The Impact of Biofuel Mandates on Land Use

by

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ABSTRACT

The use of biofuels in domestic transportation sector in the United States and European Union is attributed mainly to the binding mandates, Renewable Fuel Standard in the US and European Directive on the Promotion of Renewable Energy in the EU. The mandates have triggered production of first generation technologies that have been around for centuries and use food crops like corn or sugarcane as inputs and the second generation technologies that are still being developed but rely on cellulose or waste material. This raises important questions, what are the implications of policy mandates and biofuel production on land use change, global food crop prices and fuel blend technology as the binding mandates will rely mainly on first generation fuel technologies for the foreseeable future.

Most analysis of policy mandates and biofuel production technologies leave out the land use change impact assessment. To investigate the questions I focus on how the mandates in the US and EU interact with land use. I use a computable general equilibrium framework, the MIT Emissions Prediction and Policy Analysis (EPPA) model, which captures full economy-wide impacts of policy mandates and land use. I have developed a mechanism to integrate the first and second generation technologies, the transportation sector, and land use for policy impact analysis. I simulated the policy mandates through a permit trading system which is constrained by the blend wall technology of the underlying vehicle transportation fleet.

I find that the global biofuel crop land requirement over 2005 to 2030 time frame is 44 percent higher with the mandates. The land requirement is met primarily by the reallocation of non-biofuel crop land and partially by pasture, natural grass and harvested forest lands. The long term food crop prices increase by less than 1% per year with mandates as land productivity improvements dampen the impact of biofuel production on prices. In the case of global biofuel free-trade Brazil becomes the largest producer which reduces the deforestation in Brazil by 7 percent. I also find that fuel blend-wall acts as an implicit constraint on the domestic biofuel use as it limits the total vehicle fuel consumption.

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1. INTRODUCTION

The economic and national security concerns in the United States and the European Union over the decades have triggered debate and policy efforts focused on reducing dependence on foreign sources of crude oil. Recent price fluctuations, long term rising trend in crude oil prices and growing energy needs of the emerging economies has put pressure on EU and US policy makers to reevaluate the policies encompassing the overall domestic fuel consumption and specifically transportation fuel consumption. In the US 29% of total energy consumption is in the transportation sector (EIA 2009) and in the EU the transportation sector accounts for 31.5% of total energy consumption (EEA 2009). The international efforts on addressing global climate change along with national policies to promote domestic rural economies have put renewable biofuels at the forefront of policy debates and legislative prescriptions.

As an antidote to the global and domestic challenges, policy makers in both the United States and European Union have enacted an array of policies over the years at regional, national and state levels to promote the consumption and production of biofuels. As shown in Table 1, the policies range from tax credits for consumption, fuel subsidies for production, loan guarantees to incentives capacity investments, research grants to explore new methods and feedstock for production, import tariffs to protect domestic producers and most importantly minimum usage requirements or mandates to create a guaranteed market for biofuels in the economy.

Any fuel produced from biological materials- whether burned for heat or processed into alcohol- qualifies as a biofuel. The most often use of the term happens in the domain of transportation fuels produced from some type of biomass. Biomass is considered to be an organic matter that can be converted into energy. Examples of biomass include oilseed or grain crops, energy crops (e.g. switch grass), algae, municipal solid waste etc. The definition of biomass and the fuels that qualify as biofuels has evolved over the years with different connotations and meanings and reflects varying objectives governing the enactment of legislative policies. The primary cause of this evolution and broadening of scope is the alteration of objectives and political rational behind the domain specific policies.

In the thesis I will focus on the biofuel mandates in the United States and European Union. I will discuss the different technology pathways for biofuel production, effects of biofuel mandates on production, and study the interaction of this policy technology system with land use change, transportation vehicle fuel technology and food crop prices.

The thesis is divided into five sections, the purpose of chapter 1 is to introduce the context of my research, explain the structure of the thesis and highlight the technology policy areas. The first part of the chapter 2 will focus on the biofuel technologies (first and second generation) and policies implemented in the research model (Renewable Fuel Standard and Renewable Policy Directive for biofuel use in the US and EU respectively). The later part of the chapter will describe the research question, rational of biofuel related policies and explain the important issues affecting biofuels production and mandates. I will establish the context of research work within the confines of existing literature and policy questions and discuss the technical, environmental, political and economic issues.

The goal of chapter 3 is to describe the research methodology and explain how it depends on the use of Emissions Prediction and Policy Analysis (EPPA) model. The main focus of the chapter is to describe the implementation of biofuel mandates, first and second generation biofuels and crop production in the model. I will detail the process of generating different production blocks and input shares. I will describe the underlying principles and assumptions and explain how the new modifications are coherent and consistent.

