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# Interaction of biofuel, food security, indirect land use change and greenhouse mitigation policies in the European Union

By

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## Abstract

The European Union is putting a lot of effort in mitigating climate change effects and lessen the dependence of fossil fuels. Several policies are being proposed in the Renewable Energy Directives (RED), such as increasing the share of renewable sources in fuel mix, specific increases in fuel production? and anti-dumping strategies.  However, these policies raise concerns with respect to competition with food production, and indirect increases GHG emissions caused by land use change. Our study evaluates the RED policies together with additional climate mitigation policies using a computable general equilibrium modeling. Our results suggest that, for the case of the European Union (EU), an increase in biofuel production does not represent a threat in food security. In addition, we found that the land use change in the EU are modest compared to previous studies in developing regions. Our findings illustrate how the imposition of a regime can vary depending on the economic development of a region.



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

JEL codes: D58, Q16, Q58

Climate change has become a global issue due to its impacts on many economic and environmental systems (Stern, 2007; The CNA Corporation, 2007). Three industries are recognized as main contributors of GHG emissions: agriculture (including land use change), power generation, and transportation (IPCC-WGIII, 2014b; World Resources Institute, 2006). Hence, many mitigation methods are being investigated and implemented in these sectors to lessen climate change effects. Nevertheless, gasoline is still one of the key inputs in the production systems of many countries. This brings some concerns for the future because: (1) its price fluctuates over time, (2) it is a major source of air pollution, and (3) its availability depends on the country providers. These issues contributed to the development of a consensus on the need to replace fossil fuels with renewable energy sources (Ernst & Young, 2011).

Biofuels appear to offer a cleaner, greener and in general more sustainable alternative to fossil fuels. They are capable of achieving multiple goals such as: (1) improving the security of energy supply, (2) reducing GHG emissions, and (3) developing of business opportunities in the agricultural and rural sectors. Thus, governments around the world are promoting the use of biofuels through different macroeconomic policies (Ernst & Young, 2011).

However, recent analyses highlight concerns of biofuels' actual sustainability due to different risks associated with their expansion. Among these issues are: intensive use of natural resources, reduction in biodiversity, degradation of soil and air quality, increase in water consumption, food production competition, and GHG emissions. The last two most are the most critical of all: (1) competition with food production which makes biofuels a potential threat for food security and, (2) additional GHG emissions caused by land use change which is known as indirect land use change (iLUC) (Ajanovic, 2011; Gnansounou, 2011). Thus, biofuels could indirectly increase GHG emissions, which is contradictory to their main purpose: serve as an environmental friendly substitute of fossil fuels.

One region that has put a lot of effort towards the development of the biofuel industry 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 Renewable Energy Directives (RED) 2003/30/EC and 2009/28/EC. In addition, recent policies intend to curb biofuel imports to motivate domestic production such as the Regulation 490/2013 (Escobar et al., 2014).

The EU has also attempted to address the concerns with respect to iLUC by publishing "the iLUC proposal" in which the EU aimed to start the transition from conventional biofuels to second generation biofuels. Nevertheless, the calculation of the iLUC factor (ton of carbon emitted by MJ of biofuel) possesses a high variability according to the parameters and model structure of the models (Khanna et al., 2011; Plevin et al., 2015). Thus, in order to make a stronger statement with respect to the iLUC from biofuels that could help EU policymakers to take better decisions regarding this topic, it is required to have more studies that use different assumptions and provides a similar direction of results. Additionally, recent analyses highlight concerns of biofuels' impact on food security due to its competition with land for food (Ajanovic, 2011; Gnansounou, 2011).

For these reasons, we analyzed the economic and environmental consequences of an increase in biofuel production mandated by the RE directive and its impacts in both aspects: indirect land use change and food security. Thus, our study aims to improve our understanding of the interplay between climate change, biofuel, and food security.

