MODELLING INDIRECT LAND USE EFFECTS OF BIOFUELS:

STRENGTHS AND LIMITATIONS

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Abstract:

With the growing concerns of stakeholders regarding the environmental impacts of ethanol and biodiesel development, the quantitative assessment of biofuel policies virtues played an increasingly important role in the public debate. Numerous studies have tried to compute the indirect land use effects (iLUC) of the incremental crops demand for bioenergy, aiming to provide policymakers precise values for the iLUC coefficients. However, due to many uncertainties, these estimates have been criticised. In this paper, we show that models are still relevant for conceptualisation and understanding of problems as complicated as biofuel policies and among other aspects, iLUC issues. In particular, if doubts remain – and will remain – on the exact values of iLUC coefficients, the conclusions related to key policy options, such as what biofuel type to prefer and what trade policy to adopt, appears quite robust and should be the focus of larger attention.

Keywords: Biofuels, iLUC, Land Use Change, Computable General Equilibrium, Agricultural Trade Policies.

1. Introduction

There is rising scepticism about the potential positive environmental impacts of first generation biofuels. Indeed, the debate on indirect land use change (iLUC) launched by the articles of Searchinger et al. (2008) and Fargione et al. (2008) seriously questioned the principle of greenhouse gas (GHGs) savings associated to the processing of food crops into ethanol and biodiesel. Growing biofuel crops would induce diversion of other cultures dedicated to food and feed needs. The relocation of production could increase deforestation and bring significant new volumes of carbon in the atmosphere under an agricultural intensive management on previously uncultivated lands. This issue took wider amplitude as policy makers decided in the United States (USA) and in the European Union (EU) to take these effects into account for the life cycle assessment (LCA) of the different biofuels pathways. A need for figures arose in order to possibly incorporate estimates of GHG emissions associated to iLUC in addition to more standard "direct cycle" energy consumption values.

A large number of studies were commissioned to compute the possible range of iLUC "coefficients". Because the US biofuel policy was the most ambitious, the first integrated assessments were realised by US research teams for the California Air Resource Board (CARB) and the US Environmental Protection Agency (US EPA) using respectively a computable general equilibrium approach (GTAP model, Purdue University) and an integrated framework centred on two partial equilibrium models (FASOM and CARD-FAPRI). On the EU side, different methodologies were also applied, the results of most of them having been released in the first semester of 2010 (partial equilibrium with AgLink (OECD) and computable general equilibrium with MIRAGE (IFPRI). Figure 1 summarizes the major models used and the different findings up to date. For a broader overview and comparison of results, see Mortimer et al. (2008) and Prins et al. (2010).

[Insert Figure 1]

As the US and the EU regulation use eligibility criteria for biofuels support based on such final estimates, intense controversies outburst between stakeholders over the supposed underestimations or overestimations of these figures. This resulted in some unexpected outcome on the policy side. The US Senate decided in June 2009 to set a five years moratorium on the incorporation of iLUC calculations from EPA to decide of the eligibility of US biofuels. In 2010, the CARB decided to create an expert working group on iLUC estimations, following several critics on the validity of the methodology and significant revision of the estimates. In the EU, the European Commission was sued by a coalition of environmental non-governmental organisations for her lack of transparency in the process of determination of these iLUC effects. All these reactions reflected the lack of confidence from stakeholders in these models for determining accurately estimates of iLUC.

In this paper, we intend to show that models are relevant for conceptualisation and understanding of problems as complicated as biofuel policies and among other aspects, iLUC issues. These models can capture inter-sectoral and inter-regional linkages and provide key insights on the fuel versus food versus feed versus forest debate by describing the different substitution and extension effects that can take place. Unfortunately, in practice, the need for a large amount of data, the choice of modeling assumptions and the behavioral parameters chosen can lead to great variance in the results. Therefore, we illustrate how such variance undermines the possibility of solving the iLUC debate by quantitative assessments in the current state of science. For this, we use the MIRAGE model, a CGE based on an extended and modified version of the GTAP database specifically designed to describe biofuel related markets. In the same move, we show with this model that policy recommendations can still be derived from modeling, as long as search for four digits figures is abandoned. In particular, we show that uncertainty does not preclude the confidence in the potential positive effects on GHGs emissions of a larger use of imported biofuels.

The structure of the paper is as follows: in section 2, we present the modified global Input/Output database used, the modeling structure, and the underlying behavioral assumptions. In section 3, we stress some interesting qualitative learning from deterministic resolution of the model. In section 4, we run some systematic sensitivity analysis on the results and look at their consequences for the resolution of the questions addressed. We conclude in section 5.

2. Data and Model Description

In order to conduct our quantitative analysis, we rely on an applied computable general equilibrium model, MIRAGE, used for long for trade policy assessments (Bchir et al., 2002) and that was expanded to address more specifically agriculture and trade issues (Decreux and Valin, 2007), and in particular biofuel policies (Valin et al., 2009). The general equilibrium framework was considered the most relevant approach to take into account all possible inter-sectoral linkages as well as trade and income mediated effects.

However, CGEs are also highly dependent on a high quantity of inputs and very few available datasets currently allow to address this issue. As far as we know, most applied CGE approach at the global level rely on the GTAP datasets (Narayanan and Walmsey, 2009). Assessment of biofuel policies is no exception (Hertel et al., 2010; Banse et al., 2008; Kretschmer et al., 2009) even if modelers had to find some technics to cope with the absence of the biofuel sectors in the commercial version of the database (see Kretschmer et al to see what were the details of the different approaches used). In this part, we will first show why usual works on data consisting in carving out new sectors by splitting aggregates are insufficient and lead to highly flawed analysis and we will present our approach to reconstruct more reliable data for such assessment. In a second time, we will summarize the main characteristics of the model used in the assessment.

2.1. A Database Tracking Quantities on Homogenous Goods

Computable general equilibrium models usually work on shocks of small magnitude and usual calibration adopt a normalization of all prices in the model: physical quantities are not considered in the analysis. This approach generally makes sense when goods represented are imperfect substitutes. In particular, impact of trade policies and fiscal policies can accommodate of such approximations. However, agricultural and energy policies are different because good considered are more homogenous. Even when some subproducts can be differentiated (soft versus durum wheat or gasoline versus diesel), applying constant elasticity substitution functions (CES) to such goods assume that the substitution occurs with a technical marginal substititution rate (TMS) between two goods A and B equal to:

$$TMS_{A\,B} = \frac{dq_B}{dq_A} = \frac{\partial Q/\partial q_A}{\partial Q/\partial q_B} = \frac{p_A}{p_B}$$

where q stands for quantities and p for prices relatively to two substitutable goods A and B and Q is the CES aggregated good of q_A and q_B. In a case of high substitution elasticity, prices vary little around their initial position in a CES, the consequence of which is that the TMS will remain closely the same and its value will be equal to the initial price ratio. In the case of CGEs calibrated with normalized prices, the TMS will remain around 1 for very substitutable goods and as quantities are calibrated on values, the substitution will be operated on the basis of 1$ of good A for 1$ of good B.

Modeling biofuel policies is all about representing substitutions between highly homogenous products (ethanol, biodiesel, wheat, maize, rapeseed, soybeans, vegetable oil, etc…). These substitutions, whatever perfect they are considered in the modeling, will particularly be discriminating between domestic production and imports (Armington assumption) and between intermediates (substitution between biofuel feedstocks, between livestock meals, between fossil and different biofuels).

Usual approach for constructing data for biofuel policies assessment rely on a disaggregation of the GTAP sectors, keeping other sectors structure constant (see Hertel et al., 2008; Banse et al., 2008). No particular care is given to the relation between values and quantities, which means that the implicit TMS can be far from an expected 1 ton for 1 ton or 1 liter for 1 liter substitution. For the present assessment, we decided to follow a completely different approach, by reconstructing primary agricultural commodities production and trade flows using FAO production quantities, with a decomposition of the prices along the farm gate to final consumer chain to recompute the value equivalent and checking the physical transformation ratios (yields, crushing ratio, esterification process…) along the value chain.

Therefore, a world price matrix for homogenous commodities was constructed in order to be consistent with international price distortions (transportation costs, tariffs, and export taxes or subsidies). Several new sectors were introduced following a bottom up approach instead of the usual splitting procedure:

- 5 crops (maize, soybeans, rapeseeds, palm fruits, sunflower). Production technology for new crops sectors was inherited from the parent GTAP sector.
- 4 vegetable oil and 4 of their co products following information on the crushing cost structure (rapeseed oil and meal, soybean oil and meal, sunflower oil and meal, palm

fruit). Value and volume of both oils and meals were made consistent with the prices matrix, the physical yields, and the inputs quantity.

- 4 ethanol processing sectors and 3 of their by-products (ethanol from wheat and their DDGS, ethanol from corn and their DDGS, ethanol from sugar cane, ethanol from sugar beet and their beet pulp). The 4 ethanol products are then considered almost perfectible substitutable inputs in a single ethanol final product.
- 3 fuel sectors (fossil fuel, biodiesel, aggregated ethanol). Biodiesel was also built with a bottom-up approach to respect the production costs, input requirements, and production volume.

For all these adjustments, the value of inputs was deducted from the relevant sectors (Other Food, Vegetal Oils, Chemical products, Fuel) in the original SAM, allowing resources and uses to be extracted from different sectors if needed. At each stage, consumption data are adjusted to be consistent with production and trade flows. Finally, rates of profits are computed based on the difference between production costs, subsidies and output prices. Figure 2 provide an example for ethanol supply chain implemented in the date and providing a unique ethanol price per liter on the European market.

[Insert Figure 2]

It is important to emphasize that this procedure, even if time consuming and delicate to operate with so many new sectors, was crucial and differs from a more simplistic approach used in the literature until now. For example, the GTAP database performs production targeting only for OECD countries and therefore has an outdated agricultural production for other countries.

