Economic and Environmental Effects of the European Biofuel Policy

By Michele Rasetti, Joaquim B.S. Ferreira Filho**, Adele Finco*, Luis M. Pena-Levano***, Xin Zhao***, Jeffrey Opgrand****

**Università Politecnica delle Marche, Italy;*

***Escola Superior de Agricultura "Luiz de Queiroz" (ESALQ) - Universidade de São Paulo (USP), Brazil;*

****Purdue University, USA.*

Abstract

For many years, biofuels have been considered a cleaner, greener alternative to fossil fuels in order to reduce greenhouse gas (GHG) emissions in the transportation sector. For this reason, in recent years, many European policies has tried to promote biofuels production and consumption. However, some concerns on the actual sustainability of biofuels have arisen. In particular, scientific studies have pointed out that additional emissions from indirect land-use change (ILUC) could cancel out biofuels benefits on climate change.

This paper analyzes the global economic and environmental consequences of an increase in biofuel production, as established by the RE Directive, for the period 2001-2020. The GTAP-BIO general equilibrium model was used for the simulation. The results suggest a total emission of 168 gCO_2/MJ per year over 20 years of biodiesel production, which would mean that the GHG reduction requirements established by the policies could not be fulfilled.

Keywords: European biofuel policy, Biodiesel, GTAP-BIO, Land use change, GHG emissions

JEL codes: D58, Q16, Q58

1. Introduction

Climate change is one of the most discussed topics nowadays. Its irreversible effects can damage the world in several perspectives: health, productivity and infrastructure (The CNA Corporation, 2007; Stern, 2007). This phenomenon is produced by the accumulation of greenhouse gases (GHG) in the atmosphere (Ely, 2008). Approximately 64% of the GHGs is CO_2 (Stern, 2007), whose most noticeable direct consequence is the increase in the global temperature (also known as global warming). GHG is considered to be the biggest global market failure (Ely, 2008) because its negative effects are not reflected in the price of carbon (The White House, 2014).

One of the main sources of carbon emissions is the combustion of fossil fuels. Gasoline is one of the most important factors in the production systems in many countries; however it faces some issues: (1) its price increases over time, (2) has limited availability and (3) is a major source of air pollution. These concerns contributed to the development of a consensus on the need to replace fossil fuels with renewable energy sources. Biofuels appear to offer a cleaner, greener and in general more sustainable alternative to fossil fuels (Ernst & Young, 2011). They are capable of achieving multiple goals such as: (1) security of energy supply, (2) reduction of GHG emissions, and (3) development of business opportunities in the agricultural and rural sectors. Thus, governments around the world are promoting the use of biofuels through different macroeconomic policies.

One region that has put a lot of effort toward the development of this sector is the European Union (Stern, 2007). The European Commission (EC) has promoted public policy for biofuels by implementing a carbon market, subsidies, taxes, and mandatory quotas of biofuels in the overall fuel mix. In the European context, two political decisions have had a fundamental role in the biofuels expansion: the Directive 2003/30/EC and Directive 2009/28/EC (RED). In particular, the RED endorsed different mandatory targets: (1) a 20% share of energy from renewable sources, (2) an overall energy consumption for the European Community and (3) a 10% minimum target to be achieved by all Member States for the share of biofuels in petrol transportation and diesel consumption. All these goals have to be achieved by 2020.

The 20% target imposed by the European Community is translated into individual targets for each Member State. To have a fair policy and adequate allocation of responsibilities, every target takes into account that the Member States have different starting points and potentials[1]. The main purpose of these mandatory national targets is to provide certainty for investors in order to encourage continuous development of technologies. This effort will permit more efficient energy from renewable sources. By

[1] This takes into consideration the existing level of energy from renewable sources and energy mixes.

contrast, with respect to the 10% target, it is adequate to set the same level for each Member State to ensure consistency in the specifications of the fuel transportation and its availability.

Biofuels have to meet specific sustainability criteria in order to support the effort of the Member States to achieve the 10% goal. Among these specifications, the life cycles of biofuel production have to meet some targets in the future with respect to GHG emissions[2]. Biofuels have to be generated from specific raw materials and areas[3]. Furthermore, biofuels also have to meet social standards (Demirbas, 2009). However, recent analyses highlight concerns of biofuels' actual sustainability due to different risks associated with their expansion[4].

In response to these concerns, in October 2012, the EC published a proposal on indirect land use change (iLUC). The proposal aims to start the transition from conventional biofuels to biofuels made from non-food feedstock. This would be done by setting a cap on the 10% target[5]. Then, public support would be phased out for first generation biofuels by 2020. This action will create new installations that could emit at least 60% less in emissions of GHGs compared to fossil fuels. Likewise, this action will establish new iLUC targets to reduce the additional emissions provoked by the change in land use (USDA, 2013).

The objective of the present study is to analyze the global economic and environmental consequences of an increase in biofuel production and the GHG emissions triggered by iLUC, analyzing the parameters established by the RE Directive.

The remainder of this paper is structured as follows: Section 2 describes the methodology used in the study, the results and discussion are in Section 3, and Section 4 draws the conclusions.

2. Methodology

Because biofuels are substitutes for fossil fuels, they can simultaneously affect the economic and environmental patterns of many countries. Two of the most affected sectors are energy and transportation. In order to study widespread socio-economic impacts on bioenergy production, the most

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[2] The GHG emission reduction from the use of biofuels compared to the use of fossil fuel shall be at least 35% for current biofuels and at least 50% from 1 January 2017 onwards (Art. 17(2)). From 1 January 2018, the emission reduction shall be at least 60% for biofuels produced in installations in which the production started on or after 1 January 2017.

[3] It is taken into consideration that some types of land are unfit to grow biofuel crops.

[4] Among these concerns we have: intensive use of resources, monocultures, reduced biodiversity, degradation of soil and air quality, increased water consumption, competition with food production and, the most critical of all, additional GHG emissions caused by land use change (Ajanovic, 2011; Gnansounou, 2011; Finco et al., 2012; Ferreira Filho and Horridge, 2014).

