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Tradeoff of the U.S. Renewable Fuel Standard, a General Equilibrium Analysis

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Tradeoff of the U.S. Renewable Fuel Standard, A General Equilibrium Analysis

Abstract

Global production of biofuels has been expanding with the enduring concerns on climate change and energy security. The U.S. Congress has established a renewable fuel standard 2 (RFS2) rule that mandates annual combined production of 36 billion gallons (bg) biofuels by 2022 (USEPA, 2010). Large scale production of biofuels results in far-reaching intended and unintended consequences on the economy and environment. In this study, a computable general equilibrium model (CGE) - Applied Dynamic Analysis of Global Economy -- ADAGE-Biofuel is developed to examine the global implications of the U.S. RFS2 policy. This model is built upon a dynamic version of ADAGE model (Ross, 2009) by introducing eight crop categories, one livestock and one forestry sectors, seven first generation biofuels, three second generation biofuels and five land categories and explicitly model land-use changes. We find out that despite of continued increase in land productivity and energy efficiency, increase in population and economic growth leads to a global-wide increase in agriculture production, rise in price of food, agriculture, biofuel and energy and land conversion from the other four land types to cropland from 2010 to 2025 when RFS2 is not implemented and biofuel consumption remain at the base year (2010) level in all the regions until 2025 (BAU scenario). The implementation of RFS2 policy would require 36.3 million ha (mha) of land for switchgrass production by 2025, where 34.8 mha from existing cropland, 0.9 mha from pasture, and 0.6 mha from managed forest land. Compared with the BAU scenario, price is projected to increase by around 5~7% for eight crops, 1.6% for livestock and 1.6% for forestry as a result of reducing production. Globally, due to reduction in agriculture exports from U.S. as a result of the RFS2 policy, all other regions would allocate slightly more land for crop and food production, leading to gentle loss of natural grassland and natural forestland, especially in Africa, which would lose 0.5 million ha of natural grassland for crop and livestock production. The RFS2 policy would bring environmental benefits too. The accumulated carbon saving from 2010 to 2025 would be around 392 mmt c globally with 207 mmt c from fossile fuel and 185 mmt from land. Among it, U.S. alone would contribute 300 mmt c with 208 mmt c from fossile fuel and 92 mmt c from land.

Key Words: Biofuels, Computable General Equilibrium, Recursive Dynamic, ADAGE.

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1. Introduction

Biofuels have been in great interest during the past twenty years as it is viewed as an alternative energy, an income source for developing countries and climate change mitigation potentials. World energy demand is projected to increase by 33 percent, from 505 quadrillion Btu in 2008 to 672 quadrillion Btu in 2025 (EIA 2011) as a result of robust economic growth and expanding populations in the world's developing countries. Meeting the rising demand for energy remains a challenge for all countries. IEA (2011) projects that biofuels have the potential to contribute sustainably from their current global share of 2% to about 27% of total transportation liquids by 2050, given that the technology improvement and policy incentives. U.S. currently consumes about 25% of world oil, about 60% of which comes from imports (EIA, 2010). It becomes critical for US to find alternative energy source and enhance energy security. Biofuels, viewed as carbon neutral, may reduce overall GHG emissions, especially for cellulosic ethanol.

Biofuel production has been growing steadily during the past ten years. According to the data from U.S. Energy Information Administration (EIA), global ethanol production has increased by more than 4 times in 10 years from 2000 to 2010, amounting to nearly 23 billion gallons (bg) by 2010. Global biodiesel production has been rising for more than 21 times, reaching 5 bg in 2010. Biofuels in the U.S., mainly corn ethanol, driven by federal and state biofuel policy incentives, rising oil price and increasing oil demand, have experienced an unprecedented growth during 2000~2010. U.S. has become the largest producer with 13 bg of ethanol and 0.3 bg of biodiesel in 2010, accounting to 57% and 7% of global production respectively (see figure 1 and Figure 2).

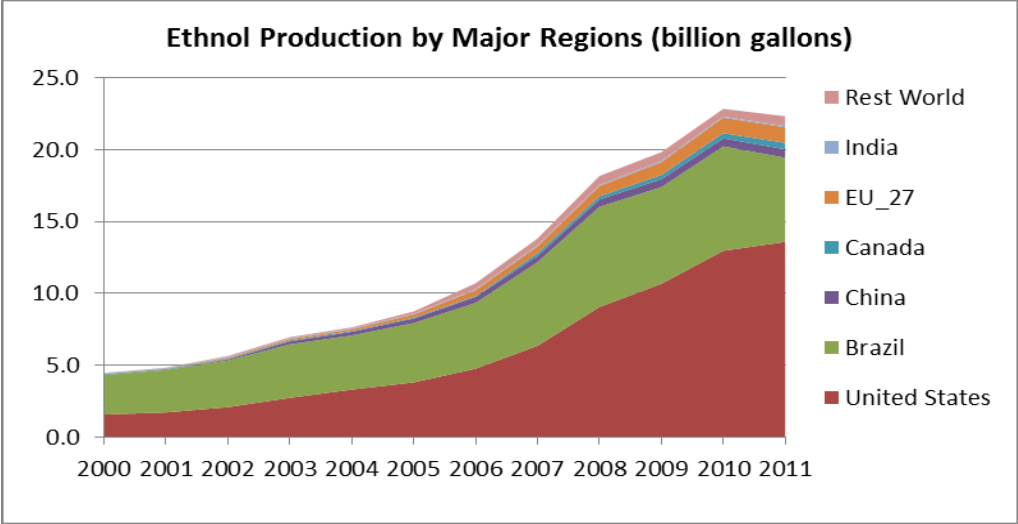


Figure 1. Ethanol production by major regions from 2000~2011 (billion gallons)

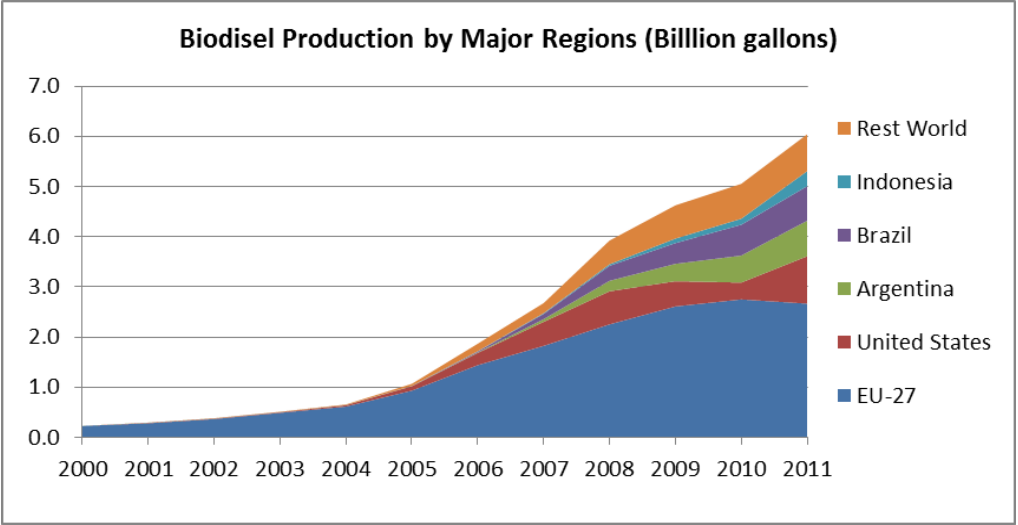


Figure 2. Biodiesel Production by major regions from 2000~2011 (billion gallons)

The U.S. Congress established the RFS2 rule that mandates annual production of 36 bg per year of total renewable fuels by 2022 (USEPA, 2010) (see Figure 3). The RFS2 volume requirement includes a capped 15 bg of corn-ethanol and 21 bg of other renewable fuels such as advanced biofuels including cellulosic biofuels (16 bg), biomass based biodiesel (1 bg), and 4 bg of other unspecified biofuels (mostly imported sugarcane ethanol). Apart from the volume mandates, the EISA also specified the thresholds on lifecycle greenhouse gas (GHG) emissions

on the qualifying biofuels such as 20% for corn-ethanol, 60% for cellulosic biofuels, 50% each for biodiesel and other advanced biofuels.