Several other databases have been associated to the core Input-Output database to specifically convert changes in endowment allocations and input use into physical units. For land use, we relied on FAO for national occupation and on the M3 database (see Monfreda et al., 2007 and Lee et al., 2007) for land distribution between different agroclimatic regions. We relied on data from IIASA (Fischer et al., 2000) for land available for crop in rainfed condition, and on IPCC AFOLU guidelines (Tier 1) for computations of greenhouse gas emissions contained in biomass and in soil. More details on the incorporation of these databases in the model are provided in Valin et al., 2009.

2.2. The Modified Version of MIRAGE for Biofuel Policies Assessment

In order to evaluate the impact of public support to biofuel production, we relied on an extended version of the trade global CGE MIRAGE, which was consequently improved in several directions. A detailed description of the model is provided in Bouet et al. (2010) and the complete list of equations in Al Riffai et al. (2010). We therefore give in this section a quick overview of the different features, emphasizing the calibration questions for each sensitive issue.

The core structure of the MIRAGE model follows the ones of standard GTAP-like trade CGEs. Each country produces a certain quantity of goods through Leontieff of intermediate inputs and value added, each of them being a CES composite of different aggregates of inputs and factors respectively. These aggregates are themselves CES composite of single products or single factors. Goods are consumed by final consumers, firms and government, or exported to foreign market. Imported goods are differentiated from domestic goods following Armington assumption. Real exchange rates between regions are endogenously adjusted to maintain current account constant as share of world GDP. The model is recursively dynamic and total factor productivity is adjusted along the baseline to follow GDP projections.

A first major improvement brought to the model was the refinement of agricultural production functions. We implemented a more precise disaggregation of factors, isolating a bundle of land

and chemical fertilizer in the tree structure of factors to better control for yield response to shock in fertilizer prices and to increase in demand. In order to limit the possibilities of land intensification around the equilibrium, the ratio *VA* / *LAND* is written as a logistic relation of *FERT* / *LAND* with *VA* standing for the aggregate volume of factors (fertilizers included), *FERT* for fertilizers and *LAND* for volume of land productivity.

Land is represented in the model through a volume of productive land equivalent and differentiated for different agro-ecological zones (AEZ) relying on the M3 database. The reasoning follows the approach generally applied on labor were wage differential explain difference in workers productivity. Therefore the value a hectare of land can vary according to its productivity. Indeed, the distribution of land endowments across sectors may be different from the distribution of areas if most productive land is affected to certain high value added crops. In most CGE[1], land markets are represented through a more of less elaborated nesting of constant elasticity of transformation (CET) functions. This can imply high substitution of land use between certain categories of crops depending on the value of elasticity chosen. Even if this framework is not considered as the more satisfying to describe all the complexity of land markets, we used this design to replicate substitution between cereals and oilseeds, as well as with other agricultural use and forestry use. This is managed through a nested structure where most substitutable crops are considered separately and pasture and managed forest conversion is assumed limited by low values of transformation elasticities. Because we did want to precisely track the substitution between land used for crop cultivation, we readjusted all crop rents to match a same value of rent per hectares and ensure a TMS of 1 for land areas used for cropland. It is to note that this operation was made possible because of the prior readjustment of agriculture targets on FAO

[1] A notable exception is the approach proposed by Gurgel et al. (2008) with the EPPA model where an approach using pure conversion cost is developed. However, this type of model does not enter into description of substitution at the crop level.

production. Otherwise, the mismatch between FAO and GTAP data would have led to completely inconsistent land rent share in the total value added of crops.

For substitution between cropland, pasture and managed forests, nested low elasticity CETs are used. For these, the TMS is not equal to 1, and one hectare of wheat in the model may be considered to be replaced by two hectares of pasture if the implicit productivity is twice lower for pasture. However, because we want to represent a fixed land coverage for a certain value of the overall land CET aggregate, this distortion related to the TMS is redressed ex post when computing the land change in areas. Marginal productivity for pasture and forest land is then considered equal to mean productivity of cropland and gain and loss in pasture and managed forest are computed on the basis of cropland area variation.

A second innovation introduced for land use change in the model is a mechanism that allows for land use expansion into unmanaged land, at the level of AEZ. Depending on the price of cropland, cropland can undergo additional expansion in new land such as natural forests and natural grasslands, through an isoelastic relationship and within the limit of availability of fertile uncultivated land. A coefficient of marginal productivity can be applied to this new land, to reflect the fact that expansion can occur in land of different quality from the land already used.

2.3. Model calibration

We would like to emphasize in this paper the difficulties of properly calibrating such a model in a changing world. The most critical parameters we need to know to properly set our design are for the different regions of interest:

- Elasticity of production to price;
- Elasticity of land input to price (and by subtraction elasticity of yield to price);

- Elasticity of expansion of cropland into other land type.

Moreover, two other parameters are particularly critical even if not driven by endogenous economic behavior in the model:

- the coefficient of marginal yield for cropland expansion;
- the coefficient of distribution of newly converted land from expansion into each of unmanaged land use type.

For these different coefficients, some values can be assumed but their robustness is very weak, and particularly for regions like Brazil, and South East Asia, where land use change are delicate to measure and long time series are missing. Using a set of plausible value is of interest for conducting some qualitative analysis and deriving some possible storyline but it should not preclude the importance of measuring uncertainty in the analysis.

To calibrate our model, we use some estimates of elasticities of agricultural production mainly provided by OECD. Elasticities of expansion of land use are sourced from a paper of Babcock et al. (2010) looking at the US and Brazil. Coefficient of marginal yield for cropland expansion are based on values used for the CARB analysis. Coefficients of newly converted land from expansion into each unmanaged land use type are taken from MODIS analysis realized by Winrock for the assessment of EPA. All these values are presented in the Table 1 and Figure 3.

[Insert Table 1 and Figure 3]

In order to conduct sensitivity analysis, we can try to determine for these coefficients some confidence intervals. Table 2 shows the differences in values observed in some econometric studies and provides an idea of plausible range of values.

[Insert Table 2]

3. Impact of EU Biofuel Policies under Different Trade Options: Deterministic Approach.

In a first step, we propose to present the main consequences of three central scenarios where we take all our coefficients and set them to the central value of the range of confidence.

3.1. Baseline and scenario description

These scenarios are run on a 2008-2020 dynamic baseline, where the US program on biofuels is implemented (target of 15 billion of corn ethanol in 2022 and 21 of advanced biofuel, including biodiesel, sugar cane and cellulosic ethanol) and Brazil is the only other major producer and consumer of biofuels. Land set aside obligation is abandoned in the EU and sugar reform is implemented. Trade barriers on ethanol are considered stable on all the period and import restriction of biodiesel from the US to the EU is maintained following the anti-dumping and countervailing measures decided by the European Commission in March 2009. The price of oil follows the projection of the AIE (2009) and the barrel of oil is assumed to reach 120$ in nominal terms in the year 2020, which also affects biofuel consumption in regions that do not implement mandates.

In the base year 2008, the initial consumption of biofuels in the EU represents 3.3% of the total energy used in transportation.[2] Consumption of biodiesel represents 8.3 Mtoe (4.4% of the diesel consumption) and ethanol accounts for 1.7 Mtoe (1.5% of the gasoline consumption).

The three scenarios come as follows:

1. The first scenario ("7%-Biod") looks at the effect of a 7% incorporation of first generation biofuels in the European Union as a consequence of the Renewable Energy

[2] Because the extended version of GTAP database is based on the 2004 year, we run a first preexperiment on the 2004-2008 period to target the different production and trade values on biofuels.

Directive (RED) [3].The final level of incorporation is considered to rely mainly on biodiesel, and ethanol incorporation remains in share at the 2008 level. As a consequence, incorporation of biodiesel reaches 11.8% of diesel consumption, whereas remains incorporated at the level of 1.1% of gasoline consumption, which with an assumption of 55% of the cars running on diesel against 45% running on gasoline, allows to reach the 7% target[4].

2. The second scenario ("7%-Etha-Dom") relies on the assumption that the same mandate resulting in 7% of first generation biofuels is enforced but is now reached only through an increase in ethanol incorporation. In order to reach 7% of incorporation, ethanol has to increase up to nine times its actual level of incorporation to represent 10.2% of ethanol consumption level in 2020. It is assumed that trade policies remain very restrictive and that a prohibitive tariff remains in place to prevent competition from foreign ethanol[5].
3. The third scenario ("7%-Etha-Lib") assumes that, like in scenario 1, ethanol will be incorporated at the level of 7% of gasoline but more place is given to imported ethanol, mainly sugar cane from Brazil countries, through the opening of the EU ethanol market.

Because of the large number of sectors impacted by biofuel demand, we ran the model on a 43 sectors x 11 regions aggregation (see Table 3). The decomposition of regions was made in order

[3] The 10% mandate also incorporates electric cars, electricity in rail transportation, and second generation biofuels. We set here an intermediary target between the usually exaggerated 10% assessed in some papers (Banse et al., 2008; Peterson et al., 2009) and the optimistic projections of 5.6% assumed by the European Commission (Al Riffai et al., 2010).

[4] Note that the current legislation limits to 10% the level of incorporation of biofuel in fuel used for standard vehicules. However, scenarios designed here do not take this restriction into account to better show the effect of the composition between feedstocks. It could also be argued that change in the legislation could possibly lead to a shift of this 10% restriction and that vehicules based on new technologies (FlexFuel) could help to go over this "blending wall" (so called by US interests groups promoting the idea of a E15 standard – gasoline with 15% incorporation of ethanol).

[5] Because the current EU tariff on ethanol (estimated at an *ad valorem* rate of about 50% initially) is not fully prohibitive (the EU imported in 2008 1,3 billion liters of ethanol, mainly for Brazil), for the purpose of the demonstration, we reinforced the uniformity of this scenario by increasing the ethanol tariff by 50%.

to isolate the most important regions involved in the production and consumption of biofuels, and low revenue countries were isolated when possible to track the impact on welfare of increased food prices (Table 4).

