\right)} \qquad (8)$$

With the same type of notation as previously, subscript n indicates non-skilled labor, subscript f indicates mineral fertilizers, and subscript k indicates capital. There are three elasticities of substitution: an elasticity of substitution between fertilizers and the land (σ_{lf}), an elasticity of substitution between non-skilled labor and the composite aggregate formed by capital and energy products (σ_{VA}), and an elasticity of substitution between the composite aggregates obtained previously (σ_{ff}).

Again, specific price elasticity of supply is the sum of price elasticities for acreage and yield. It can be easily observed that this is a generalization of elasticities calculated within the GTAP-BIO framework. Let's consider first the elasticity of acreage (equation 7). If we assume that the elasticity of the non-skilled labor supply is infinite, then we obtain formula (5). Likewise, if a farming sector did not use non-skilled labor, we obtain again the same formula. These two equations (5) and (7) differ only by their denominators that measure the reverse portion of the increase in price that will be transferred to the per unit return on the land. To help in the understanding, we express in equation (9) this increase in land return:

$$p_l = \frac{p_q}{s_l + s_n\left(\frac{\varepsilon_{p_l}^{l} + \sigma_{lf}\frac{s_f}{s_l+s_f} + \sigma_{ff}\frac{s_l}{s_l+s_f}}{\varepsilon_{p_n}^{n} + \sigma_{va}\frac{s_k}{s_n+s_k} + \sigma_{ff}\frac{s_n}{s_n+s_k}}\right)} \qquad (9)$$

This return increases when the land becomes a scarcity factor (the own elasticity tends towards zero). On the other hand, an increase in land return is lower if non-skilled labor becomes scarce (therefore farmers keep a larger part of the increase in price to pay for their labor). The increase in land return consecutive to an increase in the product price also depends on possibilities of substitution among these potentially scarce factors and other inputs (capital, fertilizers in particular). Thus, the more it is easier to substitute these inputs between each other, the less a factor's scarcity becomes a constraint. For example, the easier it is to substitute fertilizers or other factors (capital, labor) to the land, the lesser the scarcity of the land has an influence on its rise in price (see the numerator in brackets).

Let's now consider yield elasticity (equation 8). It can easily be noted again that equation (6) is a specific instance of this new equation where elasticities of substitution are all of the same value, where the share of fertilizers is assumed to be zero (because the GTAP-BIO framework does not distinguish these fertilizers from the other various inputs). What is more important to highlight is that this yield elasticity depends again fundamentally on elasticities of substitution (they all appear in the numerator). If these elasticities of substitution are weak (or ultimately zero), then yield elasticity is weak (or ultimately zero). The contribution of yield elasticity to production elasticity is directly dependent on the elasticities of substitution: The weaker they are, the weaker is the contribution of yield effects in the production effects.

Table 2 below shows an estimate of these elasticities for oilseeds within the MIRAGE-BioF framework. To calculate this estimate, we have first of all put forth several assumptions concerning the values of the expenses in each input (labor, capital, land, fertilizers, energy products). Indeed, we do not have available the full database of the MIRAGE-BioF framework, nor its projected situation by 2020. This database relies however on initial data from GTAP with, for example, a distinction of various oilseeds respecting the value of the aggregate of the oilseeds. Practically, we have used the return value for production factors and production values in the GTAP-BIO database for 2001. We assumed that the expenses in fertilizer and energy represented each 7.5% of the total cost of production (the balance being for the other variable inputs). Results are not very sensitive to these shares. They are more so to elasticities. For elasticities of substitution, we have taken the average values indicated by Laborde (2011): 0.11 for the elasticity of substitution between land and fertilizers for developed countries and 0.20 for developing countries, 1.1 for the elasticity of substitution between non-skilled labor and the aggregate including capital, finally 0.07 for the elasticity of substitution among the various aggregates.[4] For elasticities in the supply of land for oilseed crops, we have assumed values of 0.3 (i.e., the elasticity for land mobility among arable crops). Finally, the elasticity in the non-skilled labor supply in oilseed crops is equal to the ratio between the elasticity of the transformation of non-skilled labor (i.e., 0.5) and the share of labor pay for oilseed crops in the non-skilled farming labor pay (we understand indeed that non-skilled labor is mobile between agricultural sectors).

Again, this table gives the results for the main countries (available in the GTAP-BIO database and that does not correlate completely with the geographical area selected within the MIRAGE-BioF framework), estimated by weighing at the global level elasticities by areas and the contribution of the yield and supply elasticities.

Table 2: Substitution elasticities, own price elasticities of supply, acreage and yields for oilseed crops in the MIRAGE-BioF framework

	US	Europe	Brazil	China	India	South East Asia	World
Supply	1,76	4,02	4.04	1,44	0,96	0,84	2,18
Acreage	1,45	3,18	2,93	1,15	0,80	0,71	1,75
Yields	0,30	0,84	1,13	0,29	0,17	0,13	0,43
Yield share (%)	17,26	20,87	27,95	20,29	17,35	15,60	19,92

We obtain again a relatively weak contribution of yield elasticities to the supply elasticities. For example, these elasticities imply that an increase of 1% in the European price of oilseeds will lead, all things otherwise being equal, to an increase in dedicated acreage of 3.18% and yields of 0.84%. The contribution is therefore only slightly above 20%. It is at the same level on the global level.