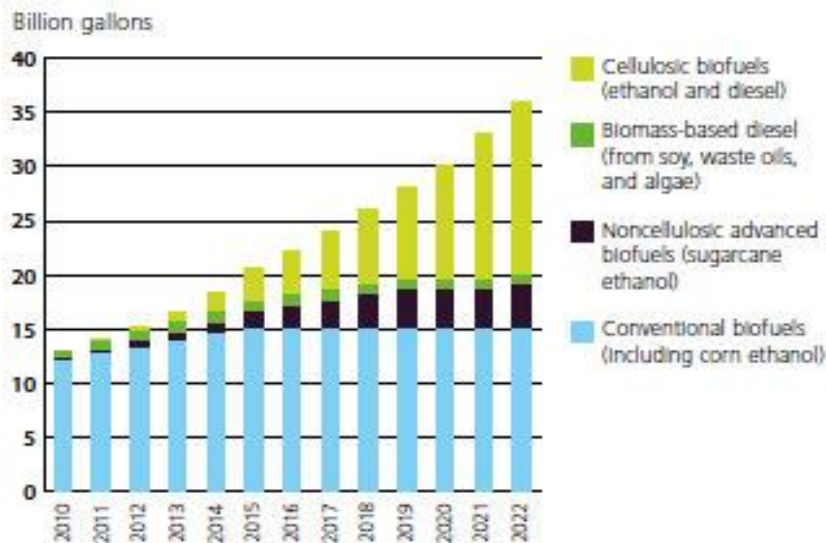


Figure 3. Minimum volume requirements of each renewable fuel category, as mandated in the RFS2 (billion gallons).

Data source: EPA 2010

Since most of biofuels are produced using agriculture and forest resources, large scale production of biofuels results in far-reaching intended and unintended consequences on the economy and environment. Researchers from Purdue University have used GTAP-BIO to study induced land use emissions and uncertainty due to first and second generations biofuels expansions (Taheripour and Tyner (2013)), global welfare, trade, land use change, price implications due to EU and US biofuels policies (Hertel et al. (2010), Birur et al. (2008)). GTAP-BIO is a comparative-static version of Global Trade Analysis Project (GTAP) model for analyzing global impacts of biofuels, byproducts, and land use change at the Agro-Ecological Zonal (AEZ) level. This model is good for analyzing short-term implications, but not good for analyzing longer-term implications as it could not include time varying macro-economic and technological change components on biofuels and feedstock crops.

Havlik et al (2011) studies global land-use implications of first and second generation biofuels expansion. Their results indicate that global expansion of first generation biofuels requires 25 years to be paid back by the GHG savings from the substitution of biofuels for conventional fuels. Second generation biofuel production fed by wood from sustainably managed

existing forests would lead to 27% lower overall emissions compared to the “No biofuel” scenario by 2030. Second generation biofuels perform better if they are not sourced from dedicated plantations directly competing for agricultural land. If so, then efficient first generation systems are preferable. However, their model, GLOBIOM, is a global partial equilibrium model with great feather by integrating the agricultural, bioenergy and forestry sectors together, but energy and other commodity sectors are not represented.

Msangi et al. (2007) explored scenarios of biomass expansion using the IMPACT model. Although all the details in the representation of demand and supply of different agriculture products are included, their IMPACT model is a partial equilibrium model that does not represent other energy markets.

A few studies on biofuels policies have been conducted using the MIT Emission Prediction and Policy Analysis (EPPA) model, a recursive dynamic, multi-sector, multi-region, general equilibrium model. Gurgel et al. (2008) investigate the potential production and implications of a global second generation biofuels industry and find out the approach with observed land supply elasticity allows much less conversion of land from natural areas, forcing intensification of production, especially on pasture and grazing land, whereas another approach with pure conversion cost leads to significant deforestation and biofuel expansion. These two approaches represent two extreme cases while the reality may stay between of them. Meanwhile, the first generation biofuel is not represented in the model. Gitiaux et al. (2009) overcome this limitation by introducing seven types of first generation biofuels technologies in the EPPA model and also account for CO₂ emissions resulting from growing feedstock crops as well as from biofuels conversion. They then use this version to study the effect of biofuels mandates on the European vehicle feet. Though this study examines the interaction of biofuel mandates, fuel tax, and tariff policies over the long-term (2030), it completely ignores the emerging cellulosic biofuels as well as land use changes which potentially have significant impact on land use and CO₂ emissions. Reilly et al (2012) develop an integrated modeling system: EPPA-TEM which fully captures the interaction of climate change, global and regional economy, agricultural activities, biofuels productions and associated land use change and land use emission. They then apply this model to study the tradeoff of using land to mitigate climate change. Their results indicate that an ambitious global *Energy-Only* policy that includes biofuels would likely not achieve the target to stabilize Earth’s average temperature within 2 °C of the preindustrial level. A thought-

experiment where the world ideally prices land carbon fluxes combined with biofuels gets the world much closer. The significant trade-off with this integrated land-use approach is that prices for agricultural products rise substantially because of mitigation costs borne by the sector and higher land prices. Higher food prices lead to a rising share of income spent on food for the poorest regions. In general, crop, livestock and forest products are generalized into one category and modeled in EPPA, so it lacks detailed representation of various agricultural products.

Al-Riffai et al. (2010) analyzed the impact of EU and US biofuels policies, by adapting the Modeling International Relationships in Applied General Equilibrium (MIRAGE) model and introducing the first generation biofuels into the GTAP version-7 data base. Those authors augment the MIRAGE model with modules on energy and biofuels interaction, feedstocks and co-products of biofuels, and AEZ level CET land supply structure similar to that of Birur et al. (2008). They examine the EU renewable energy target of 10% of transportation fuels by 2020, from the 5.6% share in the base year 2008. The study reveals that EU mandates requires considerable imports of ethanol from Brazil, with a global net balance of direct and indirect emissions of 13Mt CO₂ savings over 20 years horizon. This study did not consider the cellulosic biofuels in their analysis.

Though these studies above have analyzed economy-wide implications of biofuels, they are either a static model, or a partial equilibrium model, or being specific to a single sector, or a CGE model but lack detailed representation on ag sectors. The purpose of this study is to improve the existing methodology of various models by developing a comprehensive global model in a general equilibrium framework, with detailed agriculture, energy, and first and second generation biofuels sectors, allowing for long term macro-economic changes, technological development, and consumption changes in energy and food sectors, then apply this model to study longer-term global implications of complete execution of the U.S. RFS2 policy. This model is called ADAGE-Biofuel model. The following sections describe the model structure, land-use change representation and experimental design in section 2 and results and conclusion in section 3 and 4 respectively.

2. Model

Our point of departure is the Applied Dynamic Analysis of Global Economy (ADAGE) model described in Ross (2009). ADAGE is a forward looking, intertemporally-optimizing computable

general equilibrium (CGE) model. It can be used to simulate global and regional economy, trade, and greenhouse gas emission. Economic data in ADAGE come from the GTAP and IMPLAN databases. Energy data and various growth forecasts come from the International Energy Agency and Energy Information Administration of the U.S. Department of Energy. Emissions estimates and associated abatement costs for six types of greenhouse gases (GHG) are also included in the model. ADAGE is composed of three modules “International, “US Regional” and “Single Country”. Each module relies on different data sources and has a different geographic scope, but all have the same theoretical structure. This allows the model to estimate global results as well as detailed regional and state-level results that incorporate international impacts of policies. Adage is widely used to examine economic, energy, environmental, and trade policies at the international, national, U.S. regional, and U.S. state levels and estimate how an economy will respond over time to these policy announcements (for example, Waxman-Markey climate change Bill and the American Clean Energy and Security Act of 2009).