[Insert Table 3 and Table 4]

3.2. Results and Main Lessons

Some effects from biofuel policies are easy to anticipate. Few players are competing at the world level on the biofuel market and all the gain from the game are mainly distributed among four players: the EU which is the focus of our investigation here; Brazil for its unique position as a huge producer of ethanol at a very affordable price but also for their role on the world oilseeds and meals market; the USA which became in a decade the first producer of ethanol thanks to their very active domestic program and whose production of biodiesel for internal demand and exports undergoes a very rapid development; and Indonesia and Malaysia through their massive production of palm oil. Unsurprisingly, the three scenarios favor more or less each of these players, with the EU producing respectively an additional 9.3 Mtoe of ethanol or 8.5 Mtoe of biodiesel in the "7%-Etha-Dom" and "7%-Biod" respectively (see Table 5). Trade in biofuel remains limited in these scenario: some ethanol imports come from Brazil even with a stringent tariff in scenario "7%-Etha-Dom", and a contribution from Indonesia-Malaysia to biodiesel consumption represent 8% of the additional demand in scenario "7%-Biod". Interestingly enough, opening the ethanol markets completely disqualify domestic production, which is coherent with the assumption on production and trade costs (see Figure 2) and a result of the homogenous product assumption.

[Insert Table 5]

Looking at the composition of biofuel production in the European Union, the striking fact is the difference between the future of the two sectors. For ethanol, present share of production could apparently maintain, considering the total share of feedstock available is large in the EU and independently of any change in the processing costs or the public policy incentives (see Figure 4). However, the situation is completely different on the biodiesel side: the share of rapeseed production currently used for biodiesel is particularly significant and could only expand at significant conversion costs, whereas the world vegetable oil market could more likely provide substitutes at lower costs such as soybean oil and palm oil (see Figure 5) [6].

[Insert Figure 4 and Figure 5]

Land use change is directly impacted by the demand for crops required for producing the additional mandated biofuels event if some endogenous yield increase allows to offset a part of the pressure on land. The effect of ethanol policy mainly affects the wheat, the corn and the sugar market (see Table 6). Additional production of corn and wheat in the EU allows to respond to a significant share of the demand, and Brazil imports of sugar cane provide a complement, even when significant tariff are set at the border. The consequence in term of land use requirement are mainly located in the EU and in major temperate climate zones where cereal are produced (see Figure 8) with the notable exception of Brazil where sugar cane production expands significantly, for the “7%-Etha-Lib” scenario providing most of the mandated ethanol (see Figure 4 and Figure 7).

[Insert Table 6, Figure 7 and Figure 8]

[6] A general argument against this scenario is the regulatory limits to incorporation of soybean oil and palm oil in the current biodiesel, because of the iodine level of soybean biodiesel and the solidification of palm oil at low temperature. However, some mix of these different biodiesel are possible and already in use in the EU. Moreover, if more constraint was incorporated in the model on this aspect, the results would remain very similar because these vegetable oils would simply be substituted with some inputs from the agrobusiness sector, which massively use these oils for food.

The situation is significantly different in the case of biodiesel. Indeed, the vegetable oil market in the EU being saturated and many countries being involved in the production of highly substitutable vegetable oils, all the world market is significantly affected and producers react accordingly to signal prices in different areas of the world (see Figure 9). The yield for soybeans being particularly poor (half the one from rapeseed or sunflower and ten times less the one from palm oil), Brazil land use is particularly affected and because oilseeds are produced in a more sensitive area than sugar cane, this will have consequences for the conversion of natural land. It is also to note that the extra rapeseed required is mainly produced outside the EU (notably Canada in RoOECD, China, and India in RoW), which is coherent with the observed recent trends (in 2007, according to FAO, 30% of rapeseed oil in the EU was imported).

[Insert Figure 9]

Following the methodology exposed in Valin et al. (2009), we can therefore decompose the choc into broader land use conversion and using default emissions factors based on IPCC AFOLU guidelines, we compute the magnitude of the land use GHG emissions associated to each scenario. Results are displayed in Table 7. The most striking fact is the magnitude of effects occurring in Brazil. Two factors explain these significant emissions: the first one is that Brazil is mainly concerned by the production of crops used for producing biofuels for the EU under the different scenarios (soybeans for biodiesel or sugar cane for ethanol). The second parameters comes from the readjustment of the elasticity of land expansion to price of cropland, that we set at a low bound value provided in a recent paper from Barr et al. (2010). Because these readjustments were not made for other regions, land use expansion effects may more likely be underestimated in other areas.

[Insert Table 7]

With a reference period of 20 years, the illustrative value obtained for ILUC effects would correspond to some emission factors of 20.2 gCO2/MJ in the scenario “7%-Etha-Dom”, 75.2 gCO2/MJ in scenario “7%-Biod” and 12.9 gCO2/MJ in the scenario “7%-Etha-FT”.

4. Dealing with uncertainty: what can we finally be sure about?

In this last part, we aim to conclude the analysis by showing the strength and the limits of the approach in the current understanding of agents behaviour related to land use change. Our main focus will be to look at the striking fact of the previous part and test their robustness to thorough change in critical parameters. The first question we want to address is the environmental benefits of biofuels with respect to their environmental impact. The second question concerns the relative benefits of promoting a pro-ethanol instead of a pro-biodiesel mandate: is the model robust enough to conclude on this point. Last, the question of the value added of a trade liberalisation under an ethanol mandate deserves some better scrutiny.

In order to evaluate the robustness of the proposition, we will undertake a rich sensitivity analysis on three critical parameters. In spite of more sensitivity analysis where modelers limit their investigation to a uniform change in a parameter, we want to test here also the effect of an unevenly distributed error across regions. We therefore do our test separately on developed regions and developing regions.

Three sets of parameters are scrutinized:

- Elasticities of agricultural supply (through the non-fertilizer endogenous yield elasticity);
- Elasticities of land substitution among crops (through the elasticity of substitution between cereals, grains and oilseeds);
- Elasticities of land expansion into natural areas.

Ranges explored around the central values are exposed in Table 8. Because it did not appear relevant to limit the perimeter of investigation to one-dimensional variation around the initial set of parameters, we multiply for each parameter the possibilities of heterogeneity between developed and developing regions, applying 3 level of elasticities (much lower, unchanged, much higher). We therefore obtain 27 baseline (3^2 for of the three each elasticity group), on each of which we recomputed the 3 scenarios, whose results are now presented.

[Insert Table 8]

This approach allows to browse a much larger set of plausible values related to some economic elasticities. It should be however emphasized here that we do not look at the uncertainty – potentially also very high - on the biophysical coefficients used in this paper (emission factors from different sources, coefficients of savings from LCA, assumption on land use management), as well as the uncertainty driven by the distribution of expansion across different land use types (displayed in Figure 3).

From the economic behaviour perspective, some lessons still seems to resist to sensitivity analysis. First of them, biodiesel policies appear to be the most "ILUC-intensive" policies because they influence the vegetable oil market, whose inputs are the most related to deforestation (soybeans in Brazil and palm oil in Indonesia). In all our 27 baselines, biodiesel policies appeared as releasing more carbon emissions from deforestation than ethanol policies. Median values suggest that expanding the consumption of biodiesel in the EU would be approximately four times more prone to deforest (see Figure 10).

[Insert Figure 10]

This does not mean that land use effects are more significant in the case of biodiesel policies. Indeed, when looking at emissions from organic carbon in mineral soil, released when new land are put into cultivation, the most active policy appears to be the ethanol policy with trade barriers (see Figure 11). This is because instead of leading to more domestic production of crops, limiting trade in ethanol under a mandate will stimulate production of cereals in many other regions of the world and put pressure on land in countries where expansion can easily occur in new open areas (see Figure 8). Indeed, from various feedstocks used for ethanol, sugar cane gets a much better yield, which explains the more limited effect of its use (sugar cane typical yield is 4550 liter per ha where as wheat yield is 952 liter per ha, source: FAO, 2008).

[Insert Figure 11]

The measurement of emissions allow to derive the so-called "ILUC factors" by using an amortisation reference of 20 years or 30 years to divide the total carbon release and compare annual flows and total biomass stock variations. Results show that ILUC plausible range are wide and do not allow a convenient use as a direct additive input in LCA (Figure 12). In particular, in the case of biodiesel, emissions are likely to reach the level of total emissions from fossil fuels with a range of 45-90 gCO2/MJ. On the opposite side, ILUC effect from ethanol crops appear lower even if they can reach 30% of the fossil fuel emissions.

When taking into account the reimbursement rate relative to each type of pathway, we can compute a payback time following the approach of Fargione et al. (2008). As for the previous calculations, source of uncertainty considered have been here very limited and in particular, we did not change the assumption on direct savings relative to each pathway although high debate exist on the extent of their range (see values used in Al-Riffai et al., 2010). We obtain various range of payback time for EU policies and can compare more easily the impact of the different options. Even if uncertainty remains, biodiesel option appears to be the worst of the three scenarios scrutinised here, for the reasons developed earlier. Carbon payback time after 2020 seems to be below five years for sugar cane, between five and ten years for more diversified bioethanol policy and between 20 and 40 years for biodiesel (see Figure 13).

[Insert Figure 13]

These results are particularly interesting because they show that in spite of uncertainty, some trends seem to be resilient to change in parameters. Values of ILUC per se can significantly vary, but hierarchy of policies with respect to climate change mitigation subsist.

It is however important to stress the limited extend of the sensitivity analysis performed here. We focused on several parameters that seem uncertain and we tried to break the colinearity of sensitivity analysis usually performed, with one single multiplier on all regions. However, many parameters of great important could not be looked at in this part, because of the time necessary to run a larger number of scenarios.