In the chapter 4 I will discuss the validity of the research question and test different hypothesis given the simulation results of the model. I will describe the different scenarios implemented and the rational for doing so. The subsequent analysis and commentary in the chapter will discuss the results, research question, and the findings.

The chapter 5 will conclude the thesis, summarize the important findings and detail the future research areas worth exploring.

Table 1. Policy Areas with US and EU policy examples

POLICY AREA	UNITED STATES	EUROPEAN UNION
Tax Credits	Volumetric Ethanol Excise Tax Credit	EC Directive 2003/96/EC for Biofuel Tax Credits
	Cellulosic biofuels Production Tax Credit	EC No. 1782/2003 for Energy Crop Payments
Import Tariffs	Ad Valorem Tariff of 2.5%	Ad Valorem Tariff of 6.5%
Volume Specific Usage Mandates	Renewable Fuel Standard (RFS)	EC Directive 2003/30/EC for mandated biofuel use

2. BACKGROUND

The first part of this chapter will focus on the biofuel technologies (first and second generation) and policy mandates implemented in the research modeling system (Renewable Fuel Standard and Renewable Policy Directive for biofuel use in the US and EU respectively). The later part of the chapter will describe the research question and explain the important issues affecting biofuels production and mandates. I will establish the context of research work within the confines of existing literature and policy questions and discuss the technical, environmental, political and economic issues.

2.1 Technology Pathways

Biofuels are produced through different technology pathways, which can be viewed as input output processes. The inputs are feedstock (e.g. corn, sugarcane, cellulosic material), energy (e.g. coal, natural gas), and other supplementary yet essential resources (e.g. water). The processing can be based either on a very specific patented technology or a more general process (e.g. enzymatic, fermentation, gasification). The output of the system can be a fuel liquid or gas (e.g. ethanol, biodiesel) and other byproducts (e.g. polymers, animal feed). Figure 1 elucidates the different biofuel production pathways.

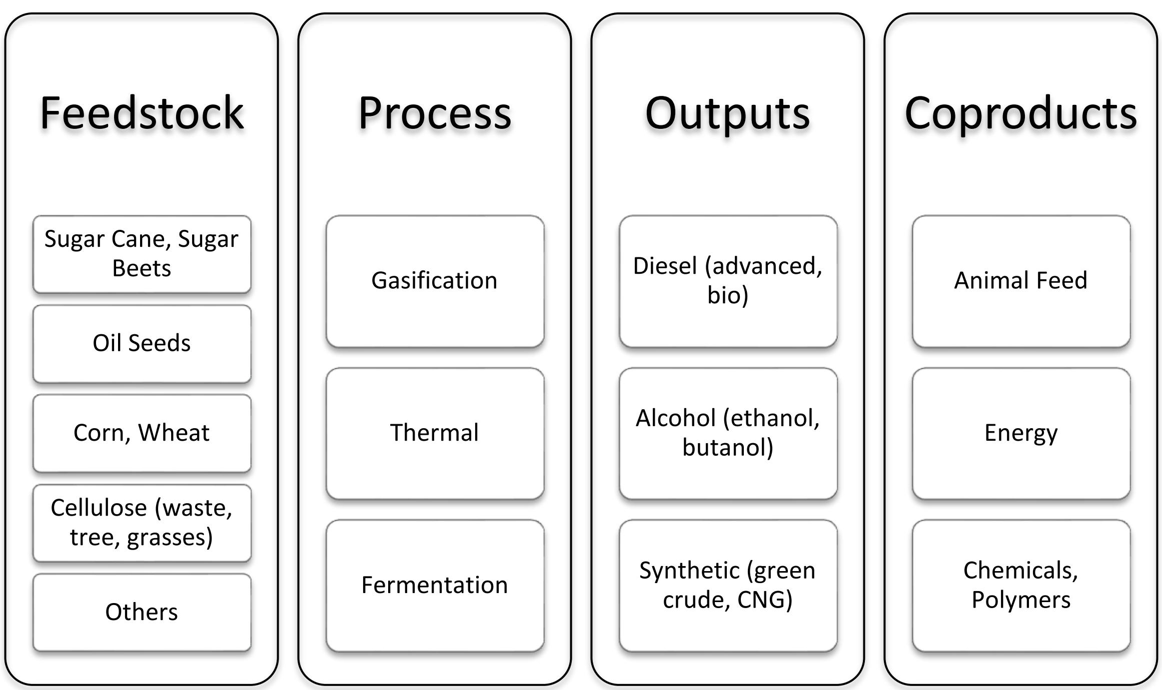


Figure 1. Examples of Biofuel Technology Pathways

The important observation is that biofuel technology is continuously evolving with the adoption of new feedstock and processes. Primarily the technologies can be classified as first generation that have been around for centuries and use food crops like corn or sugarcane as inputs and the second generation that are still being developed but could use cellulosic feedstock such as switch grass or corn stover. The more advanced generation fuels such as those from algae or municipal solid waste can be classified as advanced second generation biofuels. The two major classifications of biofuels are ethanol and biodiesel. Figure 2 shows the world biofuel consumption by type over the years.