In addition, in order to provide a wider perspective with respect to the mitigation of climate change, we also consider the contribution of (i) a carbon tax regime (in $/tCO2e) and (ii) forest carbon sequestration (FCS) as an alternative to reduce GHG emissions which is encouraged through a sequestration subsidy. Thus, this is the first study to our knowledge in analyzing both aspects (iLUC and food security) of biofuel production in a developed region (i.e., European Union) including simultaneously policy regimes that promote other mitigation alternatives to decrease GHGs. Thus, the research intends to observe (i) the emission reduction obtained under the RED mandate, (ii) the economic consequences in food security, trade and welfare of biofuels, (iii) the contribution of policies such as carbon taxes and subsidies on sequestration regimes that could help to reach the goal of the RED.

In order to meet our research objectives, we use an extended version of a well-known computable general equilibrium (CGE) model, the Global Trade Analysis Project (GTAP) model, entitled GTAP-BIO-FCS. This model is able to evaluate different policy regimes and mitigating methods such as biofuel production and forest carbon sequestration at a global scale and represents the global economy in 2004. We implement increases in biofuel production for the time horizon 2004-2020 according to the RED target and we analyze the impacts on food security, consumption, production, land use change, and welfare for the EU and also for the rest of the world (ROW). We use CGE modeling as our main framework because 1) its extensively use in policy analysis including climate change debates and 2) it is considered as an adequate representation of the real world (Bewley, 2009).

## Biofuel impacts on indirect land use and food security

The literature has expressed concerns of biofuels' actual sustainability due to different risks associated with their expansion, especially related to indirect land use change (iLUC) (Ajanovic, 2011; Gnansounou, 2011; Witcover et al., 2013). With respect to food security, the unintended consequences of biofuels are twofold: decrease of food supply and increase in food prices. Previous research suggests that there are tradeoffs between food security and mitigation of climate change, bringing negative effects for the poor due to the high share of income spent on food (Reilly et al. 2012). A recent paper, written by Cororaton and Timilsina (2012) analyzed the relationship between biofuel and poverty focusing primarily in emerging regions. They found mixed impacts: for regions such as South Asia and Sub-Saharan Africa, there was an increase in poverty due to the excessive increase in food prices. In contrast, Latin America and East Asia faced a reduction in poverty because the negative effect in prices was partially offset by the increase in the unskilled labor returns, which is an intensive source in these economies (Cororaton and Timilsina, 2012; Hussein et al., 2013).

In terms of iLUC, there is still limited research on the effectiveness of the first-generation biofuel to fulfill the reduction target. The most prominent study that analyzes the biofuel-induced LUC is Laborde and Valin (2012), whose results (which spanned between 2008 and 2020) were included in the iLUC Directive from the EC. His estimates on the EU biofuel policy were based on the IFPRI's MIRAGE general equilibrium model sensitivity analysis for its parameters. His results stated that none of the first-generation biofuel could fulfil the 35% reduction requirement. However, they held fixed the parameters for the carbon accounting component (Plevin et al., 2015). Likewise, different studies show that iLUC factor possesses a high variability depending on the assumptions made and the model framework (Khanna et al., 2011). Thus, this suggests the need for a more comprehensive study which is able to provide robust estimates for iLUC resulted from biofuel production and also its impacts on food security to understand better the spillover effects of the EU's policy.

## The European Commission policy on biofuels

The EC has promoted public policy for biofuels through different directives, among them: the Renewable Energy Directives (RED) 2003/30/EC, 2009/28/EC. These two directives endorse different mandatory targets to be achieved by 2020:

(1) 20% share of energy consumption from renewable sources for the EU as a whole. In order 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.

(2) A 10% minimum target share of biofuels in petrol transportation and diesel consumption set at the same level by all Member States. This goal is made to ensure consistency in the specifications of the fuel transportation and its availability.

In addition, the EU seeks to promote the domestic production of biofuels. Thus, new policies such as the regulations 490/2013 and 444/2011 which implements anti-dumping strategies to decrease imports from the rest of the world, particularly from Malaysia & Indonesia, South America (excluding Brazil) and United States.

In terms of addressing iLUC from biofuel production, the EC published in 2012 the "iLUC proposal" which aimed to start the transition from conventional biofuels to second generation biofuels (i.e., made from non-food feedstock). This would be done by setting a cap on the 10% target. Then, public support would be phased out for first generation biofuels by 2020 (USDA, 2013). The RED also

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

specifies (i.e., Article 17(2)) that at least 35% GHG emission reduction should come from biofuels for the first decade and before 2018 (Demirbas, 2009).