[5] On June 2014 the Energy Council reached a political agreement on the draft directive on indirect land-use change (ILUC) setting a 7% cap on the amount of energy from food or feed-based biofuels that can be counted towards the 10% target for renewable energy in transport and overall 20% renewable energy target.

appropriate approach is the use of Global Computable General Equilibrium (CGE) models (Taheripour et al., 2008; Ferreira Filho and Horridge, 2009; Padella et al., 2012; Finco, 2012). One of the most prominent CGE models is the Global Trade Analysis Program (GTAP) developed by Purdue University, USA.

2.1 Generalities About the Structure of GTAP-BIO Model

For this article, a version of the GTAP model, called GTAP-BIO version 6, was created specifically to analyze the biofuels sector, and represents the world economy in 2001. This model incorporates land use change at a global scale and the potential for intra-fuel substitution. Additionally, it captures the value added-energy input substitution in the production nest[6]. (Burniaux and Truong, 2002; McDougall and Golub, 2007; Birur et al., 2008). This model has been modified by different authors to address questions in regards to biofuel production's effects on the economy and environment (Taheripour and Tyner, 2010; Tyner et al., 2010; Taheripour and Tyner, 2011).

In terms of production, the model implements a nested CES function to handle substitution between inputs. First, the value added-energy inputs are separated from the non-energy intermediate inputs in the production structure (e.g. known as the separability assumption). Then, in the value added-energy subnest, the inputs are divided in its factors of production such as land use, labor, and capital-energy composite, allowing for capital-energy substitution (Figure I - Appendix).

The inter-fuel substitution comprises three sub-nests: (a) electricity vs. non-electricity composites; (b) coal vs. non-coal composites; and (c) between oil, gas, and petroleum products (Lee, 2005).

The database includes 18 regions, 18 Agro Ecological Zones (AEZs) and 4 factor endowments (2 types of labor, capital and natural resources), 21 sectors and 23 produced commodities, including three types of biofuels: ethanol from corn (ethanol1), sugarcane-based ethanol (ethanol2), and oilseed-based biodiesel[7](Table I, Table II and Table III, respectively - Appendix). There are two more produced commodities than the number of sectors because it is assumed that ethanol and biodiesel sectors produce byproducts: DDGS (distillers' dried grains with solubles) and BDBP (oilseed meals) respectively. These byproducts are used in the livestock industry as protein and energy sources, substituting other feed ingredients. However, one of the limitations of using GTAP-BIO is the absence of disaggregated biofuels from different feedstocks, which makes the interpretation of results by region difficult, a necessary detail to understand trade patterns between regions (e.g. European imports of

[6] It allows capital and energy to be either substitutes or complements.
[7] In this model biodiesel is produced directly from oilseeds instead from vegetable oils (as it should).

palm oil from Indonesia and Malaysia). This caveat is due to the aggregation method developed by the creators of the model.

On the other hand, land use has been disaggregated into 18 AEZs, the differentiation was based on: (1) growing period (6 categories of 60-day growing period intervals), depending on temperature, precipitation, soil characteristics and topography; (2) climatic zones, which are subdivided in 3 categories: tropical, temperate and boreal climate. Each AEZ is subdivided in forest cover, pastureland and cropland area. This disaggregation facilitates the analysis of land use change and competition within and across regions to observe easier potential changes in the land use driven by biofuel policies.

2.2 Closure and Shocks

For this experiment, the standard GE closure[8] was used. The goal of the present study is to analyze the global economic and environmental consequences of an increase in biofuel production and the GHG emissions triggered by iLUC, analyzing the parameters established by the RE Directive.

Ethanol obtained from sugar beet and wheat is absent in the model. Since these two raw materials are the main feedstocks for ethanol production in EU, we can only simulate an increase in biodiesel consumption.

The RED mandates that for each Member State the share of renewable energy should represent at least 10% with respect to transport petrol, diesel and electricity consumption by 2020. For that period, EU consumption of fuel transportation is estimated to be 316.3 Mega ton oil equivalent (Mtoe) (DG Energy, 2010). This means that the Member States should contribute jointly in a production of fuel equivalent to 31.6 Mtoe from renewable sources. For the transportation sector, the sources could be from either hydrogen, electricity, biofuels or, the use of electric railroad transportation. According to DG Energy (2010), a scenario with no contribution from electric road transportation or second-generation biofuels would require approximately 27 Mtoe of biofuels from crops. This amount would be equivalent to an 8.6% share of fuel production and energy consumption; thus, the remaining 1.4% share would come from other renewable sources[9].

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[8] The standard closure imposes equilibrium in all the markets, firms earn zero-profits, the regional household can spend only what it is determined in its budget constraint, and global investment equals global savings, i.e. Walras Law holds (in the model, *walraslack* variable is endogenous).

[9] The remaining 1.4% share that is required to be satisfied according to the mandate comes from mainly two extra sources: (1) 0.3% share would be obtained from the waste and residues of first-generation biofuels– which it is considered double counted for the authors– and (2) 0.8% share should be electricity generated for rail transportation from other renewable sources.

In addition, Laborde (2011), Darlington et al. (2013) and Kretschmer et al. (2012) stated in their studies that first-generation biofuels would be 72% from biodiesel and 28% from bioethanol. Based on these assumptions, the share of biodiesel consumption in total transport fuels should reach 6.2% in 2020. In 2001, the biodiesel share was 0.2% for the EU, therefore we would need to consider an additional increase of 6% for 2020.

In GTAP-BIO this additional biodiesel consumption has been achieved by making the renewable fuel share exogenous and the subsidy for biofuel endogenous. To offset the impacts of this subsidy, we assumed an increase in taxes on biofuel consumption (Table IV - Appendix).

3. Results

3.1 Economic Results

3.1.1 Impact on Inputs and Outputs Production

The increase in biodiesel consumption in Europe (EU27) entails higher demand and production of this commodity. According to the results simulation, the increase in biodiesel output caused by the RED mandate is very significant (+3,077%), whereas the production of the other fuels will decrease in 2020. However, fossil fuels will continue to be the main source of fuel in Europe.