ADAGE-Biofuel is built upon on the ADAGE “International” module by introducing more details on crops, biofuels and land-use changes components. ADAGE-Biofuel is a recursive dynamic, multi-region and multi-sector CGE model. The base year is 2010. It projects global economy, energy use, agriculture activity, biofuel production and land use from 2010 to 2050 at 5-year time steps. Economic development from 2010 is calibrated to the actual output. Economic growth would match the projection of GDP growth trend from International Energy Agency (IEO). Production and consumption sectors in ADAGE-Biofuel are represented by nested Constant Elasticity of Substitution (CES) functions including special cases such as the Cobb-Douglas and Leontief. The model is written in the GAMS software system and solved using the MPSGE modeling language (Rutherford, 1995).

2.1 Data

2.1.1 Baseline Data

The major underlying database for ADAGE-Biofuel, the Global Trade Analysis Project (GTAP) database version 7.1 (Narayanan and Walmsley, Ed., 2008), is updated from 2004 to the baseline year 2010 using secondary data from International Energy Agency, Food and Agricultural Organization (Beach et al, 2012). We aggregate the data into 8 regions and 36

sectors¹ (see Table 1 and Table 2) where agriculture consists of eight crop categories, one livestock and one forestry sector. Biofuel sectors include seven first generation biofuels and three second generation biofuels. The sectors are aggregated such that we could focus on the linkages among energy commodities, biofuels, feedstock crops, by-products and other important related sectors, and biofuels producing countries are emphasized in the regional aggregation.

Table 1. Regions in ADAGE-Biofuel

| Regions | Definition |
|----------------|-----------------------|
| USA | United States |
| BRA | Brazil |
| CHN | China |
| EUR | Europe Union 27 |
| XLM | Rest of South America |
| XAS | Rest of Asia |
| AFR | Africa |
| ROW | Rest of World |

Since the GTAP data base does not explicitly include biofuel-related data, we used the splitcom, a software developed by Horridge (2005), to break out the existing GTAP sectors. For example, corn-ethanol is split from food sector (ofd) and soy-biodiesel from the vegetable oils and fats (vol) sector and the sugarcane based ethanol from chemicals sector. The by-products such as distillers dried grains with solubles (DDGS) are introduced such that the total corn-ethanol industry jointly produces both corn-ethanol (ceth) and DDGS (ddgs). In order to split out a new sector in general, we used the information on trade shares, consumption shares, cost share and own use shares, in the existing aggregated sector, based on secondary data sources from Food and Agricultural Organization (FAO), IEA, U.S. Department of Agriculture, Energy Information Administration (EIA), U.S. Department of Energy, etc.

¹ The region and sector specification in ADAGE-Biofuel is flexible. Another version of ADAGE-Biofuel has 25 region and 42 sectors.

Table 2 Sectors in ADAGE-BIOFUEL

| Sectors | Definition | Sectors | Definition |
|--------------------|-----------------------|-------------------|--|
| Energy | | Industry | |
| Col | Coal | Eim | Energy-intensive manufacturing |
| Cru | Crude Oil Extraction | Man | Other Manufacturing |
| Ele | Electric generation | Srv | Services |
| Gas | Natural Gas | Trn | Transportation |
| Oil | Refined Petroleum | Vmt | Household transportation |
| Agriculture | | House | Housing |
| Wht | Wheat | Biofuels | |
| Corn | Corn | Ceth | Corn Ethanol |
| Gron | Rest of Cereal Grains | Weth | Wheat Ethanol |
| Soyb | Soybean | Scet | Sugarcane Ethanol |
| Osdn | Rest of Oilseeds | Sbet | Sugarbeet Ethanol |
| Srcn | Sugarcane | Sybd | Soy Biodiesel |
| Srbt | Sugarbeet | Rpbd | Rape-Mustard Biodiesel |
| Ocr | Crops nec | Plbd | Palm-Kernel Biodiesel |
| Liv | Livestock | Swge | Advanced cellulosic ethanol from switchgrass |
| Frs | Forestry | Celd | Advanced cellulosic biodiesel |
| Food | | Msce | Advanced cellulosic ethanol from miscanthus |
| Mea | Meat | Byproducts | |
| Vol | Vegetable Oils | Ddgs | Distillers grains with solubles (DDGs) |
| Ofd | Other foods products | Omcl | Vegetable Oil Meal |

2.1.2 Dynamic data

Economic growth in the future periods is driven by capital savings and investments, technological improvements in energy efficiency, growth in the effective labor supply from population growth and changes in labor productivity and change of natural resources stocks such as energy and land.

The key data include population from World Development Indicators, GDP growth, are based on IEA world energy outlook projections. Energy consumption, energy price are also downloaded from there to compare our results and their projections. The rest data are either directly from EPPA, or following the formulation in EPPA (Reilly et al (2012)).

2.2 Model Structure

The general structure of the ADAGE model is discussed in greater detail in Ross (2009). The ADAGE model follows the classical Arrow-Debreu general equilibrium framework covering all aspects of the economy, including production, consumption, trade, investment, etc. Production and household consumption are represented by a nested constant elasticity of substitution framework and discussed in Beach et al (2010). A representative household in each region would maximize its utility subject to budget constraints based on endowments of factors of production (labor, capital, natural resources, and land inputs to agricultural production). Income from sales of factors is allocated to purchases of consumption goods and to investment. All goods, including total energy consumption, are combined using a CES structure to form aggregate consumption goods. This composite good is then combined with leisure time to produce household utility. The elasticity of substitution between consumption goods and leisure, is controlled by labor supply elasticities and indicates how willing households are to trade off leisure for consumption. Keep in mind that the households are allowed to substitute different types of biofuels to refined petroleum, used in the personal vehicle transportation.

For various sectors in the economy, the general nesting structure of production activities and associated elasticities in ADAGE-Biofuel have been adapted from the EPPA model. Although EPPA has only one crop sector, ADAGE-Biofuel models 8 types of crops, which are produced by utilizing land, labor, capital, energy, and material inputs, with different elasticity of substitution. The livestock production structure in the ADAGE-BIO is separated for ruminants and non-ruminants to reflect differentiated use of biofuel by-products by different animals. At the bottom of the CES production structure, the DDGS is combined with other feed grains, and vegetable-oil meal is combined with oilseeds, and the two composites are allowed to substitute with the processed feed in the livestock production nest.

2.2.1 Modeling biofuel production

Currently cellulosic biofuels is not available in the market. We introduced the cellulosic feedstock (corn-stover, switchgrass, and miscanthus) based production technologies for cellulosic ethanol and cellulosic diesel in the model, such that the cellulosic biofuels could be produced in the post-2010 scenarios. The parameters for the second generation biofuels are taken from EPPA.

The first and second generations of biofuels in the ADAGE-BIO model are produced in a Leontief production structure, where the input shares are fixed over time (see figure 4). The feedstock crops enter the top level of the CES production nest in fixed proportions, along with the material inputs and capital-labor composite. The capital and labor are combined in value added composite following the Cobb-Douglas production structure. However, the second generation biofuels are currently not available. They can endogenously enter the market when they become cost competitive with rising energy price.