The effects of these yields are still largely above those calculated previously within the GTAP-BIO framework, simply because of the elasticities of substitution that are higher here

[4] 4. Precisely the elasticity of substitution value between labor and the aggregate including capital comes from an Excel™ file that was included in the publication and available from the EC. In this file, we in fact find the value of the elasticity of substitution between factors (0.07). On the other hand, we do not find the value of the elasticity of substitution between land and fertilizers. Its average in this file for all regions and crops is 0.06 (no value is given for palm crops, which may explain the discrepancy). The values of the elasticity of substitution are calibrated from the synthetic value of Rosegrant *et al.* (2008).

(see elasticities of substitution of Table 1). This contribution of yield effects at the calibration level remains however below the increases of the past few years for oilseeds (this result can be extended to other arable crops). It is also very different from the projected increases by 2020 of global yields and acreage in arable crops that Laborde (2011) uses to define the benchmark situation (reminder: The increase in production could be explained up to 64% by increases in yields and 36% for acreages). In other words, this author, like the others, assumes high increases in yield for the projection and calibrates weak yields elasticities in analyzing European biofuels policy.

Laborde (2011) conducted several simulations to explain the LUC results induced by European biofuels policy. These simulations showed in particular that an additional consumption of biodiesel resulted in a global LUC varying between 0.08 and 0.21 ha/toe depending on the vegetable oils considered. This is less pronounced if palm oil is used (but converted soils are richer in carbon), intermediary with rapeseed and soybean oil (0.16) and high with sunflower oil. It therefore appears that the result is rather close to the one obtained within the previous GTAP-BIO framework if the focus is on palm oil (around 0.08 ha/toe). These results are weaker for other oils (around 0.2 against 0.38 ha/toe), which could be explained by a higher calibration of the yield effects.

Laborde (2011) also decomposes its production effects between the acreage effects and yield effects during the simulation of the overall European biofuels policy. He finds that for all crops, the acreage effects overshadow the yield effects. For oilseed crops, the increase in production can be explained for over 80% by an increase in acreage, which seems coherent with our previous calculations of various elasticities. The contribution of the acreage effects is weaker for wheat crops (66%) because of a shift of this crop towards regions with initially weak yields.

As many authors, Laborde (2011) acknowledges the uncertainties of many parameters in the MIRAGE-BioF model and therefore conducted sensitivity tests. Unfortunately for our analysis, these tests combined simultaneously several parameters affecting both the supply and demand aspects of his model. It is therefore not possible to verify whether the LUC results (and associated GHG emissions) are highly sensitive or not to the calibration of yield effects. We note however that the maximum values of elasticities of substitution represent close to three times the average values (whereas the minimal values are close to zero, implying no yield effect at the calibration level, see equation 8). Thus, for developed countries, the maximum value of the elasticity of substitution between land and other production factors is 0.18 (versus an average value of 0.07) and the maximum value of the elasticity of substitution between land and mineral fertilizers of 0.29 (versus an average value of 0.11). However, the contribution of yield elasticities in the supply elasticities is not tripled because these elasticities of substitution also appear in the acreage elasticities (see equation 7). At the global level, they reach 45% (versus 20% in the average instance).

We also highlight that, even if the domain of variation may seem large with a tripling of the values, these maximum elasticity of substitution values are lower than the average values from syntheses carried out for OECD. Abler (2001) for the United States, Canada and Mexico, Salhofer (2001) for European countries have conducted a review of the literature on the econometric estimates of these elasticities of substitution. For the United States, Abler (2001) found that the average value of the elasticity of substitution between land and other production factors was 0.3 and the standard error was 0.8. The average value of the elasticity of substitution between land and variable inputs (fertilizers, phytosanitary products,...) was 0.5 and the standard error was 1.5. For Europe, Salhofer (2001) found that the average value of the elasticity of substitution between land and other production factors was also 0.3 and the standard error around 1. The average value of the elasticity of substitution between land and variable inputs was 1.7 and the standard error was 1.1.

Therefore, the maximum elasticity of substitution values retained for the sensitivity tests within the MIRAGE-BioF framework are lower than the average values of econometric studies concerning developed countries. Furthermore, these always imply *ex ante* (for marginal changes) yield effects, in relation to production effects, that are lower than projected increases of these yields and productions.

2.5. Synthesis

This review of the literature focused on yield effects of 4 modeling frameworks mobilized to analyze the LUC effects of European biodiesel has given us three main lessons. First, the various LUC evaluations induced by the European consumption of biodiesel all result in an increase in the production of crops essentially because of an increase in cropland and at best by a modest increase in yields on these croplands. These results differ greatly from increases observed over the long or medium-term projections where most additional production is obtained by an increase in yields. Second, the relative consensus appears hardly surprising since, according to available information, the calibration of the parameters of the underlying models relies on yield elasticities that are clearly weaker than acreage elasticities. Third, the

LUC results of these models are moreover very sensitive to calibration assumptions of the yield effects, when the calibration of the latter varies significantly. To our knowledge, these sensitivity tests have not focused directly on European biodiesel consumption, which is the subject of our next section.

3. European biodiesel and yield changes: sensitivity analysis

The LUC results from the economic models were extensively discussed in various forums. On a quality level, increases in yields have been recognised to have an impact, but available quantity evaluations were deemed relevant and consistent. For example, in their analysis of the results from the GTAP-BIO, Edwards *et al.* (2010) stated that strong yield effects could only be observed over the medium/long-term and that in the short term, the induced effects of prices on yields are weak. We share this viewpoint over the short term. On the other hand, it is always problematic to define what we mean by medium/long-term. Policies (U.S. and European) concerning biofuels cannot really be considered as very short-term policies. Goals are announced over several years and moreover, implemented gradually, thereby giving time to the actors to adjust and optimize their production plans. Therefore, it appears perfectly legitimate to us to test the outcomes of more significant changes in the farming production methods that may lead to an increase in yields.