In order to increase biodiesel production in EU, more inputs are required. Table 1 shows the change in production per sector and region in 2001-2020. Oilseed being the main feedstock in the model, its production in the EU rises by 79%, diverting intermediates products and endowments from other sectors. There is a reduction of raw materials for all the sectors in EU, especially for coarse grain (-10%), forestry (-6.5%) and other grains (-16.2%), mainly because they compete for land use (Table 1).

It is interesting to note how oilseed production registers relevant increases in all regions, especially for the other European countries outside EU27 (+23.5%), Sub Saharan Africa (+19.8%), Brazil (+26.6%), Canada (23.2%) and United States (+18.0%). That means that the European mandate stimulates production of that feedstock, also outside the European Union. This could happen for two reasons: (1) the domestic production in EU will not be enough to satisfy the required demand given the endowments; (2) attractiveness in price to export biofuel production to the EU, which would induce other regions to export to the EU.

Table 1

The expansion of biodiesel and oilseeds sectors provokes the diminution of output in almost all other sectors in the economy, except energy intensive industries (0.65%) and other industries and services

(0.11%). Table 2 describes the reason for the increase in these two sectors. As we can observe, both sectors intensively use oilseed and biodiesel as intermediates; therefore, the abrupt production of both products increases the availability of inputs that can be used in both industries. This is consistent with a derivation of H-O trade theory[10].

Table 2

3.1.2 Economic Impact on Prices of Inputs and Outputs

As economic theory suggests, simultaneous increase in consumption and production leads to a rise in prices, which is the case for the EU for both products: biodiesel (+58%) and oilseeds (88%). In contrast, supply of other crops devoted to food and feed production and livestock decreases more rapidly than the reduction in total demand[11]. As a consequence, these products become more scarce and their prices go up (Figure 1), especially for coarse grains (+20.8%) and other grains sectors (+16.8%), followed by other agricultural goods (+9.8%) and livestock (+5.1%). These goods are inputs for processing other food and livestock products. Hence, an increase in their prices cause prices in the food sectors to go up, especially in other food products (+2.2%) and processed livestock (+1.5%).

This result is important because it is the driving force of the iLUC. In fact, iLUC is an external effect of the promotion of biofuels which occurs through price effects on the world market (i.e. market mediated effect). As many biofuel feedstocks are cultivated on areas already in use for agricultural products, the area available for food and feed production is reduced. Consequently, this reduction in the supply of food and feed raises world prices, which create incentives to convert areas formerly not used for food production into agricultural land (Delzeit and Lange, 2011). This result occurs because agricultural land is a constrained resource and the demand for food and feed is considered relatively inelastic in terms of changes in price (Kløverpris et al., 2008).

Figure 1

Since we consider biodiesel a substitute for fossil fuels, biofuel production also drives a decrease in fuel and oil products prices (Figure 1). In the rest of the world (e.g. America, Asia, Africa, Oceania), the prices of the goods discussed above follow the same trend although with different intensity between countries.

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[10] Expansion in production will require the increase of the input that is used intensively. The other sectors will suffer a diminution to compensate this variation.

[11] Total demand is described in GTAP-BIO as regional household, which is divided in: private household, firms and government.

3.1.3 Impact on International Trade for the European Union

Since GTAP-BIO assumes a world with an open economy, it is appropriate to look at how the shock changes the international trade market. Table 3 reports the percentage change in exports and imports in EU27 in the 20 year period. We can observe that, even if there is an expansion in the domestic oilseeds production, this increase does not satisfy the domestic consumption. Therefore, it is necessary to import oilseed (132.7%) from other regions of the world in order to reach the mandated level. Because the imports are higher than exports, we have a positive trade balance, leading to an increase in oilseed output in the other regions. Since domestic production of biodiesel increases significantly, there is a negative trade balance with respect to biodiesel finished products obtained from decreases in imports (-99.0%), which is greater than the decrease of exports (-95.2%).

Table 3

3.1.4 Impact on Factor Endowments

Changes in inputs and outputs quantities and prices entails a change in endowments and their use in the different industries in the economy. According to economic theory, firms optimize profits by choosing the best input bundle (endowments and intermediates products).

The GTAP-BIO model assumes weak separability, i.e. we are able to break the firms' cost minimization problem into two steps: (1) the choice of the optimal mix of the endowment commodities, and (2) the choice the optimal mix of valued-added and intermediates. Thus, the specification assumes a Leontief cost function, which permits the model to have a fixed relationship between value-added and intermediates.

As expected, the biodiesel and oilseeds sectors face an increase in the demand of value added and intermediates. Table 4 shows that, for biodiesel, the increase is significantly large (3,075.9%) whereas for oilseeds, there is an increase but it is significantly lower, with similarly small variations of endowment use (around 82%) due to the small elasticity of substitution value assumed by the model.

Inside the nest of the value-added production function, we observed an increase in the demands of labor (skilled and unskilled) and capital energy bundle in both sectors (Table 4). The demand increase in land and natural resources in the biodiesel sector is misleading, since biodiesel does not use any of these endowments.

Table 4

The market clearing condition for fully mobile endowments (i.e. skilled and unskilled labor, and capital) ensures that the increase in endowments demand in these sectors must be balanced by a loss in other sectors. This result can be seen in Figure 2, where all the non-biofuel sectors face a fall in land, labor and capital demand. The only exceptions were in energy intensive industries and other industry and services [12].

Figure 2

Table 5 shows the change in endowments shares in different sectors from 2001 to 2020. In 2001, the labor and capital used in the biodiesel and oilseeds sectors were almost zero compared to the other industries and services sector. In 2020, the use of these endowments will become more intense in biodiesel and oilseeds sectors, but the share increase is relatively small compared to the rest of the economy. This means that, even when the change in capital and labor use in these sectors is important, it is not relevant for the regional economy.