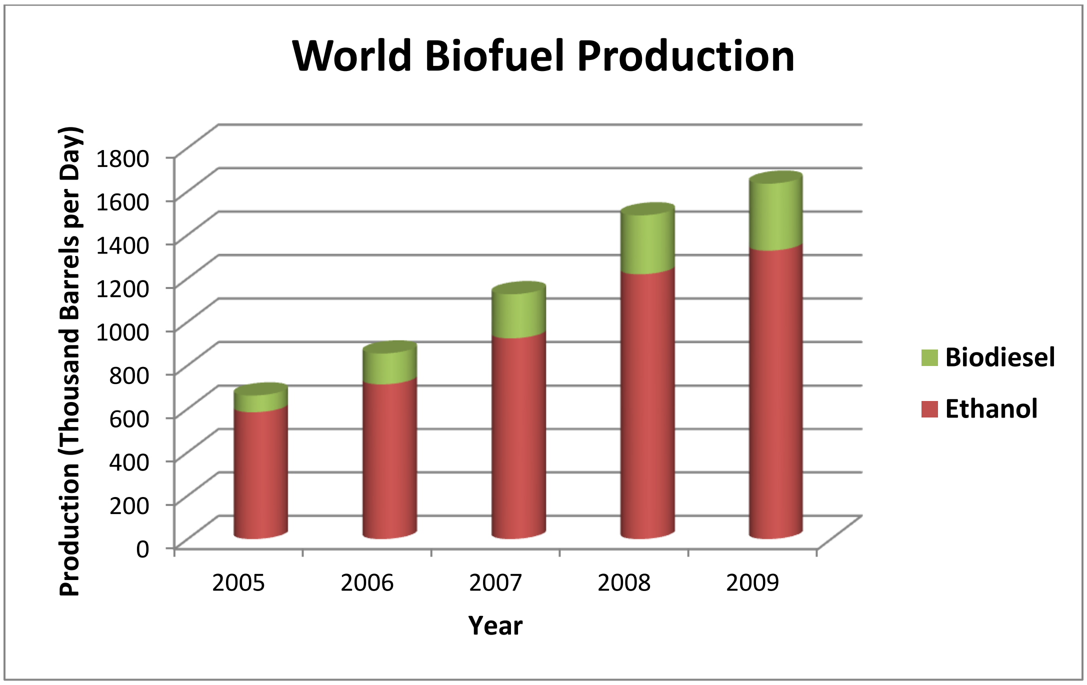


Figure 2. World Biofuel Production (thousand barrels per day), Source: (EIA 2011)

2.2 Biofuel Mandates in United States and European Union

The section will focus on the policies implemented in the modeling system, I will detail the policies and the intricate aspects of different classes of biofuels as described in the mandates.

2.2.1 Renewable Fuel Standard (RFS) in United States

The renewable fuel standard mandates a minimum volume of renewable biofuels to be blended in the US national transportation fuel supply. The initial RFS (sometimes referred as RFS-I) was enacted in 2005 as part of Energy Policy Act of 2005 (EPAct 2005) and mandated a minimum of 7.5 billion gallons of renewable fuel to be used in the nation’s gasoline supply by 2012. In 2007, the Energy Independence and Security Act of 2007 (EISA 2007) greatly expanded the biofuels mandate to 36 billion gallons by 2022 as shown in Table 2. This expanded RFS is sometimes referred to as RFS-II and applies to all the transportation fuel used in the United States (diesel and gasoline). RFS is administered by EPA and involves tradable certificates called Renewable Identification Numbers (RINs). Fuel blenders are required to incorporate mandated volumes of biofuels in their annual transportation fuel sales irrespective of market prices.

Renewable Fuel Standard sets the mandated usage volumes and extends the time frame for policy from 2007 to 2022. RFS subdivides the total renewable fuel requirements into corn based ethanol with an annual cap at 15 billion gallons from 2015 onwards and advanced biofuels—total non-corn starch biofuel, biomass-based diesel, cellulosic ethanol, and others—each within its own volume requirement or standard. The biofuel categories mentioned in the RFS have a designated volume mandate, lifecycle GHG emission reduction thresholds and are contingent on defined biomass feedstock.