5. Conclusion

European biofuel policies face more and more criticism because of the doubt on environmental benefits of first generation biofuels. In this paper, we look at the differentiated effects of several first generation plausible scenarios. We explain how we developed a specific database to represent biofuels and agricultural commodities as homogenous products. Without this care taken to data consistency, modeling exercises in CGE are likely to introduce strong biais on substitution of wheat, ethanol or vegetable oil. We expose the modeling framework relying on a detailed CGE analysis with agro-ecological zoning and a full representation of oilseeds and their products on the world market.

We propose first to develop the main facts at play under an arbitrary central scenario that allows to understand how the possible options can interfere with production in other regions and other products. The three scenarios look at the mandate composition of EU biofuels, with a biodiesel versus ethanol dimension, and for ethanol, a domestic versus full import option.

The striking facts are that a EU mandate based on domestic production would induce a strong increase in production across the world, because increase in EU production capacity would be more expensive than increase in production elsewhere. As a consequence, EU producers would shift to ethanol production, whereas lower supply to the EU and world market would need to be replaced by production elsewhere. As well, rapeseed supply has reached some structural constraint in the EU and additional incorporation in diesel would require to massively rely on foreign markets, mainly on soybeans, whose oil yield is one of the lowest. Consequences in term of land use expansion are therefore very large for biodiesel policy.

We last look at the impact of trade liberalization in case of ethanol incorporation. This policy option would strongly damage the EU biofuel sector, as production costs in Brazil are particularly low. Removing the tariff barrier and expanding incorporation of ethanol in gasoline would allocate all the benefits to sugar cane producers. This choice however appears a better climate mitigation option. Also, even if not developed here, it would release the pressure on world food prices by relying more largely on the sugar sector (with better yield and lower impact on food security) rather than the sensitive and less efficient cereal sectors to provide ethanol.

Last we confront these conclusions to a large sensitivity analysis where we run our 3 scenarios on 27 different baselines. Although the sensitivity analysis remains uncomplete because all parameters could not be tested, we emphasized the economic behavior parameters and find that results can vary in a large extent for some policies, biodiesel especially. This sensitivity analysis shows that it is very hard to derive some ILUC factors that could be summed to usual emissions factors. But the interesting fact is that the hierarchy of policies with respect to climate change remains unchanged across the baseline. Expansion of biofuel use through biodiesel always appear as the worst option, whereas ethanol liberalization appears as the most secure for the world markets and the most efficient from an environmental point of view.

Several directions remain to explore to confirm these results. Some sources of carbon emissions of importance have not been taken into account at this stage, in particular non-CO2 GHG emissions (enteric fermentation from livestock, nitrous oxides from fertilizer intensification). Additionally, sensitivity analysis on carbon stock and emission factors remains to be performed to assess all the magnitude of uncertainty and see how this affects our conclusions. Last, better understanding of economic behavior is also a future direction, especially with respect to land use change and farmer decisions.

The main conclusion this article would however like to put forward with respect to biofuel policy issues is that uncertainty is an important issue in modeling this type of issues and that ILUC emission factors cannot be measure accurately in the current state of science. However, we showed that the hierarchy between policy options with respect to a particular criteria – here climate mitigation – can show resilient to this uncertainty.

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Table 1. Elasticities of agricultural supply in MIRAGE for the European Union. Elasticity computed with a partial equilibrium extraction of the model where factor endowments are maintained constant except for land, and inputs are available with a perfectly elastic supply. Land rent elasticities are computed with respect to crop prices and comparison with Table 2 require a readjustment to go from the price of crop to the price of land.

Production

Elasticity of: (With respect to price of:)	**Rice**	**Wheat**	**Maize**	**Rape-seed**	**Soy-bean**	**Other OilSds**	**Other Crops**	**Sugar Beet**	**Veg Fruits**	**Cattle**	**Forest**
Rice	**2.00**	-0.01	-0.01	0	0	-0.01	-0.07	0	-0.21	-0.19	0
Wheat	0	**1.56**	-0.05	-0.01	0	-0.04	-0.27	-0.02	-0.19	-0.28	-0.02
Maize	0	-0.07	**1.42**	-0.01	0	-0.04	-0.28	-0.02	-0.19	-0.28	-0.02
Rapeseed	0	-0.07	-0.04	**1.5**	0	-0.04	-0.28	-0.02	-0.26	-0.36	-0.02
Soybeans	0	-0.07	-0.05	-0.01	**2.55**	-0.04	-0.29	-0.02	-0.26	-0.36	-0.01
OthOilSds	0	-0.07	-0.05	-0.01	0	**1.48**	-0.28	-0.02	-0.27	-0.34	-0.01
OthCrop	0	-0.05	-0.04	-0.01	0	-0.03	**0.95**	-0.02	-0.23	-0.32	-0.02
Sugar_cb	0	-0.05	-0.03	-0.01	0	-0.03	-0.27	**1.31**	-0.2	-0.29	-0.02
VegFruits	-0.01	-0.04	-0.03	-0.01	0	-0.03	-0.24	-0.02	**1.44**	-0.48	0
Cattle	-0.02	-0.06	-0.04	-0.01	0	-0.04	-0.36	-0.02	-0.54	**2.7**	0
Forestry	0	-0.01	-0.01	0	0	0	-0.05	0	0	-0.01	**0.17**

Land

Elasticity of: (With respect to price of:)	**Rice**	**Wheat**	**Maize**	**Rape-seed**	**Soy-bean**	**Other OilSds**	**Other Crops**	**Sugar Beet**	**Veg Fruits**	**Cattle**	**Forest**
Rice	**0.00**	0	0	0	0	0	0	0	0	0	0
Wheat	0.01	**1.03**	-0.05	-0.01	0	-0.04	-0.26	-0.02	-0.11	-0.21	-0.02
Maize	0.01	-0.07	**1.01**	-0.01	0	-0.04	-0.27	-0.02	-0.12	-0.22	-0.02
Rapeseed	0	-0.07	-0.04	**1.13**	0	-0.04	-0.27	-0.02	-0.17	-0.28	-0.02
Soybeans	0	-0.07	-0.06	-0.01	**1.84**	-0.04	-0.28	-0.02	-0.16	-0.28	-0.02
OthOilSds	0	-0.07	-0.05	-0.01	0	**1.11**	-0.27	-0.02	-0.18	-0.27	-0.02
OthCrop	0.01	-0.05	-0.04	-0.01	0	-0.03	**0.52**	-0.02	-0.13	-0.24	-0.02
Sugar_cb	0.01	-0.06	-0.03	-0.01	0	-0.03	-0.26	**0.78**	-0.1	-0.21	-0.02
VegFruits	0	-0.04	-0.03	-0.01	0	-0.03	-0.24	-0.02	**0.91**	-0.33	-0.01
Cattle	-0.01	-0.07	-0.05	-0.01	0	-0.04	-0.36	-0.03	-0.21	**1.32**	-0.02
Forestry	0	-0.01	-0.01	0	0	-0.01	-0.05	0	0	-0.01	**0.07**

Table 2. Agricultural supply elasticities for the EU provided by different articles and reports. Most of these estimates are from a review in the 2001 OECD report on Market Effects of Crop Support Measures. CAPRI estimates are based on Britz and Hertel (2009). FAPRI estimates were accessed online in January 2010.

Land elasticities				
EU27	**with respect to price of**	**Wheat**	**Maize**	**Oilseeds**
Wheat	FAPRI: EU15	0.12		
	FAPRI: EU New members	0.29		
	CAPRI Land own price elasticity:	0.85	-0.51	-0.16
	Guyomard (1996) France:	0.33	-0.11	0
	Ibanez Puerta and Perez Hulgade (1994) Spain:	0.57	-0.57	NA
	Burton (1992) UK:	0.3	NA	-0.21
	OECD (2001)	0.1 to 0.4		
Maize	FAPRI: EU15		0.08	
	FAPRI: EU New members		0.26	
	CAPRI Land own price elasticity:	-0.55	0.72	-0.08
	Guyomard (1996) France:	-0.36	0.68	-0.12
	Ibanez Puerta and Perez Hulgade (1994) Spain:	-0.69	0.69	-0.27
	OECD (2001)		0.1 to 0.4	
	FAPRI: EU New members			0.26
	CAPRI Land own price elasticity:	-0.3	-0.14	0.69
	Guyomard (1996) France:	-0.02	-0.03	0.23
	Burton (1992) UK:	NA	NA	0.53
	OECD (2001)			0.1 to 0.4
Production elasticities				
EU27	**with respect to price of**	**Wheat**	**Maize**	**Oilseeds**
Wheat	OECD (2001)	1.75	-0.57	-0.11
Maize	OECD (2001)	-0.68	1.99	-0.12
Oilseeds	OECD (2001)	-0.41	-0.38	1.61

Table 3. List of the 43 sectors in the model. Sectors in bold represent sectors whose representation is particularly important for representation of the impact of biofuel policies. Coproducts are also represented through complementary output of vegetable oil and ethanol processing sectors, going respectively to Ethanol and Biodiesel for biofuel, and Cattle and OthAnim for coproducts.