Table 5

A useful measure of the combined impact of changes in production, trade, consumption and policy incentives is given by the social welfare. This is calculated by the theorem of Equivalent Variation (EV). Unfortunately, this version of GTAP-BIO model does not incorporate the welfare decomposition in its components (allocative efficiency, endowments and terms of trade), which is available in the standard GTAP version. All we can say is that the implementation of the RE Directive, represents a loss for the European economy of approximately -44,456 US million dollars.

[12] It is important to mention that percentage changes are used for relative but not absolute comparison, therefore the relatively high increase in labor and capital demand for biodiesel and oilseeds sectors could seem exaggerated compared to the fall of the other sectors; however, the comparison does not take in consideration the comparison of absolute changes in the use of the endowments in each sector, i.e. values in tons.

3.2 *Effects on the Environment*

The increase in biodiesel consumption in EU27 leads to an increase in oilseeds production, which requires more land (+71.7%) at the expense of other food and feed sectors. The most affected sectors are grains, followed by livestock (-12.0%) (see Table 6).

Table 6

As previously mentioned, land endowment is disaggregated into 18 AEZs. It is assumed that area of land located in a specific AEZ is constant, therefore area can be moved only between sectors where the land is more suitable to be used. That is, land is mobile between crop, pasture and forestry sectors within, but not across AEZs. This assumption is due to the fact that that most crops can only grow on lands that is under certain temperature, moisture, soil type, land form, etc. The same concern arises for land used by the livestock and the forestry sectors.

Table 7 displays the changes that occur in area and yield in order to obtain the target mandated by the RED. In terms of output and area, an increase of +79.16% and +82.5% respectively, is required. In absolute values, this represents a rise in harvest area of about 10.5 million of hectares (Mha) over the baseline. The expansion of land devoted to oilseeds reduces the amount of land available for other crops by 5.6 Mha, most of which comes from area previously devoted to other grains and cereal grains. The consequences are twofold: (1) a decline in European crops exports and (2) significant price increase. This fact creates a gap in world supplies of these products, which will need to be partially satisfied by the rest of the world. This means that a simultaneous increase in worldwide production is required (Searchinger et al., 2008).

Table 7

In order to provide the necessary resources to satisfy the new biofuel demand, the EU will have a response in extensive and intensive margin in the agrosystem (Laborde et al., 2011). The intensification is due to a rise in feedstock prices, which incentivizes producers to improve yields with a contribution from investments and factor mobilization, as well as additional non-land inputs such as fertilizers and pesticides to boost production per unit of land. This is the first effect to occur, because farmers initially try to grow more from existing land and avoid the transaction costs associated with extensification.

Nevertheless, the remaining demand of biofuel that needs to be fulfilled beyond the intensification effect is met from new, extensified land. This land is assumed to have lower yields (Rajagopal, 2011). The extensive margin is defined as the change in crop yields when land employed for other uses (e.g. other crops, pasture or forest) is converted into land to grow a new crop because of higher demand for it. There are two contributors to yield extensification in the model: (1) changes in a specific crop yield when it displaces another crop within existing cropland and, (2) changes in productivity when the new crop is expanded to use pasture and/or forest lands. It is very difficult to directly separate the two extensification effects in the simulation because the GTAP model does not keep track of how many non-cropland hectares are converted into a specific crop, but rather finds the net change in total cropland (Hertel et al., 2010).

From table 7, we can observe that the net yield decreases for oilseeds since the negative extensive effect offsets the positive intensification effect; the same trend is observed for the productivity of all other crops, reinforcing the decline in their outputs.

On the other hand, the increase in oilseeds area of 10.5 Mha and the sequential consequent reduction of 5.6 Mha for the other crops, leads to a conversion of other lands into cropland in EU27 equivalent to 4.9 Mha. This land cover conversion from non-cropland to crop cultivation is the main source of iLUC that provokes GHG emissions. This consequently leads to a significant change in land use across regions, due to requirements of crops to be processed as biofuels or directly exported, in order to be transformed elsewhere or to replace other diverted crops.

In terms of AEZs for the European Union, cropland cover increases at the expense of both, pasture and forest land (Figure 3). Cropland conversion affect negatively mainly forest cover, approximately 3.6 Mha of forest will be cleared in 2020. Here it must be considered that GTAP only considers forest cover that is currently accessible and available for conversion (Hertel et al., 2010). These accessible lands are obtained by first estimating the inaccessible forestland and deducting them from total land cover (Sohngen et al., 2008). According to the same authors, the total forestland for Europe in 2005 amounted 192 Mha. In a more recent study prepared by FAO, we observe that this value tends to increase with time. FAO data estimated 195 million of hectares of total forest cover for Europe in 2010, excluding the Russian Federation (FAO, 2010).

Figure 3

In summary, in this simulation based on the RED mandate, the experiment took as baseline the 2001 economy to translate into the global economy for 2020. The imposed shock considered a significant increase in biodiesel production; hence, the forest reversion is small in Europe and it entirely weighs on the regions out of the EU27. Outside Europe, it takes place mainly in Asian countries, especially Russia.

As expected, most of the cropland conversion arises within Europe, but subsequently this change motivates conversion in Africa and Latin America, although the effect was smaller. In the rest of the countries, the net cropland cover increases mainly at the expense of pastureland, except for Canada, whose trend is similar to Europe.

To examine the global warming implications of these land conversions, we used emission factors (EF) for each type of transition by region: (1) forest to crop, (2) pasture to crop and (3) pasture to forest. Figure 4 shows emissions by region and land conversion type. The crop biomass refers to the carbon sequestered from biomass during the plant cycle of growth. The majority of emissions occur in European Union and Canada, mainly caused by deforestation.

Since Eastern Europe and Russia are the regions with the biggest share of forest reversion, the emission savings are the highest and even bigger than the emissions caused by transforming pasture land to cropland. According to the model simulation, the total global emissions due to land cover change amounts to 2,762 teragrams of CO_2.