The methodology retained in this paper consists in using the GTAP-BIO framework for two main reasons. On the one hand, it is publicly available; everyone can replicate the results reported below. On the other hand, the general equilibrium framework is considerably more rigorous and does not lead to potential inconsistencies such as those identified by Blanco Fonseca *et al*. (2010) with the AGLINK-COSIMO framework. However, this framework is not a panacea and was criticized by other economic modellers. For example, Babcock and Carriquiry (2010) questioned *i/* the fact that the possibility of double crops in the U.S. and Brazil was not taken into account, *ii/* the fact that fallow lands in many regions of the world (lands that according to these authors have a low carbon stock) were not taken into account, *iii/* the modeling of the imperfect mobility of land that implies that the extension of croplands causes too many forests to be converted and not enough grasslands (the latter being less rich in carbon), and that *iv/* the *ad hoc* assumption of a lower productivity of newly cultivated lands. For these authors, all these limitations of the modeling bias the results upwards from the GTAP-BIO framework. The use of the Wood Hole database for carbon stocks, rather than the Winrock database, is also likely to bias these results upwards (Broch *et al.* 2013).

In our paper, we are not trying to verify/integrate these remarks and are focusing our effort on the calibration effect of yield elasticities on the measure of LUC effects. It is fundamental to understand that we are not introducing in our sensitivity analysis exogenous technological shocks that would lead to an artificial/unexplained increase in yields. We simply revise the calibration of elasticities of substitution that preside over the manner in which farm producers define their production systems within the scope of a given production. Below, we first justify our calibration choices, and then report the results of the simulation. We conclude with a sensitivity analysis to the size of the simulated shock and to the timeframe of the simulation.

3.1. The alternate calibration of elasticities

To fully understand the results of our sensitivity analysis, first of all, we establish benchmark results using the GTAP-BIO calibration of various elasticities of substitution and mobility factors (land) among sectors (see sub-section 2.c.). As a reminder, the calibration assumptions imply that *ex ante* the yield elasticities are very weak compared with acreage elasticities, essentially because elasticities of substitution among inputs are weak (less than 0.1, see Table 1).

We then consider an alternate calibration of these elasticities of substitution that leads to a greater contribution of the yield elasticities in the supply elasticities. Considering their crucial importance, we justify the value we have selected. We have previously seen that the values retained in the GTAP-BIO framework as well as in the MIRAGE-BioF framework are weak compared with the econometric estimates synthesized in the OECD study (Salhofer, 2001). Thus, in this alternate calibration, we are relying on average values that are reported in the OECD studies. More specifically, we are assuming that the elasticities of substitution are identical to the two CES functions specified in the GTAP-BIO framework. We have chosen the weaker of the average values reported in the OECD study (i.e., elasticities of substitution between land and other production factors, not those between the land and variable inputs). Moreover, since the results are very close between the United States and Europe, we have assumed the same value of 0.3 for all regions. Implications in terms of elasticities in yield, acreage and supply are given in Table 3. This table is built exactly like Table 1.

Table 3: Alternate elasticities of substitution, alternate elasticities of supply, of acreage and yields of oilseed crops within the GTAP-BIO framework

United-States		Europe	Brazil	China	India	South East Asia	World
Substitution	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Supply	3.43	8.63	6.96	2.75	1.69	1.55	4.20
Acreage	2.20	5.48	4.08	1.87	1.16	1.13	2.79
Yields	01.23	3.15	2.88	0.88	0.54	0.42	1.41
Yield contribution (%)	35.91	36.49	41.42	31.89	17.79	27.15	33.59

Acreage elasticities are identical to those in Table 1 because over the long term, they are not dependent on elasticities of substitution (see equation 5). On the other hand, the yield elasticities increase, they increase greatly in Europe reaching 3.15. We are well aware that this may seem in isolation very strong. But as highlighted by Edwards *et al.* (2010), the most important is the ratio between these yield and acreage elasticities. We found that at the point of calibration, the contribution of yield elasticity reaches 36% of supply elasticity in Europe. The figure is similar in the United States. Changes are less spectacular in India or in the South East Asia area (which includes Indonesia and Malaysia) because the initial elasticity of substitution is closer to 0.3. At the global level, the contribution of yield effects is 33.6%.

Our alternate calibration therefore relies on a synthesis of elasticities of substitution carried out in 2001, which naturally does not cover data and estimations for the last decade. To our knowledge, there are very few econometric studies in the past few years that estimate simultaneously yield and acreage elasticities.

First we have the work of Huang and Khanna (2010) focusing on the United States and soybean, corn and wheat crops. However the specifications estimated in the acreage and yield equations are given in a reduced form. Therefore, the structural constraints (on the convexity of the profit functions and symmetry conditions) are not imposed, which limits the contribution of these estimates for our calibration of parameters. We note however that these authors have found that the specific price elasticities of yields for these crops are respectively of 0.06, 0.15, and 0.43. The specific price elasticities for corresponding acreages are respectively of 0.55, 0.66 and 0.50. Under the rough assumption of the absence of cross elasticities at the level of acreages, whereas the contributions (biased downwards) of yield elasticities in the supply elasticities reach respectively 11%, 23% and 86%. In a similarly rough manner (simple weighted sum of the share of acreage), the contribution of yield elasticity to supply elasticity for all of these three crops reaches 33%.