#	Sector	Description	#	Sector	Description
1	Rice	Rice	23	Coal	Coal
2	**Wheat**	**Wheat**	**24**	**Oil**	**Oil**
3	**Maize**	**Maize**	25	Gas	Gas
4	**PalmFruit**	**Palm Fruit**	26	OthMin	Other minerals
5	**Rapeseed**	**Rapeseed**	**27**	**Ethanol**	**Ethanol - Main sector**
6	**Soybeans**	**Soybeans**	**28**	**EthanolC**	**Ethanol - Sugar Cane**
7	**Sunflower**	**Sunflower**	**29**	**EthanolB**	**Ethanol - Sugar Beet**
8	OthOilSds	Other oilseeds	**30**	**EthanolM**	**Ethanol - Maize**
9	VegFruits	Vegetable & Fruits	**31**	**EthanolW**	**Ethanol - Wheat**
10	OthCrop	Other crops	**32**	**Biodiesel**	**Biodiesel**
11	**Sugar_cb**	**Sugar beet or cane**	33	Manuf	Other Manufacturing activities
12	**Cattle**	**Cattle**	34	WoodPaper	Wood and Paper
13	**OthAnim**	**Other animals (inc. hogs and poultry)**	**35**	**Fuel**	**Fuel**
14	**PalmOil**	**Palm Oil**	36	PetrNoFuel	Petroleum products, except fuel
15	**RpSdOil**	**Rapeseed Oil**	**37**	**Fertiliz**	**Fertilizers**
16	**SoybnOil**	**Soy Oil**	38	ElecGas	Electricity and Gas
17	**SunOil**	**Sunflower Oil**	39	Construction	Construction
18	OthFood	Other Food sectors	40	PrivServ	Private services
19	**MeatDairy**	**Meat and Dairy products**	41	**RoadTrans**	**Road Transportation**
20	**Sugar**	**Sugar**	42	AirSeaTran	Air & Sea transportation
21	**Forestry**	**Forestry**	43	PubServ	Public services
22	Fishing	Fishing			

Table 4. List of the 11 regions represented in the model. Regions in bold are regions whose representation is of particular importance for representation of the impact of EU biofuel policies.

#	Region	Description	#	Region	Description
1	**Brazil**	**Brazil**	7	LAC	Other Latin America countries (inc. Argentina)
2	**CAMCarib**	**Central America and Caribbean countries**	8	RoOECD	Rest of OECD (inc. Canada & Australia)
3	China	China	9	RoW	Rest of the World
4	**CIS**	**CIS countries (inc. Ukraine)**	**10**	**SSA**	**Sub Saharan Africa**
5	**EU27**	**European Union (27 members)**	**11**	**USA**	**United States of America**
6	**IndoMalay**	**Indonesia and Malaysia**			

Table 5. Effects of biofuel policies on world biofuel markets. Results of scenarios under central assumptions on parameters.

		Scenario	Baseline	Baseline	7% Etha-Dom	7% Biod	7% Etha-Lib
		Year	**2008**	**2020**	**2020**	**2020**	**2020**
All first generation	**Consumption**	**EU27**	**10.0**	**11.2**	**23.4**	**23.6**	**23.5**
		World	41.9	102.1	114.4	114.4	114.2
Ethanol	**Consumption**	**EU27**	**1.7**	**1.9**	**15.1**	**1.7**	**15.2**
		World	32.4	87.6	100.9	88.2	100.6
	Production	**EU27**	**1.2**	**1.0**	**4.3**	**1.0**	**0.7**
		Brazil	12.4	29.2	38.3	29.6	41.7
		USA	13.1	29.4	30.1	29.5	30.5
		China	3.4	16.3	16.2	16.1	16.2
		CAMCarib	0.7	7.9	8.3	8.2	7.8
		Rest of World	1.5	3.7	3.7	3.7	0.0
	EU imports	Brazil	0.4	0.8	10.3	0.7	14.5
		Rest of World	0.0	0.0	0.5	0.0	0.0
Biodiesel	**Consumption**	**EU27**	**8.3**	**9.3**	**8.2**	**21.9**	**8.3**
		World	9.5	14.5	13.5	26.2	13.6
	Production	**EU27**	**6.7**	**7.9**	**7.3**	**16.4**	**6.8**
		USA	1.6	4.2	4.1	6.3	4.6
		Indo-Malaysia	0.4	1.2	1.1	2.2	1.1
		Rest of World	0.7	1.0	1.0	1.3	1.0
	EU imports	Brazil	1.4	0.9	0.6	3.5	1.2
		Indo-Malaysia	0.1	0.3	0.2	1.4	0.2
		Rest of World	0.1	0.1	0.1	0.5	0.1

Table 6. Share of land used for biofuels feedstock in main producing regions related to EU demand

		Baseline Total land area (Mha)	Baseline Share for biofuel	Baseline Share for biofuel	7%-Etha-Dom Share for biofuel	7%-Biod Share for biofuel	7%-Etha-Lib Share for biofuel
		2008	2008	2020	2020	2020	2020
Maize	EU27	10020	2.66%	4.04%	21.50%	3.99%	3.60%
	USA	29908	20.19%	39.58%	39.75%	39.79%	40.59%
	World	**149177**	**6.27%**	**13.81%**	**15.29%**	**13.79%**	**13.96%**
PalmFruit	IndoMalay	6964	2.23%	3.18%	2.98%	6.93%	2.73%
	World	**13764**	**3.41%**	**5.59%**	**5.17%**	**19.66%**	**4.25%**
Rapeseed	EU27	4672	64.49%	65.74%	64.57%	79.98%	62.01%
	World	**26085**	**12.81%**	**12.67%**	**12.37%**	**16.62%**	**11.82%**
Soybeans	Brazil	24031	7.40%	5.50%	5.25%	12.50%	4.76%
	USA	30231	15.48%	23.70%	21.48%	36.19%	24.55%
	World	**79252**	**8.55%**	**10.16%**	**9.35%**	**17.47%**	**10.07%**
Sugar_cb	Brazil	5686	57.87%	70.27%	72.74%	70.70%	78.66%
	EU27	2216	2.28%	2.16%	16.52%	1.97%	1.70%
	World	**26482**	**13.85%**	**24.24%**	**27.12%**	**24.49%**	**30.31%**
Sunflower	EU27	3702	7.33%	13.22%	12.13%	44.02%	10.03%
	World	**20310**	**1.85%**	**3.24%**	**3.02%**	**9.47%**	**2.60%**
Wheat	EU27	26503	1.99%	1.71%	13.71%	1.61%	1.28%
	World	**214226**	**0.56%**	**0.56%**	**2.23%**	**0.55%**	**0.51%**

Table 7. Emissions from land use change associated to each scenario with the central scenario settings ($MtCO_2$ eq). The column "forest" designates emissions from above and below ground biomass contained in primary forest and in managed forests. The column "cultivation" designates emissions from organic carbon in mineral soils, released over time when a natural land is converted and cultivated under full tillage. The line "Indonesia Peatland" designates the specific emissions in Indonesia related to peatland conversion. Coefficient used for peatland are from IPCC AFOLU athough there is large debate on the conservative character of these estimates, that could be 5 to 10 times larger.

	7%-Etha-Dom			7%-Biod			7%-Etha-Lib		
	Forest	Culti-vation	Total	Forest	Culti-vation	Total	Forest	Culti-vation	Total
Brazil	42.6	42.8	**85.4**	222.4	179.4	**401.8**	32.4	88.2	**120.6**
CAMCarib	2.7	3.0	**5.7**	1.6	1.7	**3.3**	0.2	0.2	**0.4**
China	4.2	1.8	**6.0**	6.1	2.6	**8.7**	1.2	0.5	**1.6**
CIS	13.9	17.2	**31.0**	31.1	36.6	**67.7**	-0.5	2.0	**1.5**
EU27	5.6	20.0	**25.7**	7.5	25.8	**33.3**	-0.8	-2.9	**-3.7**
IndoMalay	-1.4	-0.6	**-2.0**	58.7	24.6	**83.3**	-2.9	-1.2	**-4.1**
Indo (Peatlands)			**-0.1**			**3.2**			**-0.2**
LAC	7.5	5.7	**13.2**	32.6	23.2	**55.8**	3.2	2.5	**5.7**
RoOECD	1.7	1.9	**3.5**	7.4	20.6	**28.0**	-1.0	-0.9	**-1.9**
RoW	9.6	5.8	**15.4**	9.3	5.3	**14.5**	1.3	0.7	**2.1**
SSA	4.8	9.0	**13.8**	22.3	34.2	**56.5**	0.9	1.7	**2.6**
USA	2.7	3.5	**6.2**	9.9	12.9	**22.9**	3.4	4.4	**7.7**
World	**93.8**	**110.1**	**203.7**	**408.8**	**367.0**	**779.0**	**37.3**	**95.3**	**132.4**

Table 8. Characteristics of the 27 baseline ran for the sensitivity analysis.

Effect tested	Parameter	Region	Low	Medium	High	Number of runs
Agricultural endogenous response	Elasticity of substitution between factors and land	Developed	/4	0.02	*4	
	Elasticity of substitution between factors and land	Developing	/4	0.05	*4	3 x 3= 9
Land use substitution	Elasticity of substitution between land for wheat, grain and oilseeds	Developed	/4	0.25 for US 0.2 for EU	*4	
	Elasticity of substitution between land for wheat, grain and oilseeds	Developing	/4	0.5 for Brazil 0.3 for others	*4	3 x 3= 9
Land use expansion	Elasticity of land use expansion to cropland price	Developed	/4	Calib value	*4	
	Elasticity of land use expansion to cropland price	Developing	/4	Calib value	*4	3*3 = 9

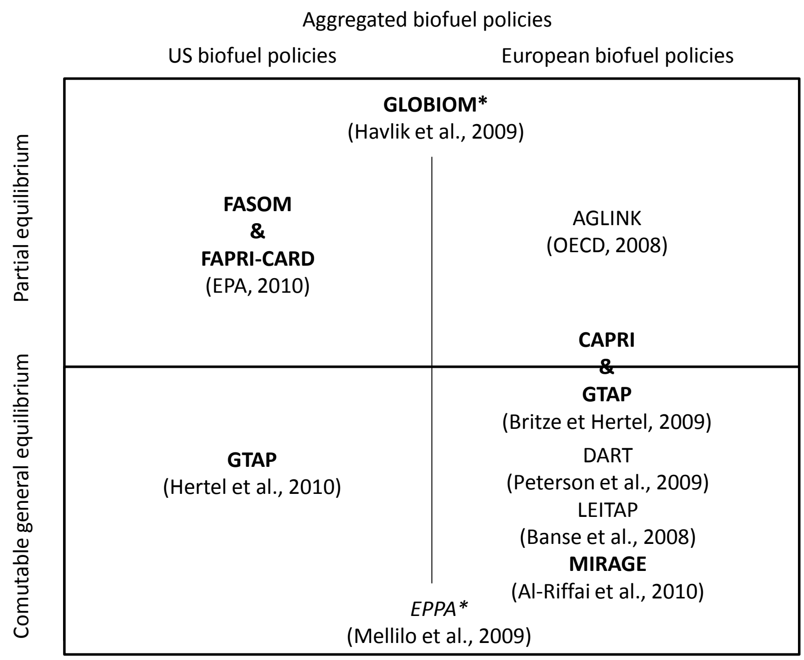

Figure 1. Different model types and results obtained for indirect land use change estimations. Names in bold designate models where GHG emissions have been computed from land use change results. Italics designate models that do not represent different types of crops. Star designates models where second generation biofuels have been added to first generation biofuels in the assessment.