In our study, we evaluate the contribution of biofuels in the RED target. We first consider that 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. We then evaluate the anti-dumping policies to encourage domestic production. Finally, we implemented two additional policies: a tax on emissions and a carbon tax with an equivalent subsidy on forest carbon sequestration to provide further declines in emission reduction of GHGs.

We simulate our policies using a comparative static framework in our CGE model in order to isolate the effect of biofuel expansion. Posteriorly, we evaluate the land use change and GHG emissions impacts of the mandate to analyze the iLUC proposal directive.

## Methodology

Because biofuels are substitutes for fossil fuels, they can simultaneously affect the economic and environmental patterns. Two of the most affected sectors are energy and transportation. In order to study widespread socio-economic impacts on bioenergy production, the most appropriate approach is the use of Global CGE models (Taheripour et al., 2007).

For our task, we use the static comparative CGE model called GTAP-BIO-FCS model, developed by Pena-Levano et al. (2016), which is an extended version of the well-known GTAP model. This model is suitable for the analysis of climate change mitigation methods such as biofuel and FCS at a global scale. It is also able to evaluate policy regimes such as carbon taxes and sequestration subsidies and provides useful tools such as welfare decomposition (which is useful in the analysis of sources of welfare variation) and includes both, $CO_2$ and non-$CO_2$ emissions (see Pena-Levano et al.

(2016) for more details). Thus, we use GTAP-BIO-FCS for the simulation of our RED policy in order to obtain consequences in the consumption and production behavior, terms of trade, GDP, welfare, prices, and land use changes. We then implement specific results into the AEZ-EF model to calculate the iLUC factor.

*Generalities about the Structure of GTAP-BIO-FCS Model*

The GTAP-BIO-FCS model represents the world economy in 2004. This extended GTAP version utilizes the GTAP-BIO and GTAP Land Use Database version 7. It is divided in 19 regions, 43 industries (including agricultural, manufacturing, and service sectors), 48 tradable commodities (including biofuel byproducts) and it has 25 endowments (18 agro-ecological zones [AEZs], capital, skilled and unskilled labor, natural resources, and 3 sources of emissions).

The model traces production, consumption, and trade of good and services at the global scale by region and their corresponding emissions. Thus, it incorporates $CO_2$ and non-$CO_2$ GHG emissions by commodity, sector and region. It also provides carbon stock from forest land at the AEZ level and carbon stock from forest biomass.

Its land structure also takes into consideration that the opportunity cost from converting forest cover to cropland is different from moving land from pasture to agriculture. It also allows substitution between capital and energy as an adoption tool and takes into account FCS and biofuel to mitigate emissions.

Ethanol can be produced by sorghum, corn or other coarse grains whereas biodiesel can be generated from rapeseed, soybean, palm, and other oilseeds. Likewise, the production and consumption structures allow for potential inter-fuel substitution between different energy sources, including petroleum products with biofuel composites, in the energy sub-nest. The model also provides ethanol and biodiesel byproducts which are used as protein source for livestock (“FEED” sub-nest) and as inputs in the vegetable and oil industries (“VOL” sub-nest) (fig. 1).