Next Carpentier and Letort (2012), in an empirical study on France, tried to allocate variable inputs among three crops (wheat, barley and rapeseed). A structural approach was adopted with a two-tier decision of the producers during a planting period: acreage allocation initially, then the application of variable inputs during the period. Econometric estimations satisfy homogeneity, symmetry and concavity conditions for the cost function. However these authors considered short-term perspectives where total allocated acreage for these three crops was exogenous. By definition therefore, supply elasticities at the aggregate level were supplied by yield elasticities. The latter vary between 0.09 and 0.21, i.e., an average of around 0.15. However, at the level of each crop, these authors calculated acreage and yield elasticities. If we make the same approximation of the lack of cross effects at the acreage level, then the contributions of yield elasticities to supply elasticities are 25% for wheat, 31% for barley and 77% for rapeseed. Still relying on the same rough assumptions, this leads again to a yield elasticity that contributes to more than one-third of the supply elasticity at the global level.

Without supplying directly the required elasticities for the GTAP-BIO framework, these two recent econometric studies indicated that our alternate calibration leads to yield/acreage elasticity ratios that remain credible.

3.2. Results

We now simulate a shock in consumption of biodiesel of one million toe. The starting point is 2001, this represents that consumption was multiplied by two. Later, we will examine the effects of a larger shock, the results not always being perfectly linear.

We began our analysis with the standard parameters of the GTAP-BIO framework (Table 1). The results on the oilseed markets, on the arable crops[5] markets, and on converted forest and

[5] 5. Arable crops are defined as the simple sum of oilseed, cereal and other sugar market crops. We have not included here the markets for other vegetable products (such as fruits and vegetables) that are not differentiated in the partial equilibrium framework mentioned above. Allocated acreages for these crops are obviously taken into account in the total acreages. We note that even if is assumed that an imperfect mobility of land between the activities, a totalizing of the acreage is possible because the GTAP-BIO framework corrects the gaps between so called effective hectares and harvested hectares (see Golub and Hertel, 2012). The totalizing of these productions is given as an index weighted by the initial prices. These definitions are obviously shared by different results presented hereinabove and otherwise similar to Edward *et al.* (2020).

grassland acreage are given in Tables 4 to 6.

Not surprisingly, we obtained an increase in the production of oilseeds in all areas. The effect is greater in Europe and reaches 1.33%. In relative terms, the largest increases follow in Brazil and the United States. Global production of oilseeds increases by 0.29%. Prices increase by 0.13%, which lead to an *ex post* elasticity of 2.23 (in the end not very far from the calibration value). We have found that in each area, the majority of additional production is obtained by an increase in acreage. For example, it reaches 1.22% in Europe and yield growth explains 8% of the increase in production. It is higher in South East Asia for example because of a higher elasticity of substitution. At the global level, we found that an increase in production is explained *ex post* at the level of 26% by an increase in yield. This proportion is very different from the calibrated value (5%) because there is a relative shift in production of oilseeds towards regions with initially high yields (Europe, Brazil, United States). Indeed, the price of these seeds increases more in these areas compared with others under the effect of the "Armington" trade modeling (the 5% proportion calculated in the first section was obtained under the assumption that all countries record the same 1% increase in their prices). This result is nothing new and is common to all the results analyzed in our review of the literature.

Table 4: Impacts on supply, acreage, yields and prices of oilseeds of the shock in biodiesel consumption in Europe of one million toe (in %).

	US	Europe	Brazil	China	India	South East Asia	World
Supply	0.21	1.33	0.45	0.09	0.02	0.10	0.29
Acreage	0.15	1.22	0.40	0.06	0.02	0.06	0.22
Yields	0.06	0.11	0.05	0.03	0.00	0.04	0.08
Price	0.14	0.35	0.20	0.06	0.04	0.13	0.13
Yield contribution (%)	29.81	7.91	11.36	29.37	16.73	35.93	26.05

The increase in the production of oilseeds and corresponding acreages has led to a slight decrease in acreage allocated to other arable crops (cereals and other arable crops). Modest increases in yield have been observed thereby. For the other crops, the contribution of the yield effects was higher than 100%. The effects are nevertheless very modest and were above 0.1% just once (decrease in European acreages of coarse grains). This implies that at the total level of arable crops and the global level, the results on oilseeds dominate. The increase in production of arable reaches 0.05%, and croplands have increased by 0.04% and yields by

0.01%. Therefore the latter contributed 25% in the increase in production. This does not preclude that at the level of each area, the yield contributions can be very different because there is a relative shift of the proportion of each crop on the croplands.

Table 5: Impacts on supply, acreage, yields and prices of arable crops due to the shock in biodiesel consumption in Europe of one million toe (in %).

United-States		Europe	Brazil	China	India	South East Asia	World
Supply	0.07	0.18	0.18	0.02	0.01	0.01	0.05
Acreage	0.02	0.12	0.12	0.02	0.00	0.03	0.04
Yields	0.05	0.06	0.07	-0.01	0.01	-0.02	0.01
Yield contribution (%)	73.92	31.06	36.32	-30.78	62.77	-112.17	24.93

This shock in European biodiesel consumption caused an increase in croplands that reached 71 thousand hectares in Europe and 206 thousand hectares at the global level. In other words, we obtained a LUC effect of 0.21 ha/toe. This effect is in the average of the effect reported in Edwards *et al.* (2010) (between 0.08 and 0.38) because we did not penalize or favor one vegetable oil over another for the production of biodiesel.

In Europe, these additional croplands do not come predominantly from the conversion of forests, but more modestly from grassland conversions. We mentioned in passing that the sustainability criteria are obviously not taken into consideration in these calculations, which is not the subject of this analysis. It appears that the decrease in global forest hectares is close to that of the European decrease (50 thousand ha.). The global decrease of grasslands has reached 153 thousand hectares, a decreased shared by Europe, Brazil and Sub-Saharan Africa.