Figure 4

The European Union uses a 20-year period to sum the emissions due to land conversion and also biofuel production on the converted land. The emissions have to be estimated over an extended period because some emissions are released slowly and their accumulation in the atmosphere can take several decades, while other emissions are released more quickly (Darlington et al., 2013). Using straight line amortization over 20 years of production, we obtain that iLUC emissions are approximately 114 gCO_2/MJ per year for the period of 2001-2020.

4. Conclusions

The increase in biodiesel consumption in the European Union (EU27) due to the mandate imposed by the RE Directive entails higher production of this commodity. As a consequence, there is a diversion of intermediates products and factor endowments from other sectors, in particular for those sectors that compete for land. Thus, rising biodiesel demand in Europe leads to significant increases of oilseed production in the Member States, but also in other regions, especially other European countries that are not part of the EU27, e.g. in Africa and America. Because the mandate requires a very high production of this biofuel, the European biodiesel sector is not self-sufficient, thus this region would need to import biodiesel feedstock from other regions to satisfy the required demand in 2020.

The decrease in supply for food and feed production (which are substituted by fuel crops) drives their output prices to go up. The conflict between food and biofuel sectors is also the driving force for the indirect land use change (iLUC), which is a market-mediated effect, since the price increase creates incentives to convert areas formerly not used for food production (i.e. forests and pasture) into agricultural land. We estimate that most cropland conversion arises within Europe, followed by Africa, Latin America and Canada. The effect on all other regions is smaller. In most of the countries, the net cropland cover increases mainly at the expense of pasture, except for EU27 and Canada where the land conversion comes from deforestation. It is worth noting that there is a considerable effort of forest reversion in East Europe and North Asia.

The process of iLUC triggers an increase in GHG emissions, shown as the iLUC factor. Using a straight line amortization over 20 years of production, as expressed in the European biofuel policy, it amounts to 114 gCO_2/MJ of emission per year. This result is significant, because when summing this value with the default direct emissions reported in the RE Directive (54 gCO_2/MJ[13]), we achieve a total emission value of approximately 168 gCO_2eq/MJ. According to the RED, the value of carbon content for fossil fuels to consider for comparison should be 83.8 gCO_2eq/MJ. This means that the GHG reduction requirement of at least 50% that should be reached in 2018 cannot be fulfilled.

The value of the iLUC factor found in this paper is approximately twice the value for oilseeds (55 gCO_2/MJ) proposed by the iLUC Directive. Despite the gap in the results, both studies suggest that none of the first-generation biodiesel would be able to fulfil the 35%, let alone the 50%, reduction requirement (Ahlgren and Di Lucia, 2014).

However, the difference between the results of the two studies is significant and must be analyzed. Looking at the literature review, variations in estimated GHG emissions from biofuel-induced LUC are driven by the differences in scenarios assessed, the assumptions that were made, distinct definitions (e.g. LUC), subjective selection of reference scenarios against which (marginal) LUC quantified, and disparities in data availability and quality (Warner et al., 2013). Therefore, comparison between studies would not be optimal. One of the most important reasons for the existing gap in the results between the two studies (apart from the differences in methodologies and assumptions) is the time span considered. This article studies the effect of the expansion of the biofuel sector in EU due to the mandates from 2001 to 2020, while the study of Laborde (whose results were included in the iLUC Directive) observed the same phenomenon starting from 2008.

The high variability of iLUC results in the literature suggests that the measurement of iLUC is still highly uncertain (Khanna et al., 2011). There is a conflict between the demand from EU policymakers for exact, highly specific values and the capacity of the current models to supply results with that level of precision. This suggests that a methodology capable of evaluating this variable has not been developed.

[13] Average of default direct emissions of rapeseed, sunflower, soybean and palm oil biodiesel.

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List of Tables and Figures:

Table 1. Percentage change of production per sector and region in the period 2001-2020

	Coarse Grain	Other grains	Oilseeds	Sugarcane	Other Ag. Products	Livestock	Forestry
United States	-1.1	-0.3	18.0	0.1	0.1	0.0	-0.2
Canada	-0.8	-0.2	23.2	-1.1	-0.8	-0.9	-0.9
European Union 27	-10.0	-16.2	79.2	-4.6	-5.5	-2.1	-6.5
Brazil	-4.4	-10.4	26.6	-3.0	-3.7	-1.1	-3.1
Japan	2.6	1.7	9.5	0.1	0.1	0.3	0.2
China, Hong Kong	0.7	0.4	9.2	0.1	0.0	-0.2	1.2
India	-0.1	1.1	1.8	0.0	0.3	-0.1	0.5
Latin American Energy Exporters	0.2	2.0	16.5	-0.3	0.3	-0.2	-0.2
Rest of Latin America and Caribbe	-0.1	0.8	18.4	0.0	0.6	-0.3	1.3
EE & FSU Energy Exporters	0.7	1.0	23.5	0.1	0.1	0.2	2.6
Rest of Europe	0.8	2.9	15.1	1.1	1.2	-0.3	1.4
Middle Eastern / N. Africa Energy Exporters	2.1	3.2	14.3	0.4	0.4	0.1	-0.4
Sub Saharan Africa Energy Exporters	0.1	3.0	19.8	0.8	1.9	0.2	0.5
Rest of North Africa & S.S.A.	0.2	3.7	21.4	1.2	2.4	0.3	0.1
South Asian Energy Exporters	0.1	0.6	4.3	0.3	0.4	0.7	1.4
Rest of High Income Asia	1.6	0.6	8.6	0.2	0.1	-0.3	1.4
Rest of Southeast & South Asia	0.1	0.9	4.8	0.2	0.4	0.1	0.5
Oceania countries	1.0	1.0	25.9	1.0	1.2	1.0	0.6

Table 2: Intermediates use intensity in oilseeds and biodiesel industries in 2020

Sectors	Oilseeds	Biodiesel
Energy intensive industries	20.6%	13.4%
Other industry and services	60.0%	1.4%