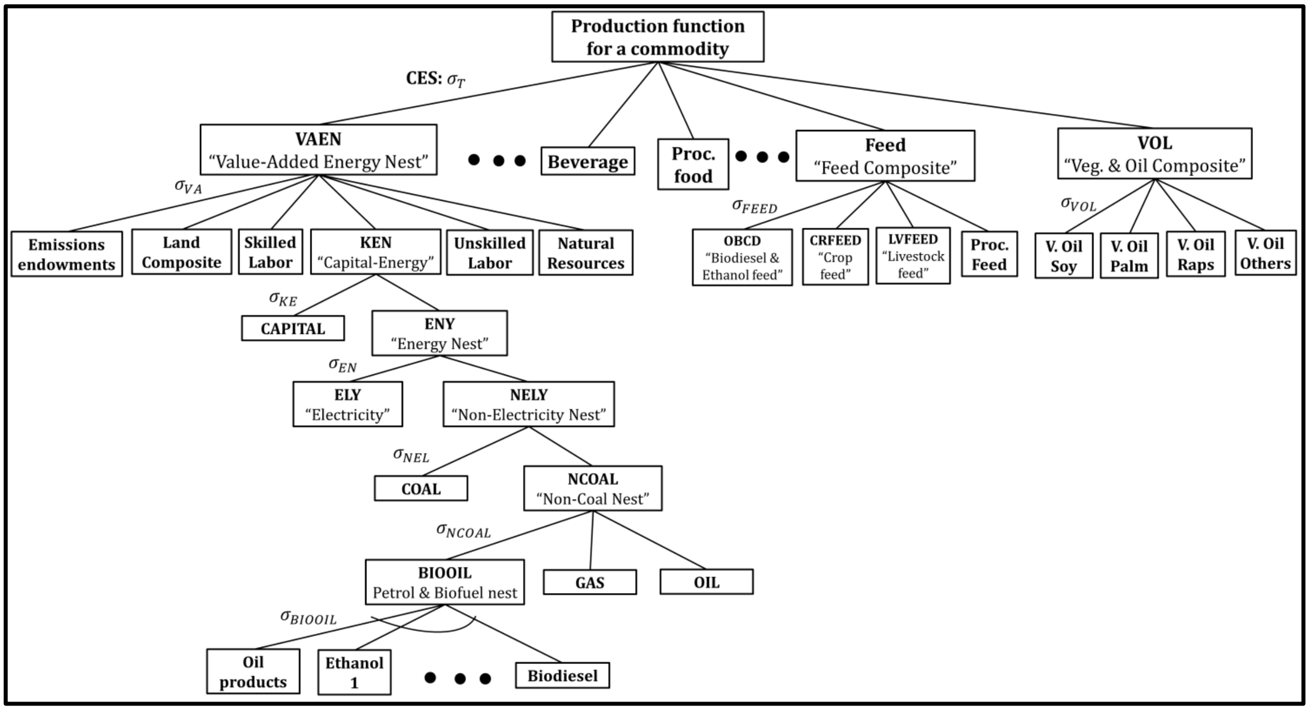


**Figure 1 Production function tree of the model for a tradable commodity**

The model also provides an “add-on” module for welfare decomposition which facilitates the analysis of drivers of changes in welfare (measured in $ of the equivalent variation [EV]) such as allocation efficiency (changes due to reallocation of endowments), technical efficiency (due to improvements on productivity), and terms of trade, among others. Thus, the GTAP-BIO-FCS provides a comprehensive model for the analysis of climate change mitigation.

*Scenarios of the model*

Experiment 1 –RED scenario: In order to achieve our goal, we develop first a scenario where we increase the biofuel production (i.e., ethanol and biodiesel) in the model given the parameters established by the RE Directive. In order to calculate the contribution of biodiesel in the RED target, we first consider that 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-equivalents (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 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 (i.e., 0.3% waste and residues from first-generation biofuels and the remaining share should be produced from other renewable sources).

Laborde (2011), Laborde and Valin (2012), 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 shares of biodiesel and ethanol consumption in total transport fuels should reach 6.2% and 2.4% in 2020, respectively.

In 2004, the biodiesel and ethanol share were 0.36% and 0.06% for the EU, respectively. Therefore, we consider an additional share increase of 5.84% and 2.34% for 2020 for each biofuel type following Padella et al. (2012). We implemented this scenario in the model as a shock in biofuels in the fuel mix.

Experiment 2 – *RED+Tariff* scenario: Here, we impose a tariff on biofuel imports from different regions, following the regulation 490/2013 and 444/2011 described previously, in addition to our increase in biofuel share. This is done to seek the increase in domestic biofuel production (i.e., specially biodiesel, which is the main biofuel source in the EU). Thus, this scenario adds additional shocks on import tariff imposition from South America, USA, and Malaysia and Indonesia towards the EU.

Experiment 3 – *RED+TAX27* scenario: Here we impose a tax regime of \$27/t$CO_2$e to releases of GHGs from consumption and production in the EU, proposed by Golub et al. (2012), to observe its contribution in the emission reduction.

Experiment 4 – *RED+TS* scenario: For this scenario, we impose carbon tax and a forest carbon sequestration subsidy of \$27/t$CO_2$e in the EU. This subsidy is intended to encourage the expansion of forest cover and the increase of FCS to further decrease GHG emission reduction.