Table 6: Impacts on global acreage, of a shock in biodiesel consumption in Europe of one million toe (in thousand hectares).

United-States		Europe	Brazil	China	India	South East Asia	World
Croplands	12.10	71.38	33.22	0.42	3.70	-0.12	205.94
Grasslands	-13.28	-20.21	-20.70	-7.17	-1.23	-0.58	-153.04
Forests	1.25	-51.14	-12.51	6.81	-2.49	0.70	-52.75

Finally, the GTAP-BIO framework offers an estimate of the tons of CO2eq that are destocked following the LUC effects. The estimate is 37.37 million tons at the global level. 49% of these emissions come from LUC in Europe. If we annualize these emissions by 20-year periods, we will find emission linked to LUC of 49.4 gCO2eq/MJ. Not surprisingly, these figures are very close to the ones reported by Britz and Hertel (2011).

Our global results are also rather close to Laborde (2011) and are useful in justifying the proposals for revising the European directives. Yields contribute modestly to the increases in global productions (of around 20% versus 26% here) and emissions associated to LUC are important (of around 54 gCO2eq/MJ versus 49 here). Impacts per country are on the other hand more contrasted, probably because of the implications of the Armington modeling of exchanges (see Golub and Hertel, 2012). Without constituting a formal proof of the equivalence of the two modeling frameworks, we have reduced in a rough manner by 20% all the elasticities of substitution within the GTAP-BIO framework (because the MIRAGE-BioF framework prohibits substitutions among factors of composite added value and other variable inputs). In this variant, the contribution of yields to increased productions is 21% and emissions associated with LUC reached 53.3 gCO2eq/MJ.

Let us now examine these same results when elasticities of substitution within the production technologies of arable crops are set at 0.3 (Table 3). The same results are reported in Tables 7 to 9.

Table 7: Impacts on supply, acreage, yields and prices of oilseeds of the shock in biodiesel consumption in Europe of one million toe (in %): Alternate calibration

United-States		Europe	Brazil	China	India	South East Asia	World
Supply	0.21	1.46	0.50	0.06	0.02	0.08	0.30
Acreage	0.10	0.85	0.25	0.04	0.01	0.05	0.14
Yields	0.11	0.61	0.25	0.02	0.01	0.03	0.16
Price	0.07	0.19	0.09	0.03	0.02	0.07	0.06
Yield contribution (%)	51.28	41.71	50.08	37.68	36.81	38.14	53.16

Since we only change the value of some parameters, these new results are of the same type as those that we have just described. Therefore we will focus on analyzing the differences among these results.

The same shock in European biofuel consumption leads in practice to the same production effects. Global production of oilseeds has now increased by 0.30% (versus 0.29%). This is caused by the fact that price effects are weaker (increase in global prices of 0.06% versus 0.13%) and therefore that consumption of food oils and meal decrease slightly less. A lesser increase in prices can be explained simply by supplies that are more elastic to prices. Not surprisingly, we now observe greater yield effects and therefore weaker acreage effects. For example, European acreages have currently increased by 0.85% (versus 1.22% previously) and yields by 0.61% (versus 0.11% previously). The contribution of yield effects to supply effects reached 42% at the European level. It is higher at the global level (53%) still linked to the relative shift of production among regions. We also have noted that the most remarkable changes logically concern areas where elasticities of substitution have increased the most: Europe and Brazil. These changes are minor in South East Asia for example.

Table 8: Impacts on supply, acreage, yields and prices of arable crops of the shock in biodiesel consumption in Europe of one million toe (in %): Alternate calibration

	United-States	Europe	Brazil	China	India	South East Asia	World
Supply	0.07	0.20	0.21	0.01	0.01	0.01	0.05
Acreage	0.01	0.07	0.06	0.01	0.00	0.03	0.02
Yields	0.06	0.13	0.15	0.00	0.01	-0.01	0.03
Yield contribution (%)	83.91	62.94	72.51	2.62	70.04	-115.19	63.09

Again, the effects on other markets of row crops are modest (not higher than 0.1%). Also, at the level of all arable crops (cereals, oilseeds, sugar beet and sugar cane), oilseeds have a dominant impact. For example, European production has increased by 0.20% with a yield contribution of 63%. At the global level, we have found exactly the same contribution; productions always increase in areas of high initial yields. A contribution of this type corresponds overall to the evolutions observed over the long term and to available projections within the FAPRI and AGLINK-COSIMO frameworks and adopted to define the benchmark situation in Laborde (2011).

Table 9: Impacts on global acreage, of a shock in biodiesel consumption in Europe of one million toe (in thousand of hectares): Alternate calibration

United-States		Europe	Brazil	China	India	South East Asia	World
Croplands	2.74	20.28	9.77	-0.08	0.99	0.17	44.23
Grasslands	-3.81	-4.50	-5.33	-1.70	-0.27	-0.16	-33.17
Forests	1.09	-15.81	-4.45	1.79	-0.72	-0.02	-11.03

Croplands have currently increased to 44 thousand ha, i.e., a LUC effect of 0.04 ha/toe. The increase in croplands is still taking place mostly in Europe (20 versus 71 thousand hectares), followed by Brazil (10 versus 33 thousand hectares). Acreages in Sub Saharan Africa are hardly increasing anymore (3 versus 27 thousand hectares). It is important to understand that it is essentially because yields have increased in Europe and Brazil and very little through an increase in yields in this region. These additional acreages are still predominantly supplied by the conversion of grasslands (33 versus 153 thousand hectares), followed by to a lesser extent the conversion of forests (11 versus 52 thousand hectares).