Table 2. Renewable Fuel Standard RFSII and RFSI

EISA Renewable Fuel Volume Requirements (billion gallons)				
Year	**Cellulosic biofuel requirement**	**Biomass-based diesel requirement**	**Advanced biofuel requirement**	**Total renewable fuel requirement**
2008	n/a	n/a	n/a	9.0
2009	n/a	0.5	0.6	11.1
2010	0.1	0.65	0.95	12.95
2011	0.25	0.80	1.35	13.95
2012	0.5	1.0	2.0	15.2
2013	1.0	a	2.75	16.55
2014	1.75	a	3.75	18.15
2015	3.0	a	5.5	20.5
2016	4.25	a	7.25	22.25
2017	5.5	a	9.0	24.0
2018	7.0	a	11.0	26.0
2019	8.5	a	13.0	28.0
2020	10.5	a	15.0	30.0
2021	13.5	a	18.0	33.0
2022	16.0	a	21.0	36.0
2023[+]	b	b	b	b

[a] To be determined by EPA through a future rulemaking, but no less than 1.0 billion gallons.
[b] To be determined by EPA through a future rulemaking.

Table 3. Mandated Reductions in Lifecycle GHG Emissions by Biofuel Category

Lifecycle GHG Thresholds Specified in EISA (percent reduction from 2005 baseline)	
Renewable fuel [a]	20%
Advanced biofuel	50%
Biomass-based diesel	50%
Cellulosic biofuel	60%

[a] The 20% criterion generally applies to renewable fuel from new facilities that commenced construction after December 19, 2007, thus exempting existing plants from any lifecycle GHG reduction requirement.

Biofuel type within each category must achieve certain minimum threshold of lifecycle greenhouse gas (GHG) emission performance to qualify for the RFS mandates as shown in Table 3. The feedstock for the biofuel must also qualify under the renewable biomass definition. Important biofuel classifications and definitions are as described.

(a) Total Renewable fuels. The mandate for the biofuels grows from 13.95 billion gallons in 2011 to 36 billion gallons by 2022 and must reduce the lifecycle GHG emissions by 20% compared to equivalent fossil fuel GHG emissions. The mandate also enacts a cap on corn based ethanol at 15 billion gallons by 2015 and remains the same thereafter.

(b) Advanced Biofuels. The mandate grows from 1.35 billion gallons in 2011 to 21 billion gallons in 2022. These fuels must reduce GHG emissions by 50% to qualify under the mandate. The category contains cellulosic biofuel, biodiesel and other non-corn biofuels.

(c) Cellulosic Biofuel. The mandate grows from 6.6 million gallons in 2011 to 16 billion gallons by 2022. Cellulosic biofuels must reduce the lifecycle GHG emissions by a minimum of 60%. This category includes cellulosic biomass ethanol as well as any biomass to liquid fuels.

(d) Biomass Biodiesel. The mandate grows from 0.8 billion gallons in 2011 to 1 billion gallons at minimum moving forward. The lifecycle GHG emission reduction threshold is 50%.

The nested nature of the biofuel categories means that any renewable fuel that meets the requirement for cellulosic biofuel or biomass-based diesel is also valid for meeting the requirements for advanced biofuel requirement. Similarly any biofuel that fulfills the requirement for advanced biofuels is valid for meeting the total renewable fuel requirement and any combination of advanced biofuels that exceeds the advanced biofuel mandate will reduce the requirement for corn-starch ethanol to meet the overall mandate.

2.2.3 European Union Directive on Biofuels

Under Directive 2003/30/EC European Union established the binding goal of reaching a 5.75% share of renewable energy in the transport sector by 2010. The goal was revised under the new EU Directive on the promotion of renewable energy in 2009; this share rises to a minimum of 10% in every member state by 2020. The new directive on renewable energy also aims to ensure that the use of biofuels in the EU is sustainable and generates clear and net GHG savings and has no negative impact on biodiversity and land use.

EU commission cited energy security and greenhouse gas emissions as main reasons for the enactment of the EU directive. In EU member countries energy consumption in the transport sector depends almost exclusively on imported fossil fuels. The sector is forecast to grow more rapidly than any other up to 2020 and beyond. The sector is considered vital to the functioning of the whole economy and requires policy action to reduce its malign contributions to environmental degradation and the insecurity of Europe's energy supply. GHG emissions resulting from transport account for 21% of the total emissions of greenhouse gases and necessitate the use of fuels that are less polluting than oil along with the urgent need to guarantee the security of energy supplies by diversifying fuel sources. Definitions of biofuel related terminologies considered by EU are as described.