**Results and discussion**

Our simulation analysis display a wide range of results in terms of economic and environmental variables at the sectorial and regional level. Here, we only present the key results to highlight the interactions among biofuels and the mitigation policies, and their implications for indirect land use and food security in the EU.

*Impacts on production and land use change*

The increase in biodiesel consumption in Europe (EU27) entails higher demand and production of this commodity (***RED*** scenario). According to the simulation results, biofuel output should increase by 18.6 billion gallons (+26%) in 2020 in order to achieve the share target. As expected, more biofuel feedstock is required (table 1), especially rapeseed – the main oilseed planted in the EU -, which needs to increase by almost 200%. Consequently, supply prices for this food commodity are driven up by 6%.

It is not surprising that this need for more feedstock for biofuels increases the demand for oilseeds and sugar crops, and the import of coarse grains (i.e., such as soybeans rapeseed). As a consequence, the regional harvested area increases by an overall 1.2% which drives forest cover reduction of 0.9% in the EU. Additionally, in order to boost production of agricultural commodities which are competing also in land (especially crops for biodiesel), it is required an increase in land productivity (through better management practices, changes in fertilization and other components of the intensive margin). Thus, in order to fulfill the target, there is an overall increase in crop yields in this region.

**Table 1. Changes in output and prices (in %) of agricultural commodities**

| **Product** | **% Change in Output** | | | **% Change in Price** | | |
|---|---|---|---|---|---|---|
| | RED | RED + TAX | RED + TS | RED | RED + TAX | RED + TS |
| **Paddy Rice** | 0.0 | -10.9 | -11.1 | 0.2 | 5.4 | 5.5 |
| **Wheat** | 15.7 | 12.1 | 11.9 | 1.0 | 4.1 | 4.3 |
| **Sorghum** | -3.0 | -2.8 | -2.8 | 0.3 | 3.6 | 3.8 |
| **Other Coarse Grains** | -5.6 | -6.6 | -6.7 | 0.1 | 3.4 | 3.7 |
| **Soybeans** | 9.3 | 4.7 | 4.4 | 0.7 | 2.6 | 2.8 |
| **Rapeseed** | 197.4 | 184.8 | 184.1 | 6.2 | 8.7 | 9.0 |
| **Other Oilseeds** | 2.8 | -0.4 | -0.7 | 0.5 | 2.9 | 3.1 |
| **Sugar Crop** | 52.0 | 49.8 | 49.7 | 2.5 | 6.0 | 6.3 |
| **Other products** | -0.3 | -1.4 | -1.6 | 0.4 | 2.2 | 2.4 |

Interestingly, oilseed production (i.e., rapeseed) registers relevant increases in all regions, especially for rapeseed in China and Canada. 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.

As expected, the expansion of biodiesel and oilseeds sectors provokes the diminution of output in the other energy sectors of the economy (coal, oil, gas, electricity, and oil products). In addition, there is an increase in output for biofuel byproducts (i.e., DDGS from ethanol and vegetable oil from biodiesel). For the cases of the livestock sectors, there is a slight decrease in production, mainly because there are two effects: (i) there is less available land for pasture, but (ii) there is more abundance of biofuel byproducts that can be used as feedstock.

When we add the tariff regime to the ***RED*** scenario in order to avoid biodiesel imports from different regions (i.e., Malaysia & Indonesia, USA and South America), we observe that it does not affect significantly EU domestic biodiesel production (***RED+Tariff*** scenario). This is because the imports in 2004 of biodiesels from these regions were small. Thus, the anti-dumping measure seems not to provoke additional effects on crops harvested area or sectorial outputs.