Figure 1: Percentage change in prices in EU27 by commodity

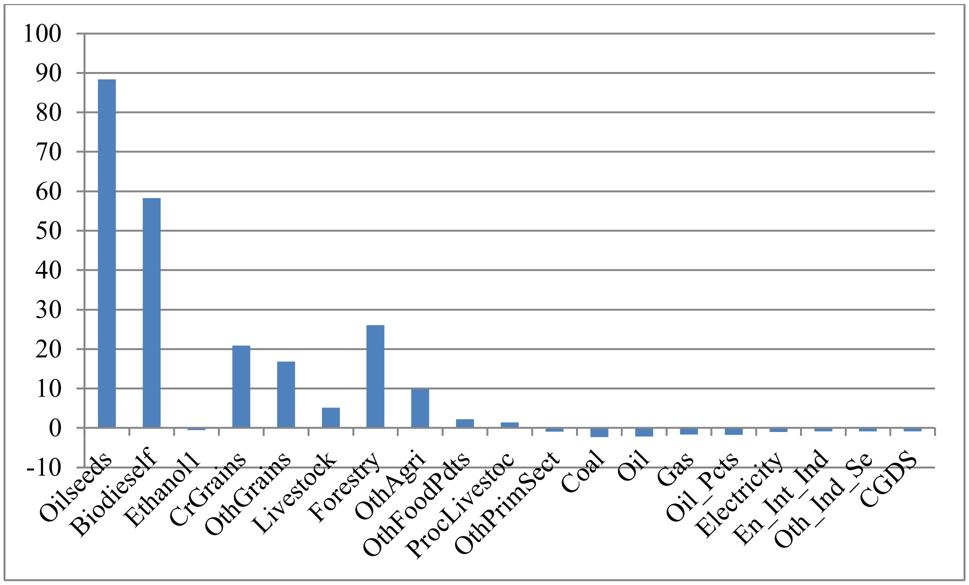


Table 3: Impacts on trade - exports and imports in EU27 (percentage change)

	Imports	Exports
Cereal grains	-1.24	-14.05
Paddy and Wheat	7.17	-33.88
Oil seeds	132.70	-72.53
Sugar cane, sugar beet	32.33	-13.28
Cattle, Animal products, Milk, Wool	1.65	-5.47
Forestry	15.76	-24.75
Ethanol2 (sugarcane based)	-17.62	4.49
OthFoodPdts	-1.47	-3.16
Meat, Dairy products	-0.49	-2.27
Other agriculture goods	0.99	-11.84
Other Primary Fishery & Mining	-0.23	0.13
Coal	-3.63	0.90
Crude oil	-3.06	0.77
Natural gas	-2.97	2.01
Petroleum, coal products	-3.06	-1.81
Electricity	-2.94	-1.56
Energy intensive Industries	0.01	0.73
Other industry and services	-0.25	0.79
Ethanol produced from corn	-13.15	-13.15
Dried distillers grains with solubles	119.52	-62.54
Biodiesel produced from oilseeds	-98.96	-95.26
Biodiesel byproducts (oilseeds meals)	2,344.65	154.36

Table 4: Endowments and capital-energy composite demand in the biodiesel and oilseeds sectors in EU27 (in percentage change)

	Biodiesel	Oilseeds
Land	39.1	71.7
Unskilled labor	3,078.1	81.9
Skilled labor	3,074.5	81.9
Natural Resources	0.0	0.3
Capital Energy	3,075.9	81.9

Figure 2: Endowments and capital-energy composite demand change in other sectors (percent change)

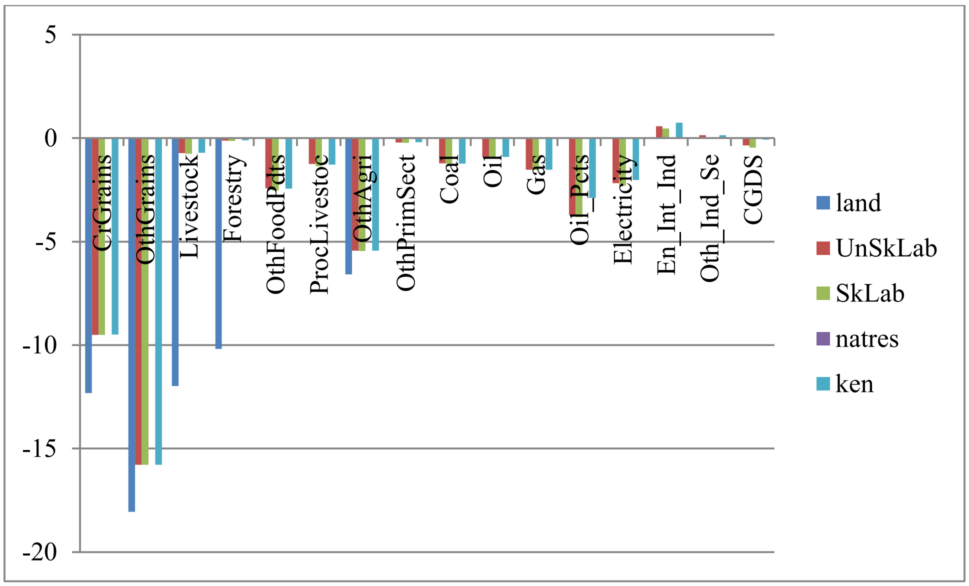


Table 5: Labor and capital use intensity in different sectors in 2001 and 2020 (in percentage)

	2001			2020		
	Oilseeds	Biodiesel	Oth_Ind_Se	Oilseeds	Biodiesel	Oth_Ind_Se
UnSkLab	0.1	<0.1	86.2	0.2	<0.1	86.3
SkLab	<0.1	<0.1	92.2	<0.1	<0.1	92.2
Capital	<0.1	<0.1	87.8	<0.1	<0.1	87.9