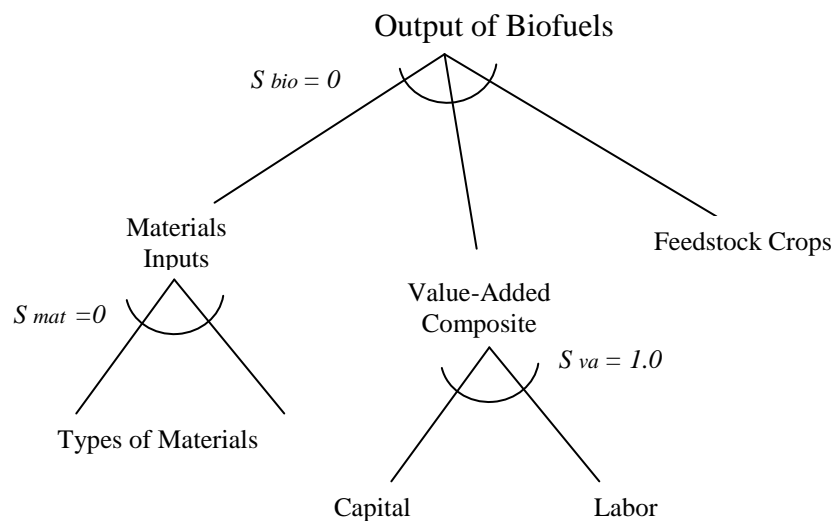


Figure 4. Biofuels production in ADAGE-BIO

2.2.2 Modeling land use change

The land use change in Beach et al (2010) is specified as a nested constant elasticity of Transformation (CET) function where the land is first allocated across three cover types (cropland, pastureland, and forestland) and in the second tier cropland is allocated across 8 alternate crops. After shift in cropping patter within in the cropland, additional demand for land is met by the pasture and forest covers. A land supply elasticity of each type is implied by the elasticity of substitution and implicitly reflects some underlying variation in suitability of each land type for different uses and the cost to or willingness of owners to switch land to another use. The CET approach can be useful for short term analysis. This approach has been criticized as share preserving which assures that radical changes in land use does not occur, making longer term projections unrealistic. Meanwhile, this approach does not explicitly account for conversion

costs, nor address the value of the stock of timber when natural forest land is converted to managed forest land. We also find out total land over time in a region couldn't remain constant, thus fails to maintain the physical account consistency.

Following Gurgel et al (2008), we adopted a CES approach for land use transformation. Land is separated into five types: cropland, pasture land, managed forestry land, natural forest and natural grassland. Cropland could be used to grow various crops and second generation biofuels. Pasture land and managed forest land are exclusively used by livestock sector and forestry sector respectively. Natural grassland and natural forest land could provide no-use value.

Land could be converted from one type to another type. To integrate land use change into the CGE framework, two key requirements have to be retained: (1) consistency between the physical land accounting and the economic accounting in the general equilibrium setting; (2) introduced land use data needs to be consistent with observations as recorded in the base year, so the base year would be still in the equilibrium as observed. To retain consistency between physical land accounting and economic accounting, we assume that one hectare of land of one type is converted to 1 hectare of another type, and through conversion it takes on the productivity level and land rent for that type for that region. It is in that sense that another type of land is "produced." To achieve the second requirements, the marginal conversion cost of land from one type to another should be equal to the difference in value of these two types. A fixed factor and the elasticity between it and other inputs are introduced into the top level of the land transformation function, representing the long-term response of land use change (see figure 5). The lower level would follow the same structure of agriculture production function. This structure is quite simple for pasture land and forest land as they are exclusively used by livestock sector and forestry sector respectively. It would be more complicated for cropland. As cropland is used for eight types of crops and cellulosic biofuels (once cellulosic biofuels become cost competitive), the production function for cropland is obtained by taking the share of these aggregated eight crops. When natural forest land is converted to forest land, timber is also produced in addition to the "produced" managed forest land. On the other hand, when managed land can be abandoned and converted to natural land, no cost is associated with the conversion.

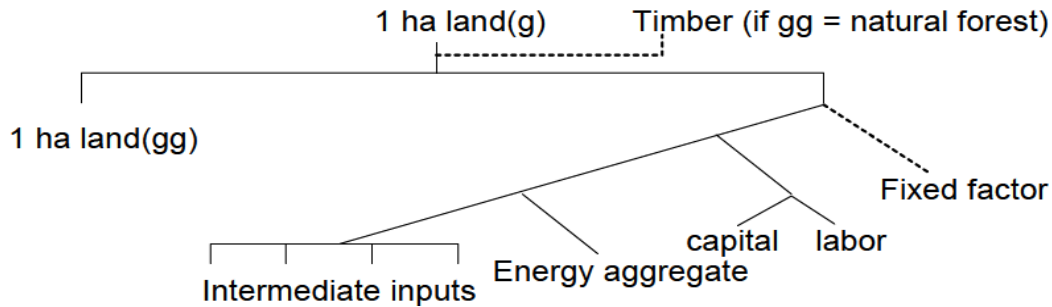


Figure 5. Land use change function (g is one type of land and gg is another type of land)

2.2.3 Implementing the RFS2 policy

As discussed above, the focus of this study is the U.S. RFS2 on biofuels. Two scenarios are developed to explore the implications of U.S. RFS2 policy: (a) the Business-as-usual (BAU) scenario that assumes biofuel consumption remains at the base year (2010) level in all the regions until 2025; (b) the RFS2 scenario, where the U.S. biofuels mandate is implemented in U.S. from 2010 to 2025 using a share approach, while other regions continue to remain the base year biofuel consumption. Any import of biofuels into the U.S. subjected to RFS2 implementation is allowed to adjust depending on the price changes and trade restrictions. The share approach targets share of biofuels in transportation liquids (used in personal vehicles) based on energy content. The share approach forces the specified level of a particular biofuel in each region, thus the mandate could be implemented precisely than the permit approach (Gitiaux et al., 2009).

4. Results

I will report the baseline results in section 4.1 and the impact of RFS2 policy on section 4.2.

4.1 Baseline

Upload the production, price, land-use change and co2 emission from land use change here.

Our results indicate despite of continued increase in land productivity and energy efficiency, increase in population and economic growth leads to a global-wide increase in agriculture production, rise in price of food, agriculture, biofuel and energy and land conversion from the other four land types to cropland in the BAU scenario from 2010 to 2025.

4.1.1 Production

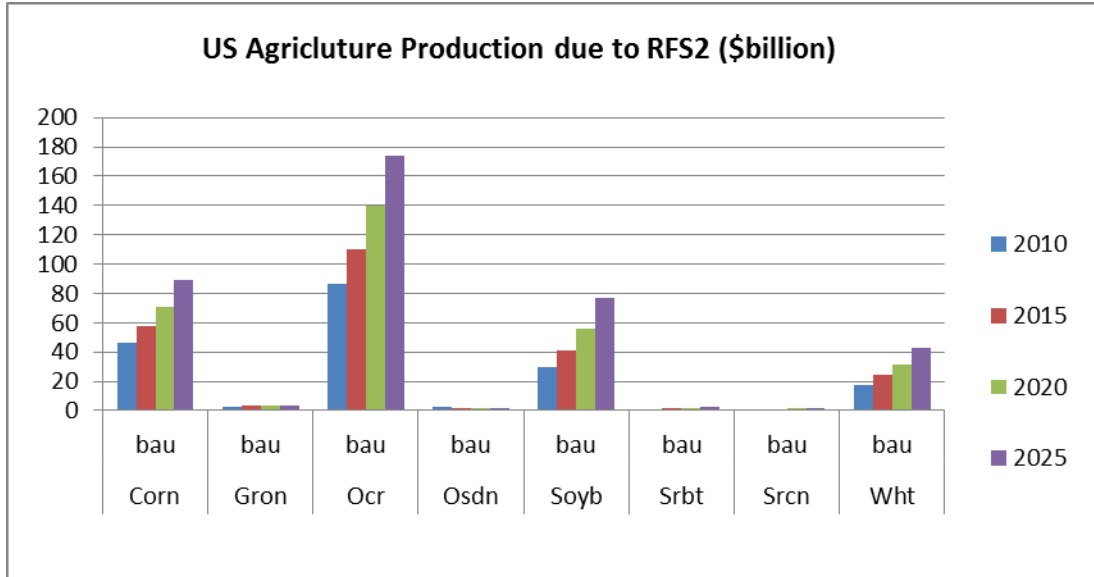


Figure 6. Major ag production in U.S. (\$billion)