**Table 2 Changes in output and prices (in %) of relevant non-agricultural industries**

| | % Change in Output | | | % Change in Price | | |
|---|---|---|---|---|---|---|
| **Industries** | **RED** | **RED+TAX** | **RED+TS** | **RED** | **RED + TAX** | **RED + TS** |
| **Dairy Farm** | -0.3 | -1.7 | -1.7 | -0.2 | 5.1 | 5.4 |
| **Ruminant** | -0.2 | -4.4 | -4.5 | -0.5 | 9.1 | 9.3 |
| **Non Ruminant** | -0.1 | -1.4 | -1.5 | -0.5 | 3.0 | 3.0 |
| **Coal** | -0.6 | -15.4 | -15.4 | -1.0 | -9.5 | -9.5 |
| **Oil** | -0.8 | -1.3 | -1.2 | -1.5 | -2.5 | -2.5 |
| **Gas** | -1.7 | -16.9 | -16.8 | -0.3 | 0.6 | 0.6 |
| **Oil Products** | -3.3 | -5.8 | -5.8 | -1.0 | -0.8 | -0.8 |
| **Electricity** | -1.1 | -5.7 | -5.7 | -0.1 | 10.1 | 10.0 |
| **Energy Intensive industries** | 0.1 | -1.0 | -0.9 | -0.1 | 0.7 | 0.6 |
| **Other Industry Services** | -0.2 | -0.2 | -0.2 | 0.0 | -0.1 | -0.1 |

The addition of the tax regime adds a new layer on the analysis. The imposition of the \$27/t$CO_2$e on emissions further reduces output for paddy rice and livestock sectors (tables 1 and 2), which are considered 'dirty' products because of their emissions of non-$CO_2$ gases (i.e., land for rice and animals in livestock releases methane). Overall, there is a moderate decrease in the other crop categories, in part due to the fact that some of them are intermediate products for livestock and processed food and feed (which are also taxed on their emissions). Many energy sectors (i.e., coal, oil, gas, electricity and oil products) are substituted away by capital in order to reduce emissions. This drives down the shares of combustible in the fuel mix, which means that biofuels do not require increasing as much as before to achieve the target.

The subsidy on forest carbon sequestration simultaneously with the tax regime (***RED+TS*** scenario) provides an incentive to expand forest by almost 4% in this region (which can be considered from forest reversion and reduction of deforestation).Thus, forest plays a role in the GHG mitigation, making the reduction in production of energy sectors slightly lower compared to the ***RED+TAX***.

Nevertheless, due to land competition between forest and agriculture, there is a reduction in cropland. Thus, crop production decreases slightly for all the agricultural sectors. This small difference in agricultural output between ***RED+TAX*** and ***RED+TS*** can be attributed to the need for the farmer - given a reduction in land -, to become more efficient with their available territory, thus there is larger increase in crop productivity of land the ***RED+TS*** scenario.

*Impacts in prices of inputs and outputs: Addressing food security*

As economic theory suggests, simultaneous increase in consumption and production leads to a rise in supply prices (***RED*** scenario), which is the case for the EU for biofuel products and their feedstock. In terms of crops, the increase in price is small for coarse grains and competitor crops (e.g., paddy rice, wheat) and only a slight increase for sugar crops (about +2.5%). The most noticeable increase is rapeseed (+6.2%), which is the main crop used for biodiesel in the EU. Prices for ethanol and biodiesel outputs increase on average by +5 and +9%, respectively. This provides an important insight, considering that the European Union is a more efficient region in terms of carbon generation from its consumption and production, prices, and quantities are not affected drastically as in the cases for the developing regions studied in previous research.

**Table 3 (%) Changes in biofuel prices in the European Union**

| Biofuel product | RED | RED+TAX | RED+TS |
|---|---|---|---|
| **Ethanol from Corn** | 6.1 | 7.6 | 7.6 |
| **Ethanol from Sugarcane** | 1.5 | 4.6 | 4.7 |
| **Soy biodiesel** | 11.9 | 12.2 | 12.2 |
| **Palm biodiesel** | 2.5 | 2.9 | 2.9 |
| **Rapeseed biodiesel** | 9.2 | 10.0 | 10.1 |
| **Biodiesel from other oilseeds** | 7.3 | 7.9 | 7.9 |

On the other hand, under the ***RED+TAX*** (and ***RED+TS***), there is a higher increase in consumer prices, especially for livestock and paddy rice due to the implementation of the \$27/t$CO_2$e tax on emissions (an overall +3% for agricultural sectors, +5% for dairy farms and +9% for ruminant cattle). The prices are slightly higher under the tax-subsidy regime because the land use competition drives up the cropland rent. This is consistent with Peña-Lévano, et. al (2016) in which they stated that one of the consequences of implementing forest carbon sequestration incentives is the increase of land rents which ultimately affects food prices. Interestingly, considering the effect specifically on the EU, even under an additional tax-subsidy policy which can be implemented together with the RED directive, the impact on food security seems not to represent a significant threat for this particular region.