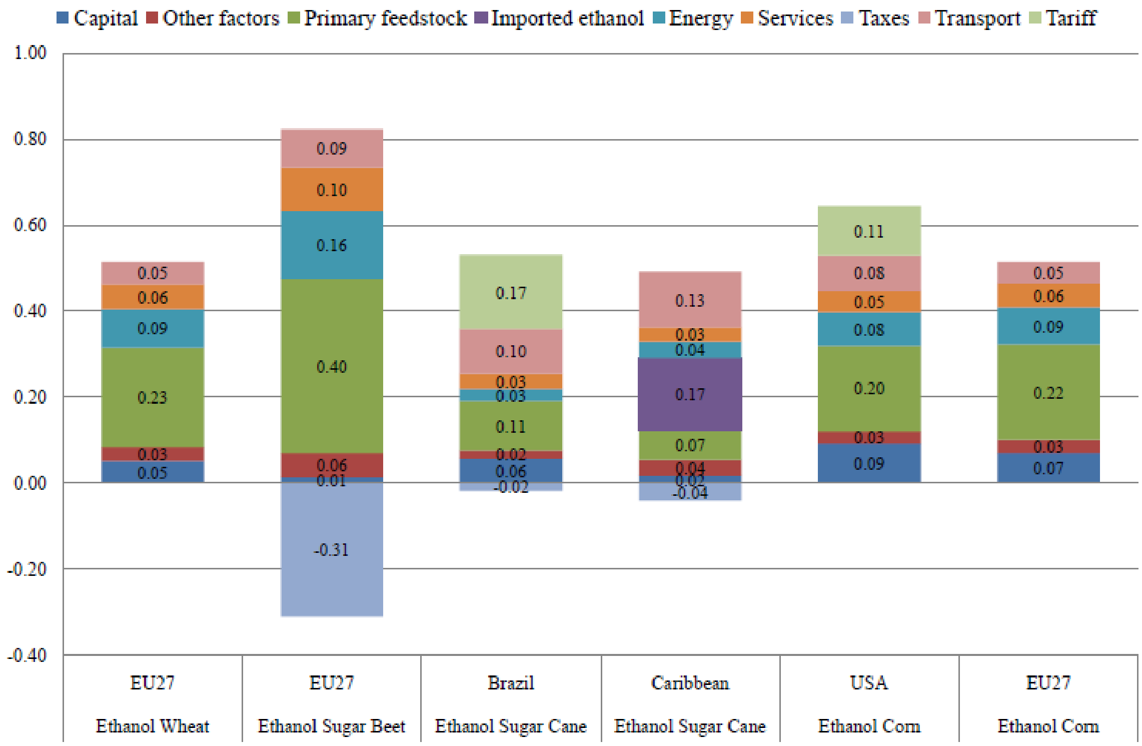

Figure 2. Cost structure USD per liter of ethanol supplied on the European market per country of origin and process in 2008. The ethanol market price is set to 0.514 cents per liter at EU market price, before application of fuel and value added taxes. In the case of Sugar beet ethanol, a subsidy has been calibrated to ensure the profitability of the technology based on existing regulated sugar beet price in the EU. Source: MIRAGE model.

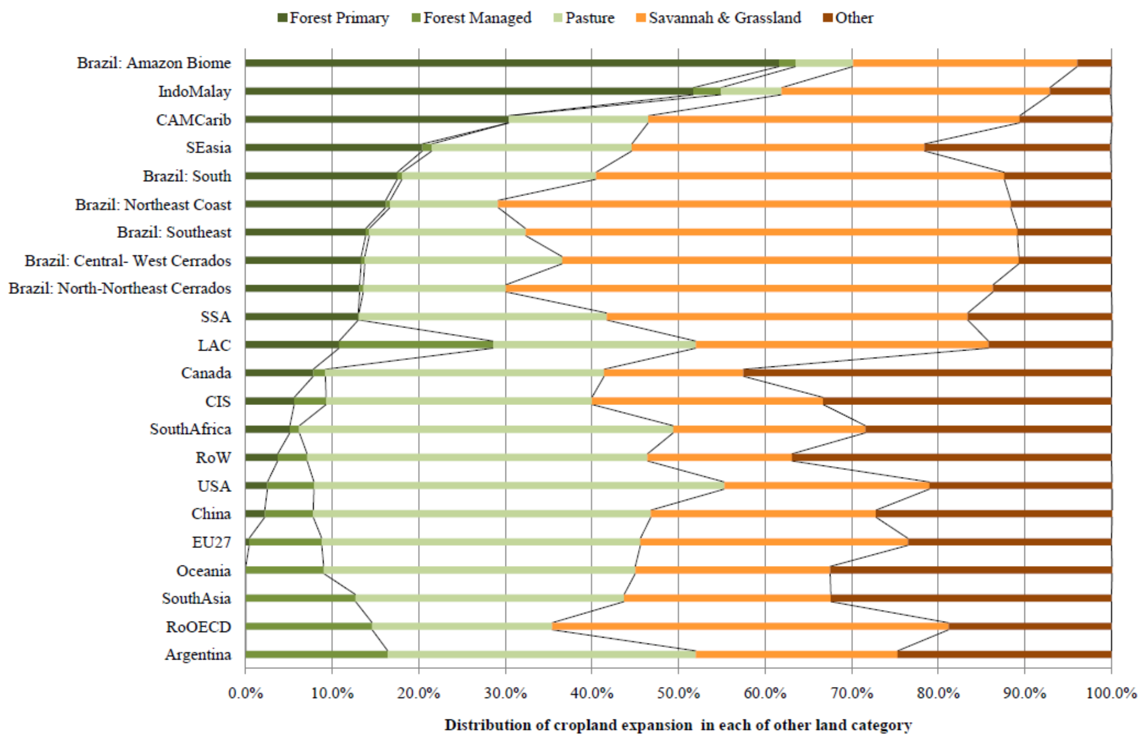

Figure 3. Distribution of cropland expansion across land use type categories for regions in the model. Brazil has been decomposed among six regions corresponding to different AEZ zones explicitly represented in the model in order to better track expansion effect of sugar cane. To map land use categories, some change to raw Winrock data are made: forest category is split within primary and managed forest, grassland category is split between pasture and natural grassland, wetland and barren are merged with others, and mixed are distributed between all land use categories. Note that when cropland substitution is measured endogenously with forest managed and pasture, expansion shares are only used in the model for primary forests, savannah and grassland and other, after a rescaling to 100%. Source: EPA for raw data.

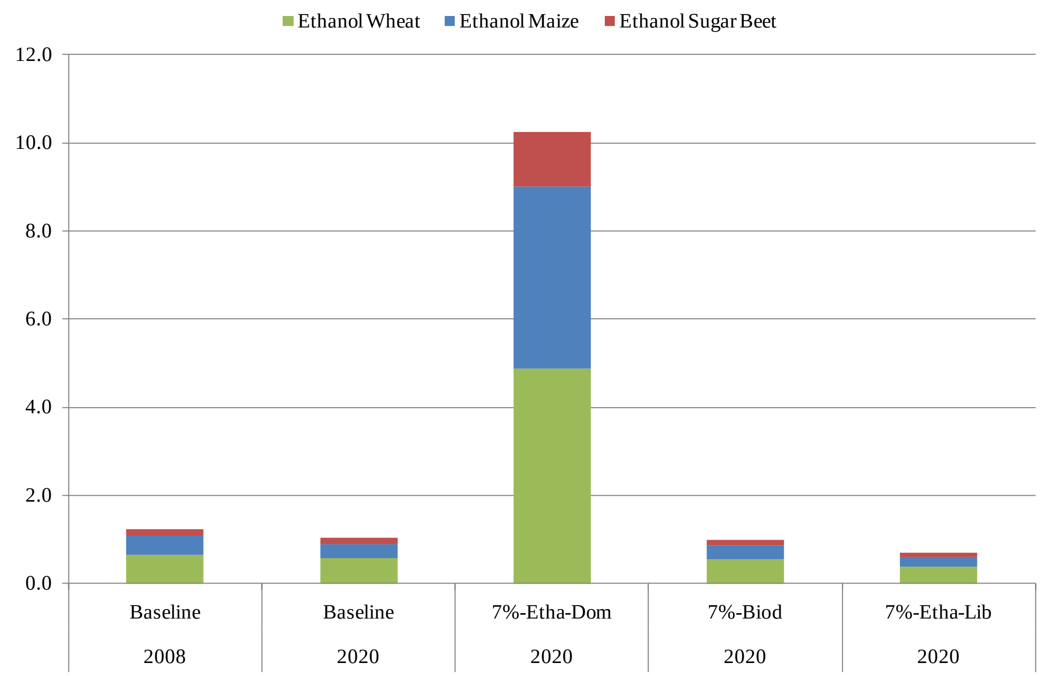

Figure 4. Composition of EU ethanol production for the central scenarios (Mtoe).