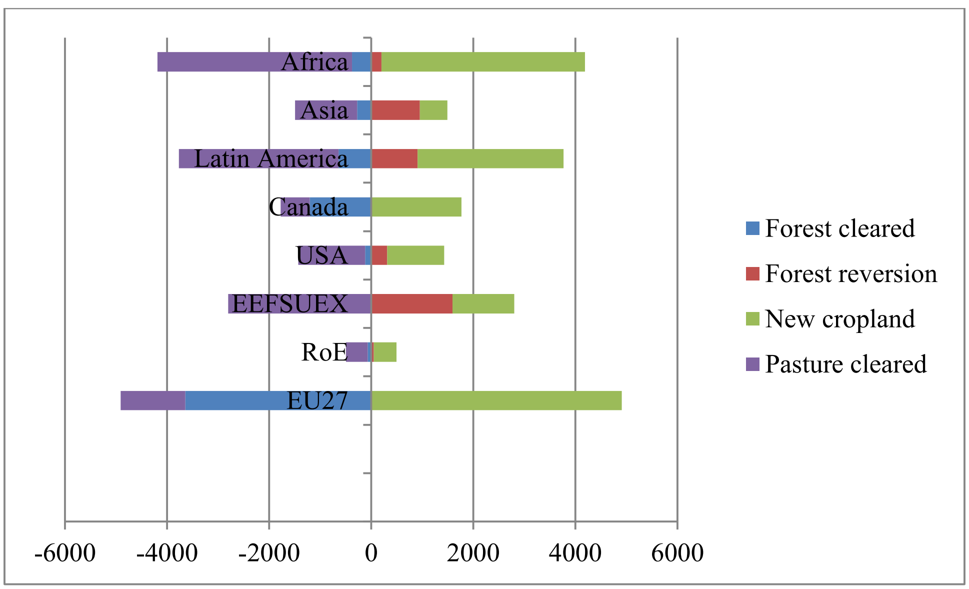
Table 6: Percentage change in demand of land in different sectors in EU27

Coarse Grains	-12.3
Other Grains	-18.1
Oilseeds	71.7
Livestock	-12.0
Pastureland	-10.2
Other Agricultural products	-6.6

Table 7. Land use change[14] (based on harvested data), by crop, for the European Union

	Coarse grains	Oilseeds	Other Grains	Other Ag. Products
DECOMPOSITION OF OUTPUT CHANGES, %				
Output	-10.0	79.2	-16.2	-5.5
Area	-6.2	82.5	-12.4	0.3
Yield	-3.7	-1.7	-4.4	-5.6
DECOMPOSITION OF YIELD CHANGES, %				
Intensive margin	2.6	4.4	2.3	1.1
Extensive margin	-6.3	-5.8	-6.5	-6.6
Harvested area (Mha)	**-2.2**	**10.5**	**-3.1**	**-0.3**

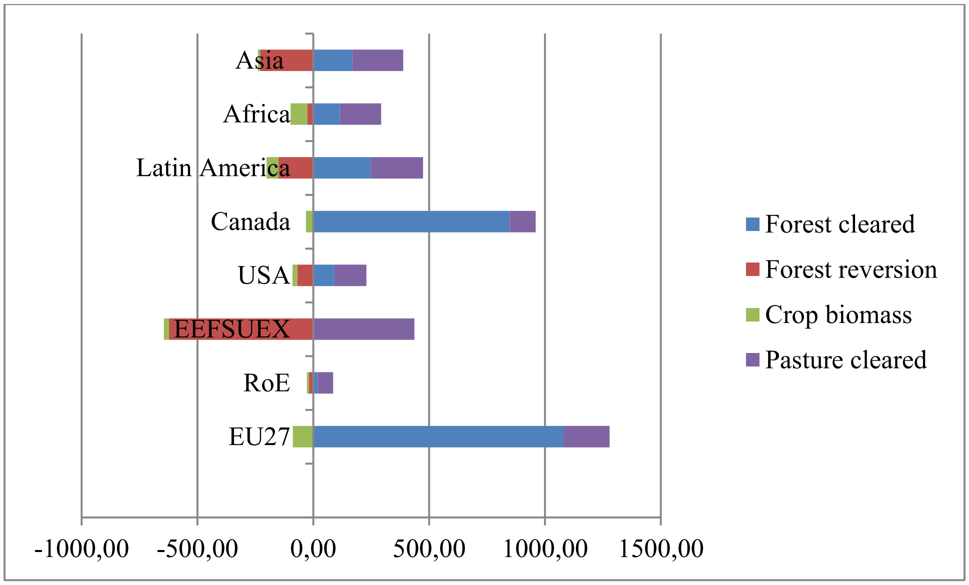
Figure 3: Global land cover changes[15], 1000 ha



[14] The term "land use" refers to management within a land-cover type, such as forest or cropland; land use is based on harvested area. For example, the harvest of wood does not change the designation of the land as forest although the land may be temporarily treeless (Houghton et al., 2012).