Nevertheless, the decrease of oil products in the fuel mix, prices for this product are driven up by about 40%. This is the highest price increase in the EU economy. As expected, this is the main contributor of the 1% rise of the consumer price index (CPI). The tax on emissions (under both ***RED+TAX*** and ***RED+TS*** regimes) makes more expensive oil prices by 10% compared to the ***RED*** scenario, which contributes an additional 0.57% of the CPI increase (table 4).

Table 4 Changes in macroeconomic variables, welfare and emission reduction

| Indicator | RED | RED+TAX | RED+TS |
|---|---|---|---|
| **CPI (%)** | 1.02 | 1.57 | 1.56 |
| **GDP (%)** | -0.74 | -0.91 | -0.92 |
| **Net emission reduction (%)** | -1.46 | -14.23 | -14.64 |
| **Equivalent Variation ($ billion)** | -94.78 | -115.50 | -117.38 |

*Impacts on international trade for the European Union*

According to our results, there is increase in the EU imports of commodities that are feedstocks for biofuels. This means that the expansion in domestic crop production does not satisfy the demand for food and biofuels. Thus, imports of biofuel feedstocks increase, especially for rapeseed. The changes in biofuel net exports are negligible (***RED*** scenario). There is only a very small decrease in imports of biodiesel from soybean and palm due to the antidumping regime in the ***RED+Tariff*** scenario (which can be considered negligible in absolute numbers).

When the tax regime is imposed, there is a rise in the trade deficit of many agricultural products (except soybeans but especially for the "other crops" category). In addition, due to the decrease in cropland from the incentive on FCS, net trade exports of all agricultural products further decrease.

*Impacts on GDP and welfare*

Likewise, with respect to changes in GDP (in % terms), the implementation of the RED policy represented a decrease of 0.74% in GDP for the EU. The other regions had negligible changes, as expected. The addition of the tax regime (which also drove up the CPI) reduces GDP by 0.91% (and 0.92% under the tax-subsidy scenario). Thus, we clearly observe no major changes in GDP from implementing mitigation methods to reduce climate change.

A useful measure of policy implementation is the welfare impact measured in $ of Equivalent Variation (EV). The implementation of the RE Directive alone represented a loss for the EU economy of approximately $USD -94.8 billion. This is driven mainly by variation in the allocation efficiency (i.e., moving labor, capital or land from one sector to another). The addition of the tax regime increases welfare losses by about $20.7 billion, which is partially attributed to the loss in technical efficiency. Finally, the subsidy to expand forest through FCS incentives reduced moderately the welfare (by only around -$1.8 billion).

*Reduction in GHG emissions*

The increase in biofuels encouraged a reduction in emissions of about 68Mt$CO_2$e (-1.5%) in the European Union (***RED*** scenario). This decrease is manly driven by a decline in private consumption of about 12% when the RED is imposed, mainly from the energy sector (coal, gas, oil) and fossil fuels. In contrast, there is an increase in crop emissions of 22Mt$CO_2$e (+10.5%) from output and changes in harvested area (+12% cropland). Additionally there is some deforestation (-0.9% less cover) occurring in this region due to the competition for land with agriculture.

Table 5. Sources of emission reduction (in Mt$CO_2$e)

| Source | RED | RED+TAX | RED+TS |
|---|---|---|---|
| **Priv. Consumption** | 564 | 128 | 128 |
| **Crops** | 234 | 6 | 6 |
| **Dairy Farms** | 111 | 22 | 22 |
| **Ruminant** | 161 | 60 | 60 |
| **Non-Ruminant** | 79 | 10 | 10 |
| **Proc. Food** | 68 | 6 | 6 |
| **Electricity** | 1447 | 296 | 296 |
| **Eng. Int. Industry** | 358 | 24 | 24 |
| **Transport** | 1382 | 80 | 81 |
| **Other Industries** | 363 | 35 | 35 |
| **Gross GHG** | 185 | 667 | 668 |
| **Forest Sequestration** | 4768 | -5 | 13 |
| **Net GHG** | 4583 | 662 | 681 |