4.1.2 Price

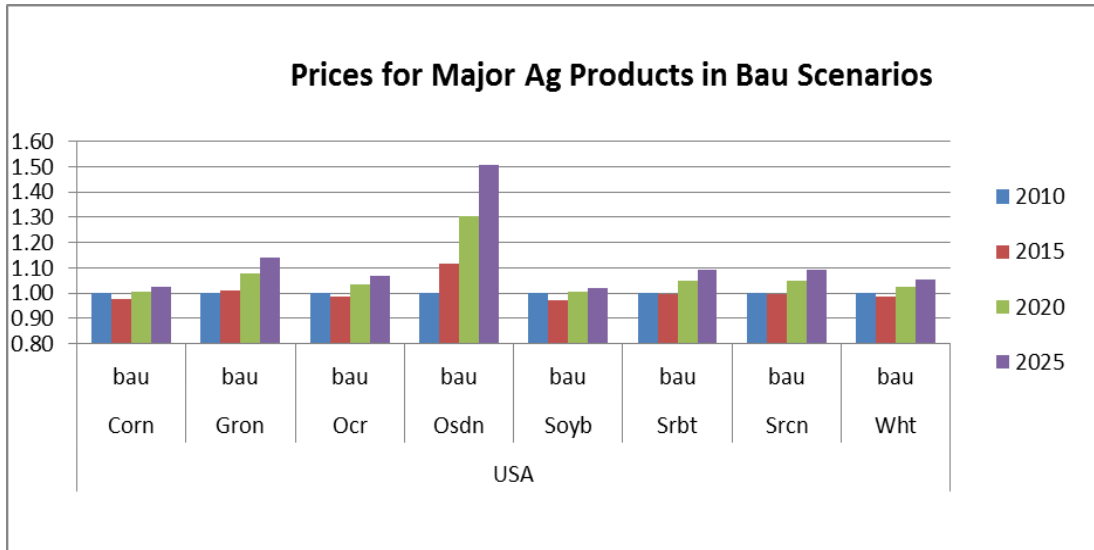


Figure 7. Major ag price in U.S. (baseyear =1)

4.1.3 Land use change

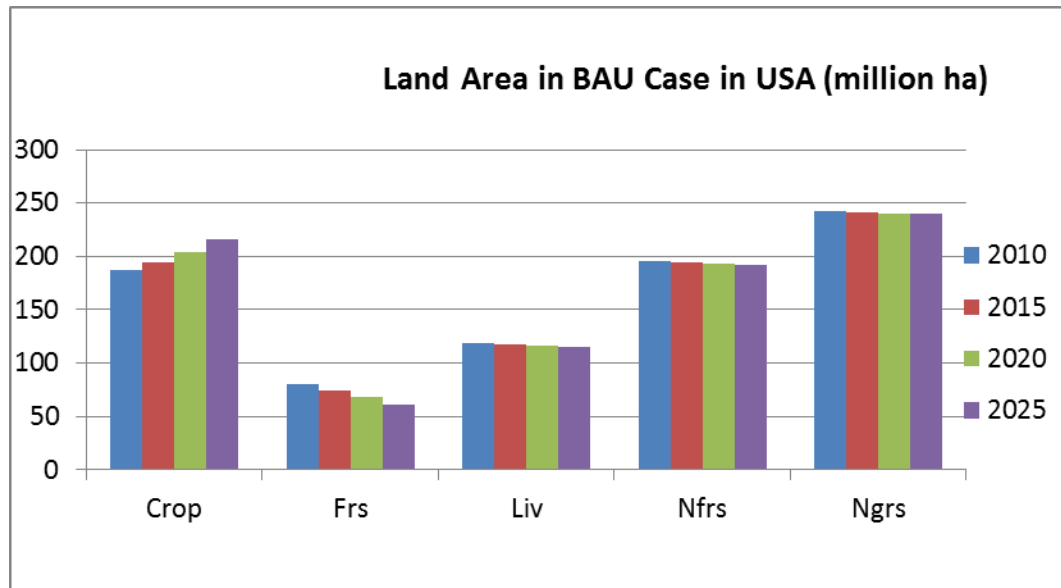


Figure 8. Land use change in the Baseline (million ha)

4.2 Impact of the RFS2 Policy

The RFS policy causes changes in the output quantities and prices of all agricultural commodities, as the use of corn ethanol, switchgrass-based cellulosic ethanol, and soybean biodiesel increase. Mandating the production of these fuels increases the production of their feedstocks and increases the demand for cropland. This increase in demand affects the production of all crops, as well as the prices and quantity of forest and pastureland. The requirement of 13.7 billion gallons of cellulosic ethanol (assumed to come from switchgrass) has a pronounced effect on land use and agricultural output because the feedstock crop does not appear in the baseline and must displace other uses for land. The following sections describe the changes in agricultural and energy markets in the US resulting from the 2025 US RFS policy.

4.2.1 Production

Production of corn ethanol increases by 3.7 billion gallons, output of soybean biodiesel increases by nearly 1.1 billion gallons, and 13.8 billion gallons of cellulosic ethanol are produced to meet the RFS requirements. These changes in volumes are displayed in Table 3. As land moves into the production of switchgrass, the outputs of all other agricultural products, such as

other crops, forestry and livestock products, and other types of biofuels decrease (see figure 9~11).

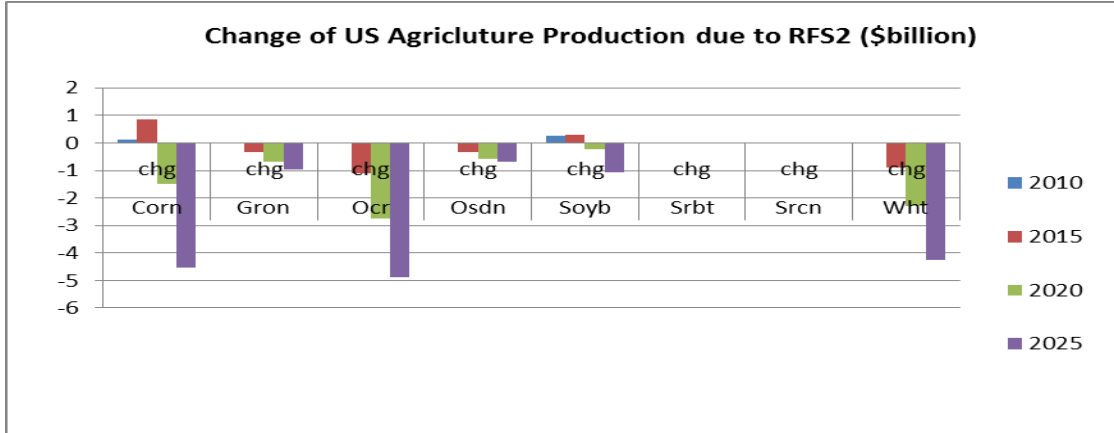


Figure 9. Change of Crop production in USA due to the RFS2 scenario (\$billion)