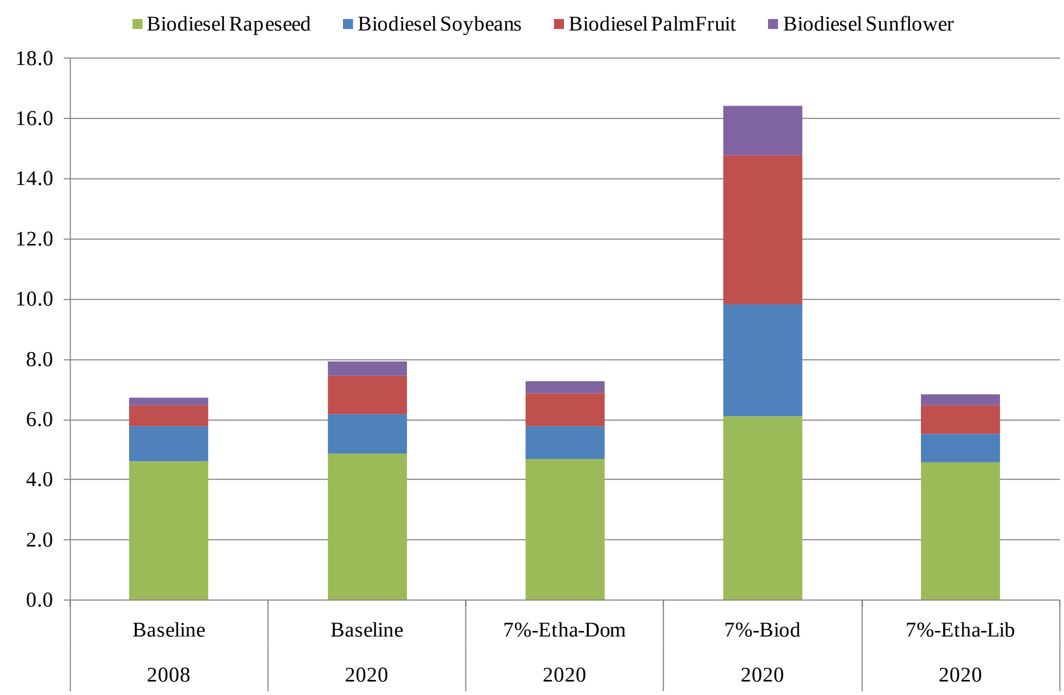

Figure 5. Composition of EU biodiesel production for the central scenarios (Mtoe).

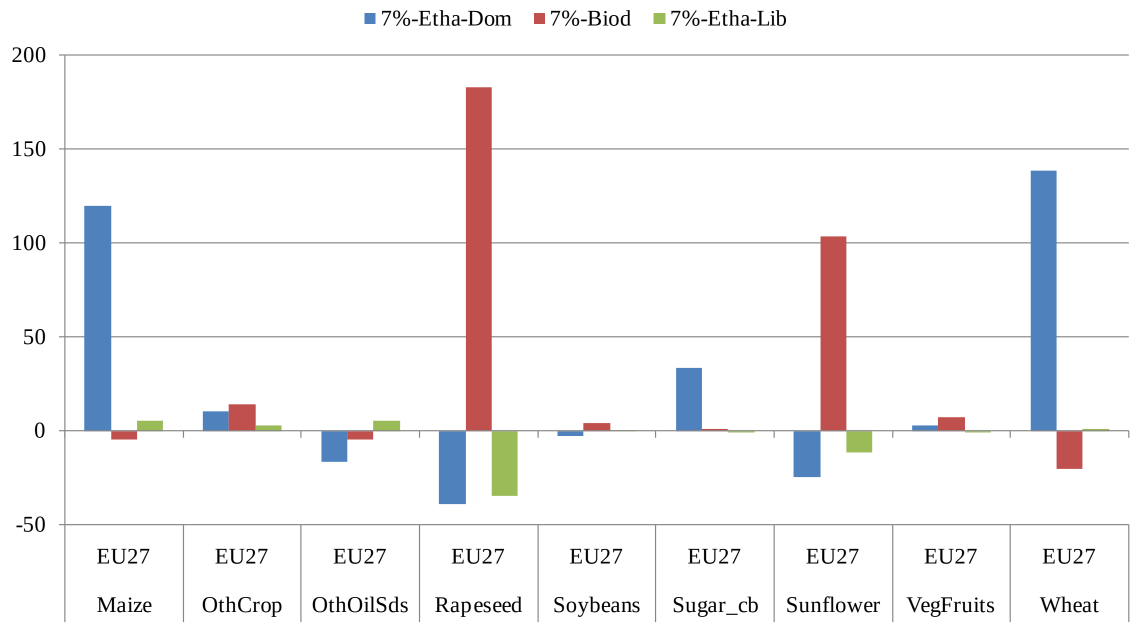

Figure 6. Change in crop occupation in the European Union for different scenarios (1000 ha).

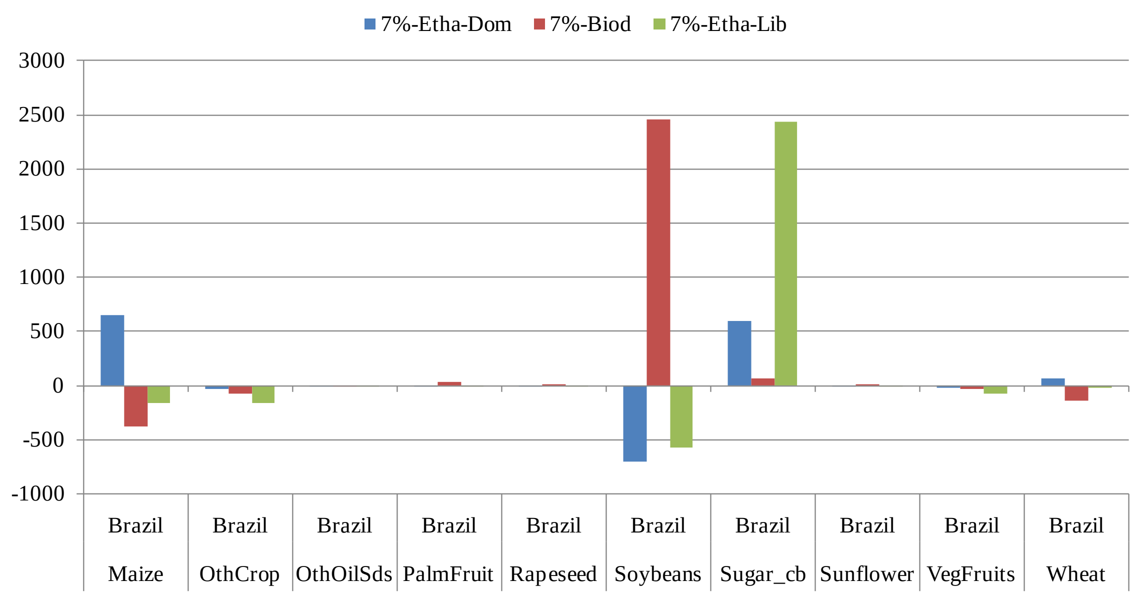

Figure 7. Change in crop occupation in Brazil for different scenarios (1000 ha).

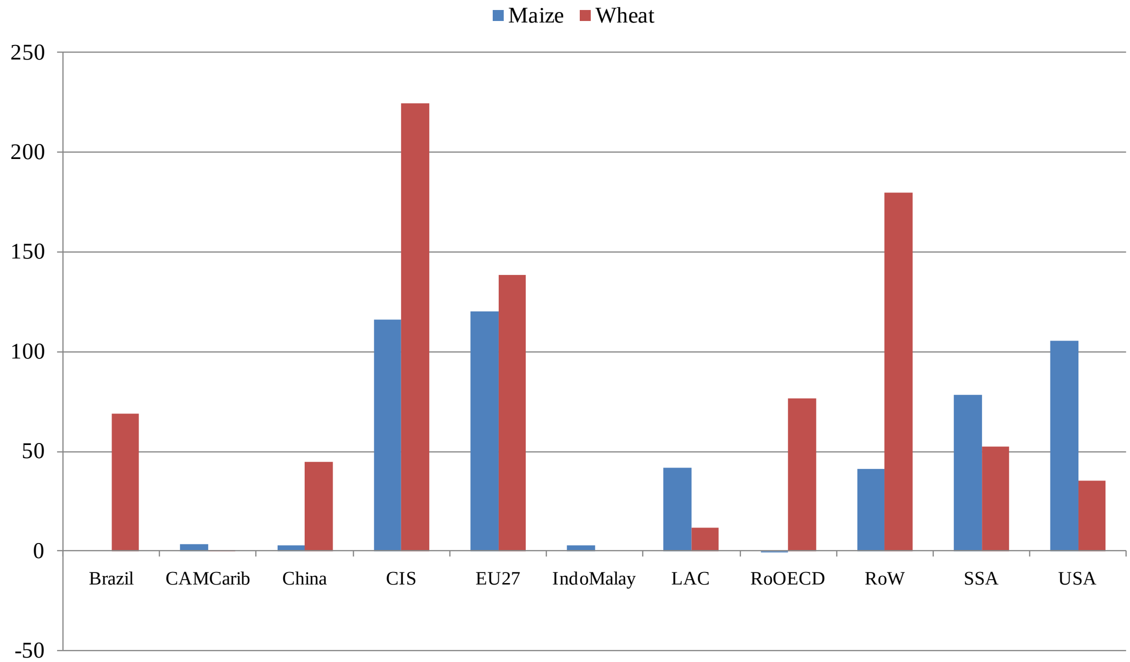

Figure 8. Land use change per ethanol cereal feedstock and per region for the scenario 7%-Etha-Dom (1000 ha).