The tax rate (***RED + TAX*** scenario) decreases the production of almost all sectors, especially carbon-intensive emitters. Private consumption falls by 20% (-8% more than in the previous case), which can attributed due to a simultaneous decrease in consumption of oil products (-18%) and livestock production (-37%). Interestingly, the electricity industry would the responsible of the highest share in emission reduction (45%) which is driven by its decline in production of about 300 $MtCO_2e$. As a result, there is reduction of 662 MtCO2e in regional emissions for the European Union.

Surprisingly, providing a tax on emissions together with the forest carbon sequestration subsidy did not decrease substantially the net emissions (e.g., 681 $MtCO_2e$ reduction). FCS contributed only about 13 $MtCO_2e$ in the mitigation effort (***RED+TS*** scenario). This provides an important insight, a FCS incentive of \$27/$tCO_2e$ does drive significant emission reductions when is applied in a developing such as Europe. This is partially due to the forest sequestration intensity and quantity of forest land, which is low relative to places such as South America and Sub-Saharan Africa. The other sectors industries remained relatively constant.

Reforestation due to FCS subsidy increases forest land by 4% at expenses mainly from pasture land (-6.5%). Cropland also decreased by 1.5%, nevertheless this is partially offset by (i) improvements in land productivity (which drives up land rent and consequently food prices) and (ii) increase in imports. Thus, consumption and production of food remains at almost samelevels as the ***RED+TAX*** scenario but at slightly higherr food prices.

**Conclusions**

The European Union is one of the regions that is putting a lot of effort towards the development of the biofuel industry to mitigate climate change effects and lessen the dependence of fossil fuels. Several policies are being proposed in the Renewable Energy Directives, such as increasing share of renewable sources in fuel mix, specific increases in fuels, and anti-dumping strategies. However, recent analyses highlight concerns of biofuels' actual sustainability due to different risks associated with their expansion. The most critical of all are competition with food production and additional GHG emissions caused by land use change.

Our study aims to improve the understanding of the interaction between climate change, biofuel, and food security. We use a computable general equilibrium modeling called GTAP-BIO-FCS for the evaluation of the RED policies in the European Union together with additional mitigation policies suggested by the literature such as carbon taxes and forest carbon sequestration for the period 2004-2020.

Our results suggests that under the RED regulations 490/2013 and 444/2011, the increase of biodiesel consumption in Europe (EU27) entails higher demand and production of biodiesel and oilseeds. As a consequence, the regional harvested area increases by an overall 1.2% which drives forest cover reduction of -0.9% in the EU. The addition of the tax rate on emissions ($27/t$CO_2$e) on emissions reduces output for paddy rice and livestock sectors, which are considered 'dirty' products. Many energy sectors (i.e., coal, oil, gas, electricity, and oil products) are substituted away by capital in order to reduce emissions.

The subsidy on forest carbon sequestration simultaneously with the tax regime provides an incentive to expand forest by almost 4% in this region. Due to land competition between forest and agriculture, there is a reduction in cropland. Thus, crop production decreases slightly for all the agricultural sectors which is partially offset by importing more crop commodities from other regions of the world and increasing productivity of land.

The RED policy affects mainly prices for crops in which there is competition between food and biofuel expansion such as sugar crops. When a tax on emissions is implemented, this is translated into the output price, especially for livestock and paddy rice. Additionally, incorporating forest carbon sequestration subsidy increases land competition between forest and agriculture driving up land rent.

Nevertheless, the FCS subsidy does not provoke drastic expansions of forest. Thus, the subsidy only reflect a moderaterly increase in food prices.

As a whole, our results suggest that, for the case of the European Union, an increase in biofuel production does not represent a threat in food security. Furthermore, land use change in EU are modest compared to previous studies in developing regions. Thus, our study illustrate how the imposition of a regime can vary depending on the economic development.

**Future research**

Considering our results for the European Union, our next step will be to investigate monetary transfers from the EU to other developing regions in a effort to increase reforestation in order to achieve the RED targets.

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