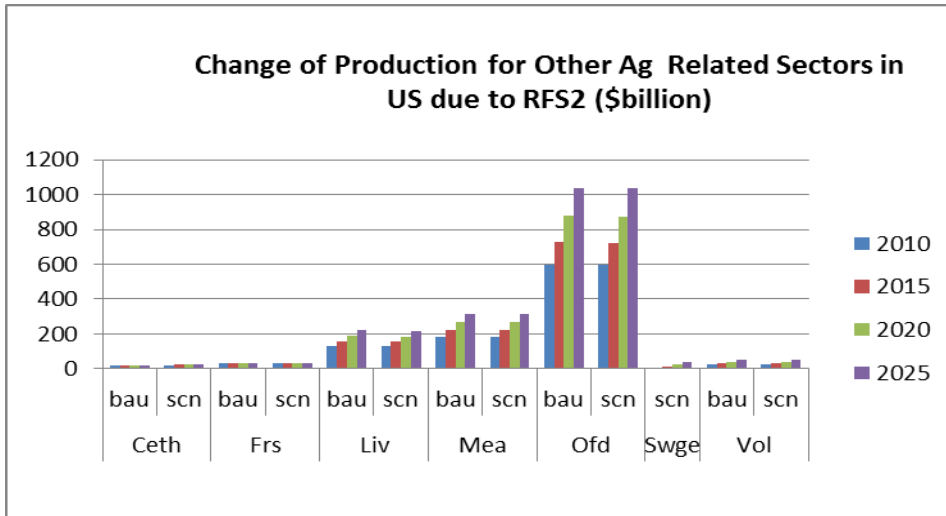


Figure 10. Other agriculture production in USA in the baseline and the RFS2 scenario (\$billion)

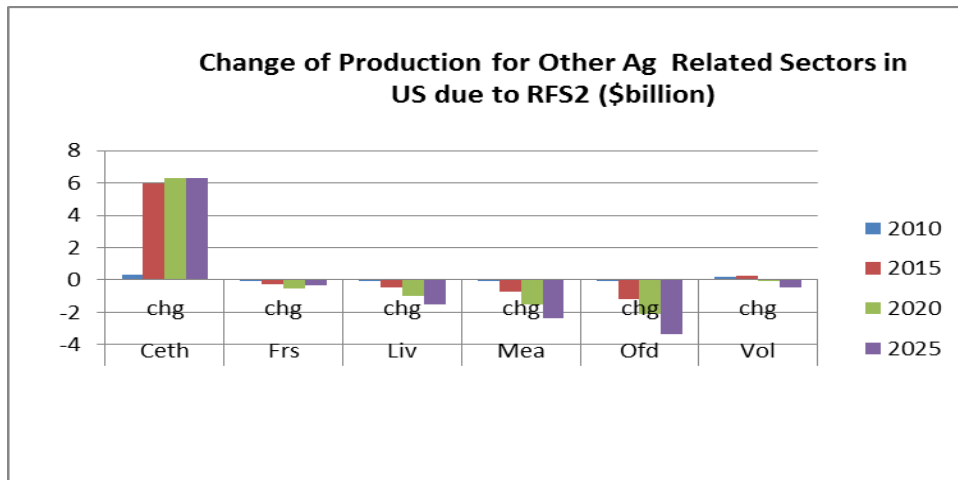


Figure 11. Change of Other agriculture production in USA due to the RFS2 policy (\$billion)

Corn and corn ethanol markets: The US RFS policy causes an increase in the amount of corn ethanol used and produced domestically. Corn ethanol use increases from 11 to 14.7 billion gallons, with other types of ethanol making up the rest of the 15 billion gallon requirement. US corn output remains relatively constant (a decrease of less than one percent) and the increase in corn ethanol production is achieved through input substitution, representing a technological change.

4.2.2 Prices

Energy goods: Within the US, as demand for biofuels increases and the price of land rises, the prices of biofuels increase as well. The price of corn ethanol increases by 1.4%, while the price of soybean biodiesel increases by 15.2%. The increase in energy costs associated with the increase in biofuels use will further reduce demand for conventional transportation fuels by US consumers. The reduction in demand for oil by 25 billion barrels within the US causes the world oil price to fall by 3%. The reduction in oil prices in other regions reduces the prices of crops both by lowering the cost of inputs to production and by reducing the demand for biofuels and the associated feedstock crops. These price changes are reflected in the increase in US imports and decrease in US exports of biofuels. Selected energy price and their percentage changes are found in Figure 12~13.

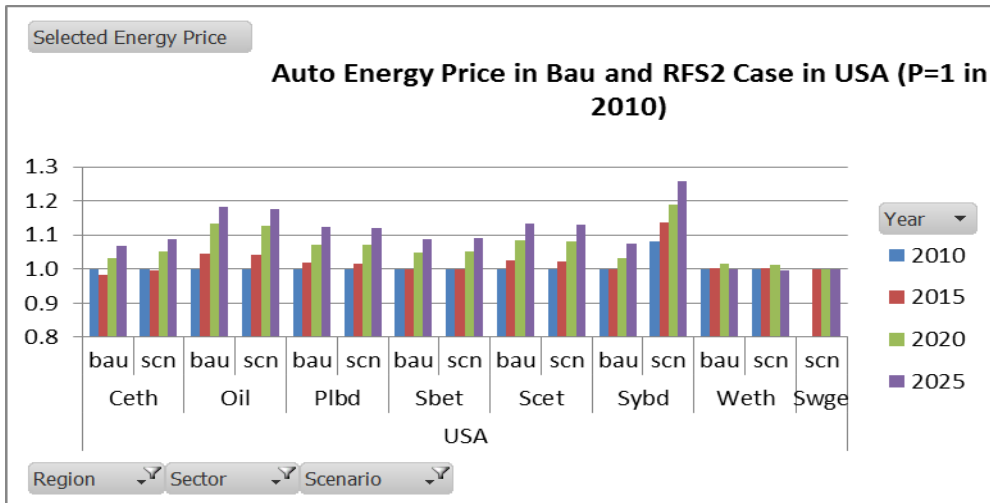


Figure 12. Auto Energy Price in the baseline and RFS2 scenarios

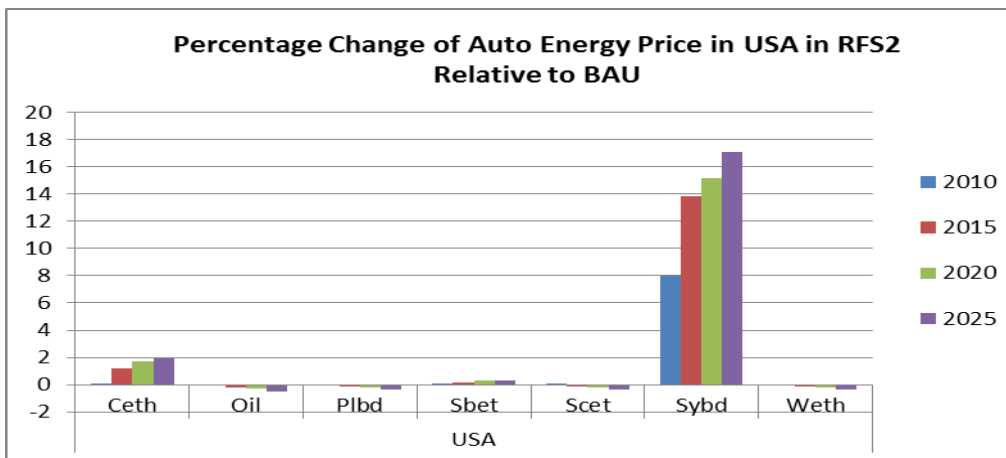


Figure 13. Percentage Change of Auto Energy Price due to RFS2 Policy (%)

Agricultural goods: Within the US, prices for all agricultural goods rise as land moves into the production of biofuels (see figure 10). The scarcity of land causes changes in the prices of crops of up to 3.5%, and smaller changes in the price of processed foods. Meat prices rise by less than 1% as increasing prices for land and feed are tempered by the increased supply of DDGs available as livestock feed. Forestry prices also increase by less than 1%. The changes in prices of meat and forestry products are sensitive to assumptions about the ease of land conversion and the yield of biofuels crops.