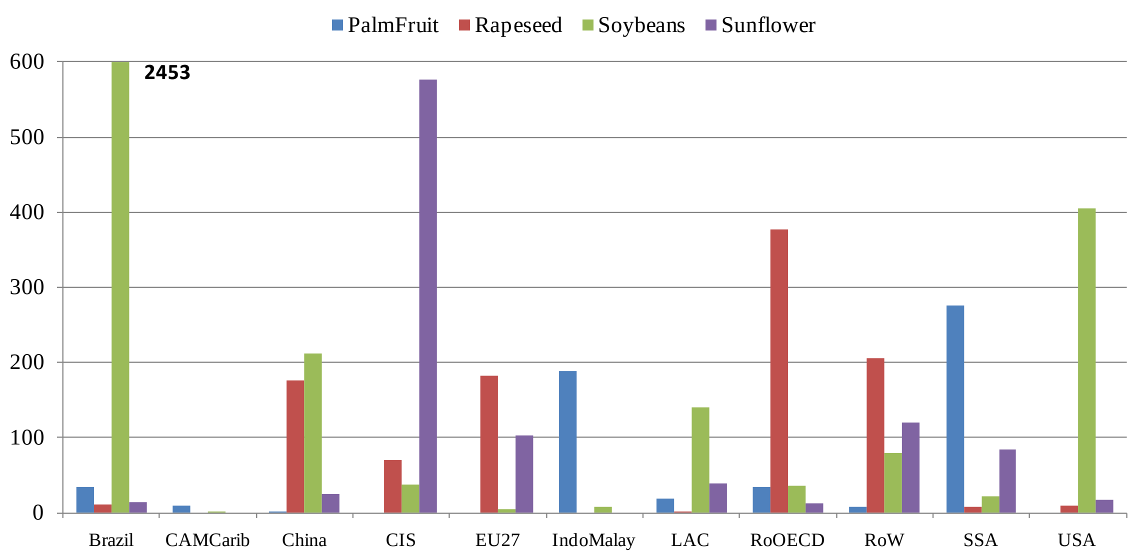

Figure 9. Land use change per oilseed type and per region for the scenario 7%-Biod (1000 ha).

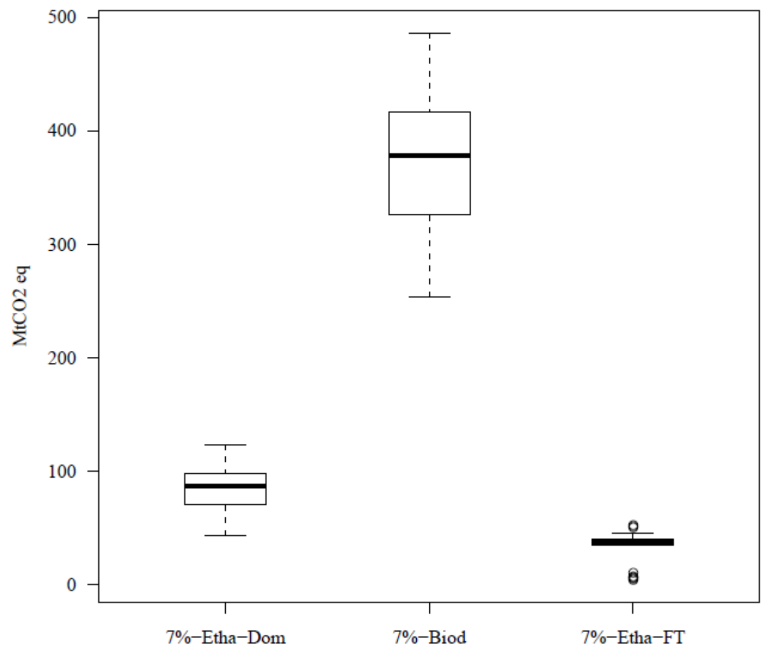

Figure 10. Additional emissions from deforestation on the 2008-2020 period (MtCO2 eq). Thick line indicates median value, box delimits first and third quartile. Dots for values over 1.5 inter quartile distance. Values displayed do not provide information on probabilities.

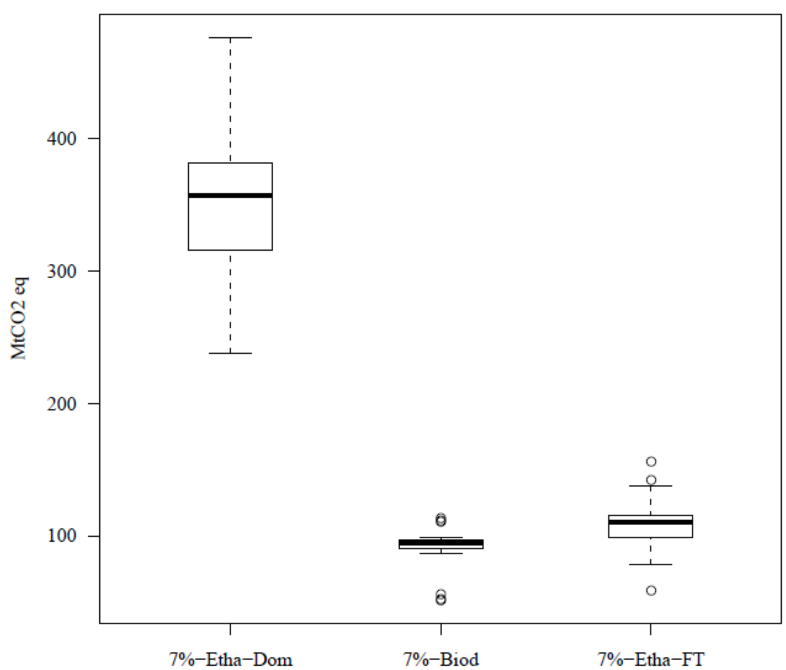

Figure 11. Emissions from cultivation of new land under full tillage assumption on the 2008-2020 period (MtCO2 eq). Thick line indicates median value, box delimits first and third quartile. Dots for values over 1.5 inter quartile distance. Values displayed do not provide information on probabilities.

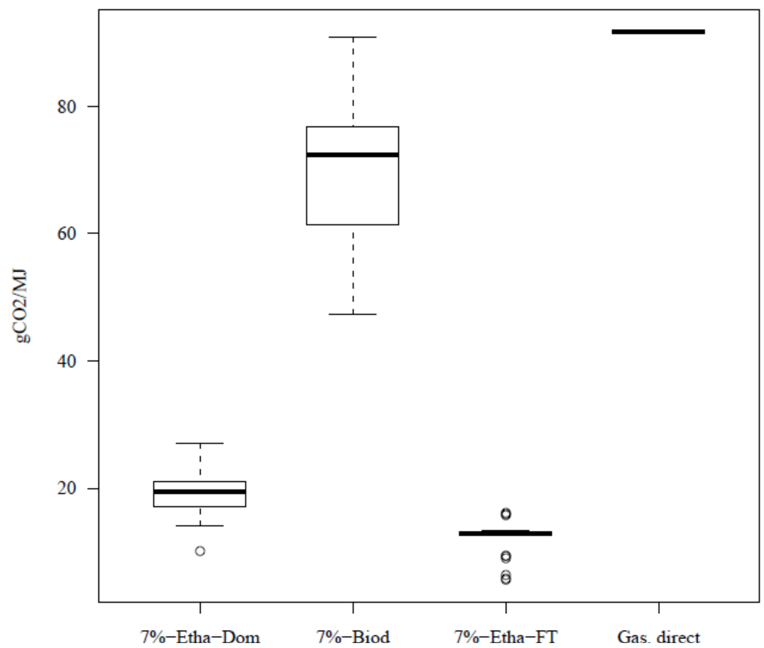

Figure 12. Possible ILUC range on a reference period of 20 years (gCO2/MJ). "Gas. Direct" designates the direct emissions from gasoline cycle. Thick line indicates median values, box delimits first and third quartile. Dots for values over 1.5 inter quartile distance. Values displayed do not provide information on probabilities.

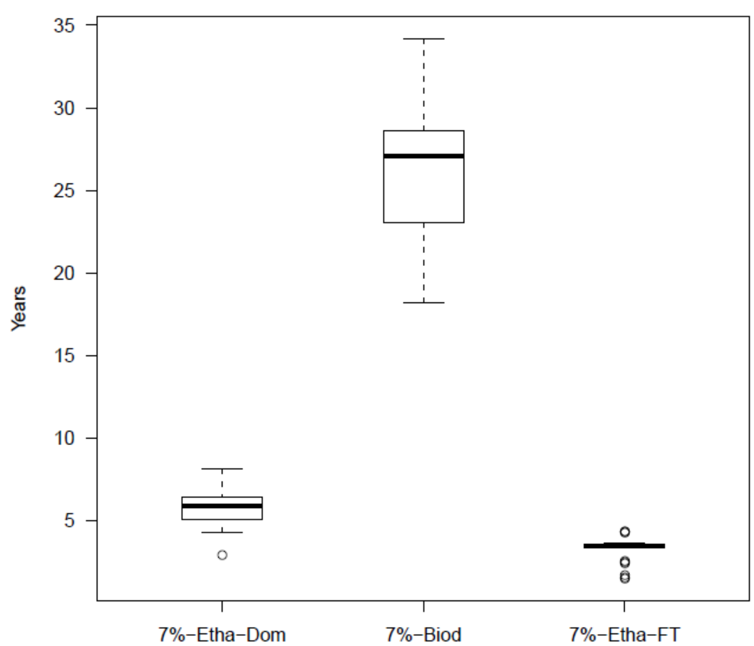

Figure 13. **Carbon payback time for each of the policy options after 2020.** Values over one indicate that one year of cultivation Thick line indicates median value, box delimits first and third quartile. Dots for values over 1.5 inter quartile distance. Values displayed do not provide information on probabilities.