The LUC effects are therefore divided by about 5. Logically, emissions are also divided by 5. Annualized, they currently reach 10.4gCO2eq/MJ. For reference, Dumortier *et al.*, (2011) with the FAPRI framework also found a strong impact of yield effects that lead to 87% decreases in their estimates of emission in connection with U.S. bioethanol. Blanco Fonseca *et al.*, (2020) found with the AGLINK COSIMO framework a decrease of 96% of LUC effects. Britz and Hertel (2011) found a drop of 16% in induced emissions when European elasticities were revisited. We have found a decrease of around 80% of LUC effects and associated emissions in connection with European biodiesel with a coherent calibration of elasticities of substitution in all the areas of the GTAP-BIO framework.

The EC is not considering any of these three modeling frameworks to justify its proposals for revising the European directives on biofuels. However, it would appear quite astonishing to us (but surely informative) that an analysis of sensitivity of this type should not lead to the same type of results with the MIRAGE-BioF framework.

3.3. Sensibility analysis

Previous results show a strong sensitivity of estimates to the calibration of elasticities of substitution and therefore of yields. We are now striving to see if this strong sensitivity is robust enough to the size of the shock on the one hand, and on the other to the time frame of the simulation.

First, let's examine the sensitivity of our results to a greater shock in European biofuel consumption. The GTAP-BIO framework is rather relevant over the long term because the production factors are assumed to be mobile among sectors. Yet, over the long term, the shock induced by European consumption is not marginal. Results obtained in the literature show that the effects are rather linear (Edwards *et al.*, 2010) but not entirely (see for example Laborde, 2011). This is why we simulated a shock of 10 million toe. This is not a perfect estimate of the increase in consumption, but it is close to the one simulated for example by Laborde (2011). We are showing below the tables of results on the oilseed markets and global acreages for the two sets of parameters.

Table 10: Impacts on supply, acreage, yields and prices of oilseeds of the shock in biodiesel consumption in Europe of 10 million toe (in %)

	United-States	Europe	Brazil	China	India	South East Asia	World
The GTAP-BIO calibration							
Supply	2.61	14.59	4.81	1.07	0.40	2.21	3.44
Acreage	1.82	13.50	4.24	0.79	0.28	1.45	2.61
Yields	0.79	1.09	0.57	0.28	0.12	0.76	0.83
Price	1.77	4.57	2.34	0.76	0.61	2.55	1.66
Yield Contribution (%)	30.35	7.45	11.84	26.56	29.48	34.30	24.18
Alternate calibration							
Supply	2.49	16.77	5.21	0.73	0.34	1.93	3.57
Acreage	1.22	9.53	2.57	0.43	0.21	1.18	1.70
Yields	1.27	7.24	2.64	0.30	0.13	0.75	1.87
Price	0.80	2.24	1.00	0.31	0.29	1.71	0.78
Yield contribution (%)	50.91	43.19	50.68	41.21	37.92	38.82	52.45

This shock obviously leads to very important effects. For example, the global price of oilseeds increases by 1.66% (versus 0.13% in the previous scenario) when the standard GTAP-BIO calibration was adopted. The effects appear to be slightly non-linear. What seems the most interesting to us is the increase in the contribution of yields. At the global level and with the standard calibration, this contribution reaches 24.2% (versus 26.1% in the previous scenario). This is due to the fact that the shocks lead to a relatively stronger increase in oilseed production in India and in Sub Saharan Africa where initial yields are lower. When we adopt our alternate calibration, the contribution at the global level is more stable (52.5% versus 53.2%). These differences can seem modest but in terms of displaced acreage, this is not trivial. Indeed, with the standard calibration, croplands increased by 2501 thousand hectares with a decrease in forests of 553 thousand hectares (i.e. 22% of the expansion of croplands). With our alternate calibration, croplands increased by 550 thousand hectares with a decrease in forests of 76 thousand hectares (i.e. 13% of the expansion of croplands). Associated GHG emissions on an annual basis reached 56.6 gCO2eq/MJ with the standard calibration and 10.0 gCO2eq/MJ with the alternate calibration. The effect of these assumptions of yields is therefore higher. The economic intuition is the following: The more the possibilities of yield increases are limited (standard calibration), the more additional acreage is needed when the size of the shock increases. Consequently, there are more associated GHG emissions. On the other hand, when the possibilities of increased yields are feasible by substitution of inputs (our alternate calibration), then more acreage is not needed proportionally if the size of the shock increases. Substitution takes place with inputs that are more available.

This simulation leads to substantial difference in yields: an increase in European oilseed yields of 1.09% with the GTAP-BIO calibration, and 7.24% with our alternate calibration. This is only possible with contrasted evolutions in the use of other inputs (chemical products, energy, labor, capital). In fact, in each calibration, these inputs change in the same proportions because input supply is perfectly elastic. These increases reach around 14.7% with the GTAP-BIO calibration, 17.6% with our alternate calibration. Therefore there is an increase in the use of other inputs (of around 3%) that can lead to an increase in direct emissions. These increases in input use are lesser at the total European level of arable crops with 2.6% and 3.9% respectively, i.e., a difference of 1.3%. At the global level, the difference is even more modest with respectively 0.8% and 0.9%, i.e. an increase limited to 0.1%.