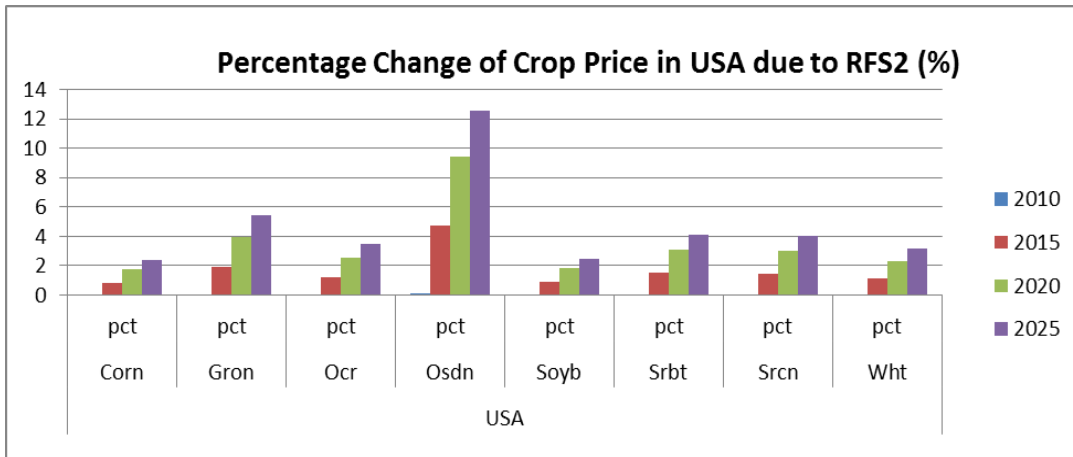


Figure 14. Percentage change of crop price in USA due to the RFS2 policy (%)

Internationally, prices of all agricultural prices fall because of the decrease in the world oil price. Because we assume that other countries do not have RFS policies in place in our scenario, international consumers can switch more easily from biofuels to cheaper oil, contributing to the decline in prices of biofuel crops. The US will import more of these crops as well as the final biofuels products.

4.2.3 Land Use Change

The increase in the production of cellulosic ethanol will require land to be used for the cultivation of switchgrass, a crop that does not appear in the baseline. Forcing a significant amount of land into this crop will raise land prices and reduce the land available to other sectors. The amount of land used by the other agricultural sectors in the US decreases by 8-12%. Land used in forestry and livestock in the US declines by over 9%. Globally, pastureland and forest decrease by less than one percent in area by region. Figure 8 presents the change in land use for livestock, forestry, and three crops in the US. Land use change in Brazil and Europe are also shown for comparison.

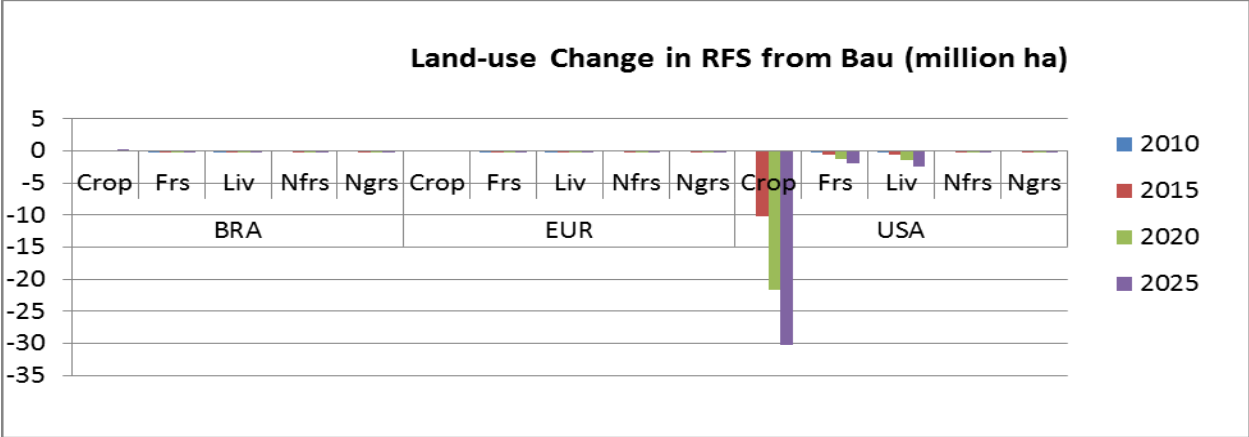


Figure 15. Land use change due to RFS2 policy in selected regions (million ha)

4.2.4 Carbon emission

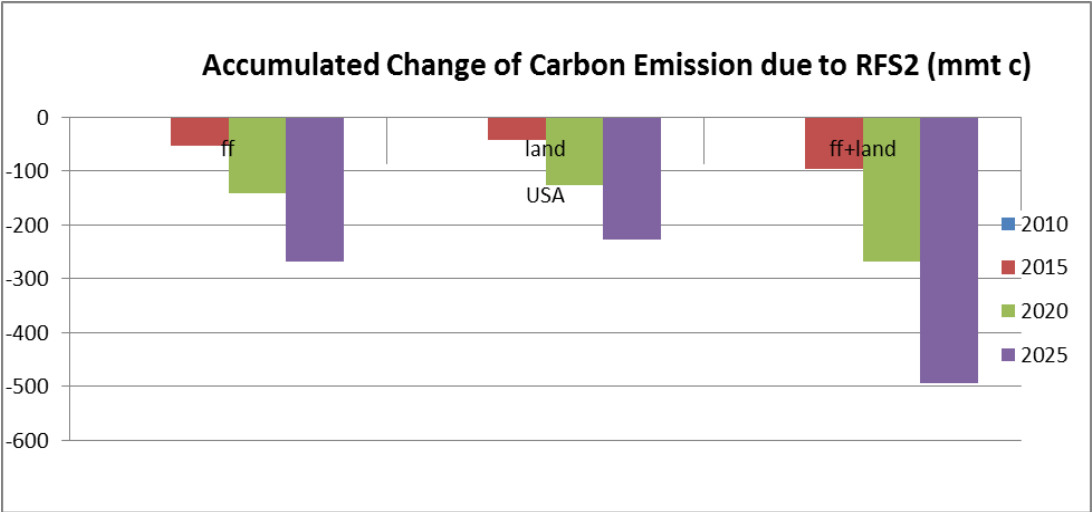


Figure 16. Change of accummulated carbon emission in US from 2010 to 2025 due to the RFS2 policy (mmt c)

4.2.5 GDP

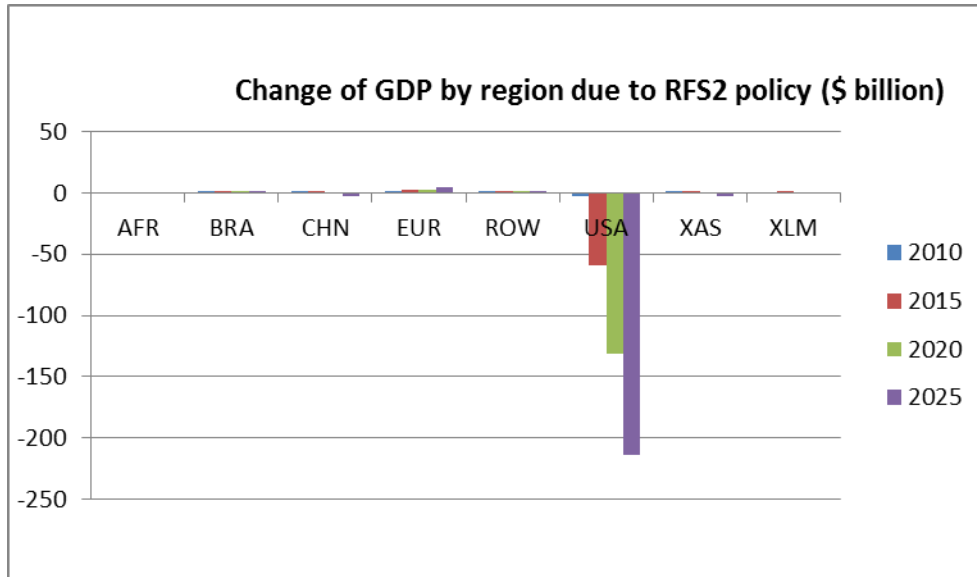


Figure 17. RFS2 impact on U.S. GDP (\$ billion)

5. Conclusions

Our results indicate despite of continued increase in land productivity and energy efficiency, increase in population and economic growth leads to a global-wide increase in agriculture production, rise in price of food, agriculture, biofuel and energy and land conversion from the other four land types to cropland in the BAU scenario from 2010 to 2025.