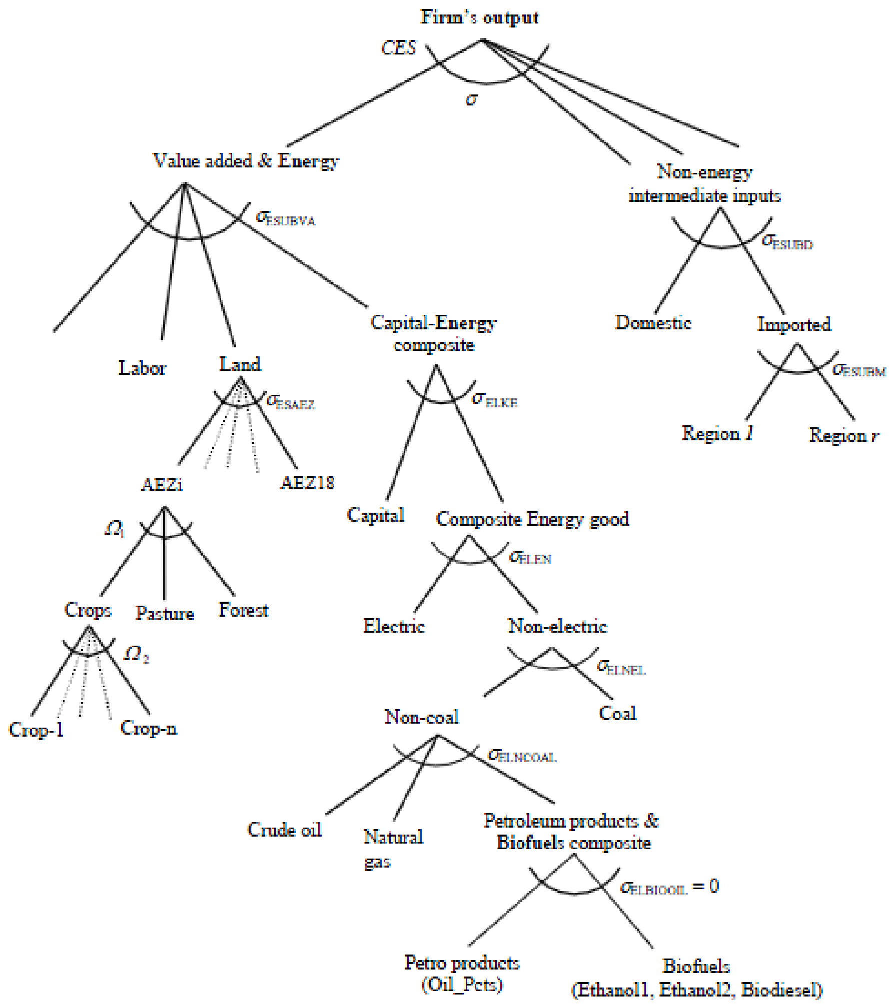
[15] "Land-cover change", in contrast to land use change, refers to the conversion of one cover type to another, for example, the conversion of forest to cropland (Houghton et al., 2012).

Figure 4: Global greenhouse gas emissions, teragrams of CO_2



APPENDIX

Figure I: Production tree in GTAP-BIO



Source: Tyner et al. 2010[16]

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[16] Even if it is not graphically reported in the Figure, each intermediate in the Capital-Energy composite and in the Non-energy inputs is subject to the Armington approach.

Table I: Regions and their members

Region	Description	Corresponding countries in GTAP
USA	United States	usa
CAN	Canada	can
EU27	European Union 27	aut bel dnk fin fra deu gbr grc irl ita lux nld prt esp swe bgr cyp cze hun mlt pol rom svk svn est lva ltu
BRAZIL	Brazil	bra
JAPAN	Japan	jpn
CHIHKG	China, Hong Kong	chn hkg
INDIA	India	ind
LAEEX	Latin American Energy Exporters	mex col ven arg
RoLAC	Rest of Latin America+Caribbean	xna per xap chl ury xsm xca xfa xcb
EEFSUEX	EE & FSU Energy Exp	xef rus xsu
RoE	Rest of Europe	che xer alb hrv tur
MEASTNAEX	Middle Eastern N Africa E Exp	xme tun xnf bwa
SSAEX	Sub Saharan Energy Exporters	xsc mwi moz tza zwe xsd mdg uga xss
RoAFR	Rest of North Africa & SSA	mar zaf zmb
SASIAEEX	South Asian Energy Exporters	idn mys vnm xse
RoHIA	Rest of High Income Asia	kor twn
RoASIA	Rest of Southeast & South Asia	xea phl sgp tha bgd lka xsa
Oceania	Oceania countries	aus nzl xoc

Source: Birur et al., 2008

Table II: Endowment commodities (ENDW_COMM)

Name in GTAP BIO	Description
AEZ1-18	Agro Ecological Zones 1-18
UnSkLab	Unskilled labor
SkLab	Skilled labor
Capital	Capital
NatRes	Natural Resources

Table III: List of industries and commodities

Industry name	Commodity name	Description	Corresponding name in the GTAP BIO
CrGrains	CrGrains	Cereal grains	Gro
OthGrains	OthGrains	Paddy and Wheat	pdr wht
Oilseeds	Oilseeds	Oil seeds	Osd
Sugarcane	Sugarcane	Sugar cane, sugar beet	c_b
Livestock	Livestock	Cattle, Animal pdts, Milk, Wool	ctl oap rmk wol
Forestry	Forestry	Forestry	Frs
EthanolC	Ethanol1	Ethanol produced from corn	eth1
	DDGS	Dried distillers grains with solubles	
Ethanol2	Ethanol2	Ethanol2 (sugarcane based)	eth2
Biodiesel	Biodiesel	Biodiesel produced from oilseeds	Biod
	BDBP	Biodiesel byproducts (oilseeds meals)	
OthFoodPdts	OthFoodPdts	OthFoodPdts	vol ofd
ProcLivestoc	ProcLivestoc	Meat, Dairy products	cmt omt mil
OthAgri	OthAgri	other agriculture goods	v_f pfb ocr pcr sgr b_t
OthPrimSect	OthPrimSect	Other Primary Fishery & Mining	fsh omn
Coal	Coal	Coal	Coa
Oil	Oil	Crude oil	Oil
Gas	Gas	Natural gas	gas gdt
Oil_pcts	Oil_pcts	Petroleum, coal products	p_c
Electricity	Electricity	Electricity	Ely
En_Int_Ind	En_Int_Ind	Energy intensive Industries	crpn i_s nfm
Oth_Ind_Se	Oth_Ind_Se	Other industry and services	tex wap lea lum ppp nmm fmp mvh otn ele ome omf wtr cns trd otp wtp atp cmn ofi isr obs ros osg dwe

Table IV: Shock and swap statements[17]

swap c_SHRRENEWi("biodieself",”EU27”) = tpd("biodieself","EU27")	-
swap del_taxrpcbio("EU27") = tpbio("EU27")	-
shock c_SHRRENEWi("biodieself","EU27")	0.06

[17] Where: tpd=shift in tax on private domestic consumption;
tpbio=tax to implement renewable fuel (RFSS);
c_SHRRENEW=share of renewables in total liquid fuels;
del_taxrpcbio= change in ratio cons tax on bio oil to Income;
biodieself = Biodiesel consumption;
EU27 = The European Union (including the 27 Member States).