Direct GHG emissions are not studied very much in conjunction with the above-mentioned economic models. The GTAP-BIO framework is not really ideal for such an analysis because the various inputs (fertilizers, pesticides, seeds) are not differentiated. Our modest contribution here is to show that there can be a modest increase in direct emission (0.1% at the global level) associated with a decrease in indirect emission caused by LUC.

Table 11: Impacts on global acreage, of a shock in biodiesel consumption in Europe of 10 million toe (in thousand hectares).

	United-States	Europe	Brazil	China	India	South East Asia	World
GTAP-BIO calibration	153.5	801.27	366.60	5.79	59.55	6.18	2501.16
Croplands	-177.86	-196.97	-254.43	-96.58	-18.10	-8.96	-1947.23
Grasslands	24.38	-604.30	-112.13	90.79	-41.47	2.70	-553.36
Forests							
Alternate calibration	36.03	221.58	108.16	-0.54	18.93	8.22	550.31
Croplands	-58.24	-20.20	-80.94	-27.20	-4.74	-3.51	-473.56
Grasslands	22.30	-201.36	-27.18	27.78	-14.20	-4.70	-76.42
Forests							

Let's now examine the sensitivity of our results with the time perspective. The assumption of perfect mobility among all the production factors, except land, is certainly excessive in the medium term (physical and human capital are in part specific to sectors of activity). For example Laborde considers that non-skilled labor is imperfectly mobile between sectors of activity. Keeney and Hertel (2009) consider also that in the medium term (approximately 5 years) labor and capital cannot completely mutually adjust. They then proceed to model an imperfect mobility of these factors with mobility elasticities close to one (a value that also appears in the OCDE synthesis). Thus, we have adopted these values to obtain medium-term effects. This implies that at the calibration level acreage, yield and supply elasticities are decreased. For European oilseeds, the specific price elasticity of supply is 1.56 with the GTAP-BIO elasticities of substitution and 1.85 with elasticities of substitution set at 0.3 (as a reminder, they rise respectively to 5.73 and 8.62 in the long term). The results of a shock of 10 million toe are reported in the Tables 12 and 13 (to be compared with Tables 10 and 11). The effects are qualitatively identical for a shock of one million toe.

Table 12: Impacts over the medium term on supply, acreage, yields and prices of oilseeds of the shock in biodiesel consumption in Europe of 10 million toe (in %)

	United-States	Europe	Brazil	China	India	South East Asia	World
The GTAP-BIO calibration							
Supply	2.99	9.50	4.40	1.49	0.70	2.56	3.14
Acreage	2.16	8.88	3.91	1.16	0.55	1.83	2.54
Yields	0.83	0.62	0.49	0.33	0.15	0.73	0.59
Price	3.35	7.51	4.07	1.66	1.28	4.08	3.11
Yield contribution (%)	27.85	6.54	11.15	22.08	20.93	28.63	18.94
Alternate calibration							
Supply	3.09	10.27	4.88	1.29	0.67	2.40	3.23
Acreage	1.71	6.73	2.67	0.87	0.48	1.65	1.91
Yields	1.38	3.54	2.21	0.42	0.19	0.75	1.32
Price	2.44	6.09	2.95	1.15	0.92	3.38	2.34
Yield contribution (%)	44.78	34.49	45.20	32.82	28.61	31.24	40.92

The main remarkable results are an increase in price effects since supply becomes less elastic in the medium term. Correlatively we obtain a lower increase in global production (a decrease in food demand). The global increase in oilseed prices over the medium term reaches 3.11% (versus 1.66% over the long term) with the GTAP-BIO elasticities. We also note an increase in oilseed production that is more evenly spread at the global level (it becomes relatively harder to increase European production). Therefore, the yield effects are relatively less important (less than 19% over the medium-term versus over 24% over the long term). When we increase elasticities of substitution to 0.3, the yield effects increase but relatively less: Over the medium term, they rise to less than 41% whereas they were higher than 52% over the long term.

On the acreage level, the effects are also modified with LUC now at around 0.22 ha/toe and 0.06ha/toe. Associated GHG emissions still decrease but relatively less, dropping from 59.5 to 18.4gCO2eq/MJ (i.e. a drop of 70%). This lower decrease can be explained simply by a lower increase in the contribution of yields to increases in production.

Table 13: Impacts over the medium term on global acreage, of a shock in biodiesel consumption in Europe of 10 million toe (in thousand of hectares)

United-States		Europe	Brazil	China	India	South East Asia	World
GTAP-BIO calibration	170.21	584.06	355.41	17.86	91.82	11.24	2246.22
Croplands	-184.14	-158.54	-211.62	-103.33	-23.00	-8.19	-1639.96
Grasslands	13.86	-425.54	-143.78	85.46	-68.82	-3.03	-606.34
Forests							
Alternate calibration	52.02	162.14	109.02	7.31	44.51	13.10	629.94
Croplands	-70.96	-28.83	-55.25	-39.74	-9.00	-3.03	-430.44
Grasslands	19.04	-133.33	-53.78	32.41	-35.48	-10.10	-199.40
Forests							

4. Conclusions

Measuring the effects on acreages and induced emission of GHG caused by an increase in biofuels is a difficult empirical question because of the interaction of many economic mechanisms. Many economic models have been used in order to estimate these effects. Within the framework of European biodiesel, a majority of these economic studies have concluded that there are acreage displacements and associated emissions causing the efficiency of European public policy to be questioned. In this paper, we have focused our attention on the assumptions of economic models concerning possible increases in yields. We have also analyzed the results of simulations in terms of increases in acreages and yields.