The implementation of RFS2 policy would have different global and regional implications on land-use changes, prices for food/agriculture and energy/biofuel, and carbon emissions. In the United States, the biofuel mandates require 36.3 million ha (mha) of land for switchgrass production by 2025, where 6.7 mha comes from corn, 4.7 mha from soybean, 6.0 mha from wheat, 17.6 mha from the rest crops, 0.9 mha from pasture, and 0.6 mha from managed forest land and none from natural grassland and natural forestland. Compared with the BAU scenario, price is projected to increase by around 5~7% for eight crops, 1.6% for livestock and 1.6% for forestry as a result of reducing production. Prices of biofuels increase slightly, by 4.1% for corn-ethanol, 1.3% for sugarcane- ethanol, and 2.8% for soybean-diesel. Since biofuel substitutes away from petroleum fuels in personal vehicle sector, oil price decreases slightly by 0.9%. Overall, the RFS2 policy would cost the United State \$68 billion in total, approximately

0.3% of GDP in 2025, where the personal vehicle sector alone would incur \$115 billion loss as the combined effect of declining oil consumption and oil price, which is not fully compensated from the gains of \$80 billion from corn-ethanol and switchgrass ethanol. While grain crops would lose \$2.1 billion GDP, the rest agriculture sectors gain \$12.5 billion in GDP.

Globally, due to reduction in agriculture exports from U.S. as a result of the RFS2 policy, all other regions would allocate slightly more land for crop and food production, leading to gentle loss of natural grassland and natural forestland, especially in Africa, which would lose 0.5 million ha of natural grassland for crop and livestock production.

The RFS2 policy would bring environmental benefits too. The accumulated carbon saving from 2010 to 2025 would be around 392 mmt c globally with 207 mmt c from fossil fuel and 185 mmt from land. Among it, U.S. alone would contribute 300 mmt c with 208 mmt c from fossil fuel and 92 mmt c from land.

The ADAGE-Biofuel represents the entire global economy, including eight crop categories, seven first generation biofuels, three second generation biofuels and five land categories explicitly. As such we are able to identify sectors with more details that face multiple pressures from land competition. Our preliminary analysis indicates although the RFS2 policy would enhance energy security in U.S. and reduce carbon emission globally, the United States has to bear some cost on loss of GDP and rising food/agricultural price. The results are comparable with reports from EPA (2010). When designing these kinds of biofuel-related policies, policy makers should be very cautious to take into consideration of benefits from enhanced energy security, environmental benefits/damage, as well as food security concerns especially in the developing countries.

References:

- Al-Riffai, P., B. Dimaranan, and D. Laborde. (2010). Global Trade and Environmental Impact Study of the EU Biofuels Mandate. Final Report Submitted to the Directorate General for Trade, European Commission.
- Birur, D.K., T.W. Hertel and W.E. Tyner (2008) "Impact of Biofuel Production on World Agricultural Markets: A Computable General Equilibrium Analysis". GTAP Working Paper No. 53, Center for Global Trade Analysis. Purdue University, West Lafayette, IN.

- EIA (2010) “*Annual Energy Outlook 2010*.” U.S. Energy Information Agency, Department of Energy. Washington, D.C. Available at: <http://www.eia.doe.gov/oiaf/aeo/>
- Gitiaux, X., S. Paltsev, J.M. Reilly, and S. Rausch (2009) “Biofuels, Climate Policy and the European Vehicle Fleet.” MIT Joint Program on the Science and Policy of Global Change, Report 176, Cambridge, MA.
- Gurgel, A., J.M. Reilly and S. Paltsev (2008) “Potential Land Use Implications of a Global Biofuels Industry.” MIT Joint Program on the Science and Policy of Global Change, Report 155, Cambridge, MA.
- Hertel, T.W., W.E. Tyner, and D.K. Birur (2010) “The Global Impacts of Biofuel Mandates.” *The Energy Journal*, 31(1): 75-100.
- IEA (2011) “Technology Roadmap – Biofuels for Transport.” International Energy Agency, Paris, France. Available at: http://www.iea.org/papers/2011/biofuels_roadmap.pdf
- IEA (2010) “*World Energy Outlook 2010*.” International Energy Agency (IEA), Paris, France.
- Ludena, C.E., T.W. Hertel, P.V. Preckel, K. Foster, and A. Nin (2007) “Productivity Growth and Convergence in Crop, Ruminant, and Non-Ruminant Production: Measures and Forecasts.” *Agricultural Economics*, 37(1):1-17.
- Melillo, J. M., A.C. Gurgel, D.W. Kicklighter, J.M. Reilly, T.W. Cronin, B.S. Felzer, S. Paltsev, C.A. Schlosser, A.P. Sokolov and X. Wang (2009) “Unintended Environmental Consequences of a Global Biofuels Program.” MIT Joint Program on the Science and Policy of Global Change, Report 168, Cambridge, MA.
- Narayanan, B.G. and T.L. Walmsley (Editors) (2008). “Global Trade, Assistance, and Production: The GTAP 7 Data Base.” Center for Global Trade Analysis, Purdue University, West Lafayette, IN.
- Reilly, J., J. Melillo, Y. Cai, D. Kicklighter, A. Gurgel, S. Paltsev, T. Cronin, A. Sokolov, A. Schlosser (2012): Using land to mitigate climate change: hitting the target, recognizing the tradeoffs. *Environmental Science and Technology*, 46 (11), pp 5672–5679.
- Ross, M. (2009) “Documentation of the Applied Dynamic Analysis of the Global Economy (ADAGE) Model.” Working Paper 09_01, April 2009, RTI International, Research Triangle Park, NC.
- Havlik P, et al. (2011) *Global land-use implications of first and second generation biofuel targets*. *Energy Policy*, vol 10, Page 5690–5702.
- Schnepf, R. (2010) “Agriculture-Based Biofuels: Overview and Emerging Issues.” Congressional Research Service 7-7500, R41282, June 22.
- Farzad Taheripour and Wallace E. Tyner (2013) “Land Use Emissions due to First and Second Generation Biofuels and Uncertainty in Land Use Emission Factors.” *Economics Research International*, vol 2013, Article ID 315787.

Taheripour, F., Hertel T. W., Tyner, W. E., Beckman J. F., & Birur, D. K. (2010). "Biofuels and their By-products: Global Economic and Environmental Implications". *Biomass and Bioenergy*, 34(3): 278-289.

USEPA (2011) "National Renewable Fuel Standard Program – 2010 and Beyond." Office of Transportation and Air Quality (OTAQ), U.S. Environmental Protection Agency (USEPA). Available at: http://www.usbiomassboard.gov/pdfs/epa_rfs_feb2011.pdf

USEPA (2010) "Renewable Fuel Standard Program (RFS2) Regulatory Impact Analysis" Report No. EPA-420-R-10-006. Assessment and Standards Division, Office of Transportation and Air Quality (OTAQ), U.S. Environmental Protection Agency (USEPA).