All the studies show that increases in production needed to meet biofuel demand will be essentially obtained by increases in acreage. Yields increase at best to a modest degree. In the partial equilibrium models, this result is linked to the presumed absence of induced technical progress following the biofuels shock. We have shown that, in the general equilibrium models, this comes rather directly from the calibrated values of the elasticities of substitution that control the share between land and other farming inputs. Calibrated values are weaker than those given by econometric estimates that are currently available.

This has led us to want to test the influence of the calibration choices on the LUC results and associated emission induced by the growth of biodiesel in Europe. This test was carried out on the basis of the GTAP-BIO model that is similar in structure to the MIRAGE-BioF selected by the EC to justify its proposal for revising the European directives. We thereby show that estimates of LUC and associated GHG emissions are very sensitive to the values of the elasticities of substitution. When the calibrated values rely on the econometric results, then LUC effects and long-term emission are reduced by over 80%. We have also shown that in this instance, the contribution of yield effects to an increase in production does not exceed what is generally projected over the medium term.

In this study, we only focused on LUC and associated emissions. This study must be followed-up for example by an analysis of the efficiency of European Public Policy on biofuels. Our calculations suggest that the assessment in terms of net GHG emissions from biofuels is higher than the one estimated up to now. Is this nevertheless the best policy to reach the goals of mitigating climate change? For example, must we favor second-generation biofuels against first-generation ones? This depends in part on the relative technological progress one can hope for these two supply chains. Our results simply show that we should not necessarily underestimate the possible gains from the first-generation supply chain.

References

Abler, S. (2001). *Elasticities of Substitution and Factor Supply in Canadian, Mexican and United States Agriculture. Annex 2 to the OECD report "Market Effects of Crop Support Measures"*.

Babcock, B.A., Carriquiry, M. (2010). *An Exploration of Certain Aspects of CARB's Approach to Modeling Indirect Land Use from Expanded Biodiesel Production.* CARD Staff Report 10-SR25, 39 p.

Blanco Fonseca, M., Burrell, A., Gay, H., Henseler, M., Kavallari, A., M'Barek, R., Perez Dominguez, I., Tonini, A. (2010). *Impacts of the EU biofuel target on agricultural markets and land use: a comparative modeling assessment.* JRC Scientific and Technical Reports, disponible à http://ec.europa.eu/energy/renewables/studies/doc/land_use_change/study_jrc_biofuel_target_iluc.pdf

Britz, W., Hertel, T.W. (2011). Impacts of EU biofuels directives on global markets and EU environmental quality: An integrated PE, global CGE analysis. *Agriculture, Ecosystems and Environment*, 142: 102-109.

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

CARB (2010*). Land Use Change Effects for Soy Biodiesel and Renewable Diese*, disponible à http://www.arb.ca.gov/fuels/lcfs/lcfs-background.htm#modeling

Carpentier, A., Letort, E. (2012). Accounting for heterogeneity in multicrop micro-econometric models: implications for variable input modeling. *American Journal of Agricultural Economics*, 94: 209-224.

CE (2012). *Impact Assessment accompying the proposal for a directive of the European Parliament and of the Council amending Directive 90/70/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*. Commission Staff Working Document SWD (2012) 343 final, disponible à http://ec.europa.eu/energy/renewables/biofuels/doc/biofuels/swd_2012_0343_ia_en.pdf

De Cara, S., Goussebaile, A., Grateau, R., Levert, F., Quemener, J., Vermont, B. (2012). *Revue critique des études évaluant l'effet des changements d'affectation des sols sur les bilans environnementaux des biocarburatns*. Rapport ADEME disponible à http://www2.ademe.fr/servlet/getBin?name=7AC5DFA02A2CE66DFDE000D7FA33AA56_tomcatlocal1333626720098.pdf.

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*. Scientific and Technical Reports of the Joint Research Center, European Commission, disponible à http://ec.europa.eu/energy/renewables/consultations/doc/public_consultation_iluc/study_4_iluc_modelling_comparison.pdf

Elobeid, A.E., Carriqiuiry, M.A., Fabiosa, J.F. (2012). Land-Use Change and GreenHouse Gas Emissions in the FAPRI-CARD model system: Addressing Bias and Uncertainty. *Climate Change Economics*, 3(3): 1-26.

Golub, A., Hertel, T.W. (2012). Modeling Land-Use Change Impacts of Biofuels in the GTAP-BIO Framework. *Climate Change Economics*, 3(3): 1-30.

Huang, H., Khanna, M. (2010). *An econometric analysis of US crop yield and cropland acreage*. Discussion paper, Univ of Illinois, Urbana Champaign.

Keeney, R., Hertel, T.W. (2009). Indirect land use impacts of US biofuels policies: The importance of acreage, yield and bilateral trade responses. *American Journal of Agricultural Economics*, 91: 895-909.

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, 111 p, disponible à http://trade.ec.europa.eu/doclib/docs/2011/october/tradoc_148289.pdf

Laborde, D., Valin, H. (2012). Modeling Land-Use Changes in a Global CGE: Assessing the EU Biofuel Mandates with the MIRAGE-BioF Model. *Climate Change Economics*, 3(3):1-39.

Rosegrant, M., Ringler, C., Msangi, S., Sulser, T.B., Zhu, T., Cline, S. (2008). *International Model for Policy Analysis of Agricultural Commodities and Trade: Model Description*, disponible à http://www.ifpri.org/publication/international-model-policy-analysis-agricultural-commodities-and-trade-impact-0

Salhofer, K. (2001*). Elasticities of Substitution and Factor Supply in European Agriculture: A Review of Past Studies. Annex 3 to the OECD report "Market Effects of Crop Support Measures"*

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

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