- **(a) Biofuel:** liquid or gaseous fuel used for transport produced from biomass.

- **(b) Biomass:** the totality of organic animal or vegetable matter. This includes in particular the biodegradable fraction of products, wastes and residues from agriculture, forestry, industry and households.

- **(c) Biodiesel:** a methyl-ester produced from vegetable or animal oil, of diesel quality, to be used as biofuel.

- **(d) Bioethanol:** ethanol production from the fermentation of plants rich in sugar/starch, to be used as biofuel.

2.3 Research Question

The policies enacted in the US and EU are responsible for increased demand of biofuels in the transportation sector e.g. subsidies, tariff, mandates etc. The increased demand has driven explosive growth in the production of biofuels primarily through the first generation technologies which rely heavily on food crops for the feedstock input. The increased use of first generation fuels, the slow progress in commercialization of second generation fuels (non-food crops) accompanied with annual compliance requirements of policy mandates both in the US and EU has raised serious concerns about the sustainability of biofuels and potential leakage effects of the policies on other parts of the world economy as alluded by (Walsh 2008).

The policy tradeoffs between economic benefits to rural economies, perceived beneficial environmental impact and enhancement of energy security through domestic fuel sources as opposed to huge government expenditure, pressure on food crops, land use change and potential indirect environmental damages have necessitated the need for a careful study and analysis of these tradeoffs and unintended effects of biofuel mandates.

The focus of my research effort is to identify and study the implications of biofuel mandates in the US and EU on regional land use change, global food crop prices and vehicle fuel technology. Foremost the research will try to elucidate the land use change in different regions of the world given the demand for the biofuel crop land. The land use change is expected to be affected by the need for arable land to produce additional biofuel crops. The research inquiry will further explore the implications of land productivity improvement, price trends of global food crops, international biofuel free trade impacts, and fuel blend-wall constraint on the vehicle fleet.

The study of these aspects is undertaken through an experimental design implemented in a controlled environment of a computational economic model (EPPA). The methodology of inquiry is based on comparing different scenarios designed around the US and EU mandates, land use change, blend-wall levels, trade, cropland productivity and cost competitiveness of various biofuel technology pathways.

The complex interaction of various economic, social and technological agents as a result of renewable fuel mandates has been responsible for a vigorous debate and conflicting viewpoints. The proponents argue that the benefits of these policies and increased use of biofuels produced domestically will result in increased farm incomes, rural development, greenhouse gas reductions, and national energy security. They also make the case for continued investment in innovation as technological change will lead to more sustainable sources of biofuels in the future and governments should continue with the current policy portfolio to speed up or at least maintain the current progress of innovation.

Critics argue that biofuel policies distort the energy markets and are responsible for channeling the resources towards economically and environmentally less efficient technology prescription, since the limited resources allocated to biofuels can be more efficiently utilized in the development of other renewable sources of energy such as solar and wind. They argue that the biofuels mandates have taken public and private investment to less beneficial and inadequate technology which will compromise the intended policy aims, due to indirect effects of land use change, food price pressures and leakage effects of biofuel trade (Grunwald 2008).

2.4 Issues Affecting the Biofuel Mandates

The section will cover the rational of biofuel related policies and explain the issues affecting biofuels production and mandates. I will establish the context of research work within the confines of existing literature and policy questions and discuss the technical, environmental, and economic issues.

There are several important factors that impact the suitability of RFS and EUD mandates given the somewhat vague and contradictory policy goals of energy security, lifecycle GHG emission reductions and sustainability. The objectives and pathways to achieve these goals are based on the values, perceived strengths of the underlying socio-economic systems and patriarchal concerns of the legislative or governing institutions and countries.

2.4.1 Energy Supply and Demand

It is important to put these issues within the context of overall energy consumption debate. At the turn of 21st century the world's commercial energy consumption was about 400 exa-joules (EJ) per year, with fossil fuels contributing about 85% and all others (nuclear, biofuels, hydro, wind, solar) contributing only 15%. Typical projections of the world economy imply energy demand in 2050 of 550-1000 EJ per year, depending on resource availability, and the price, scope and effect on energy demand of policies to limit greenhouse gas (GHG) emissions and air pollutants (Clarke et al., 2007). To limit the GHG emissions, we will need a variety of low-carbon energy sources operating at a very large scale; for example, sources supplying 55-100 EJ/year would meet only about 10% of the estimated demand.

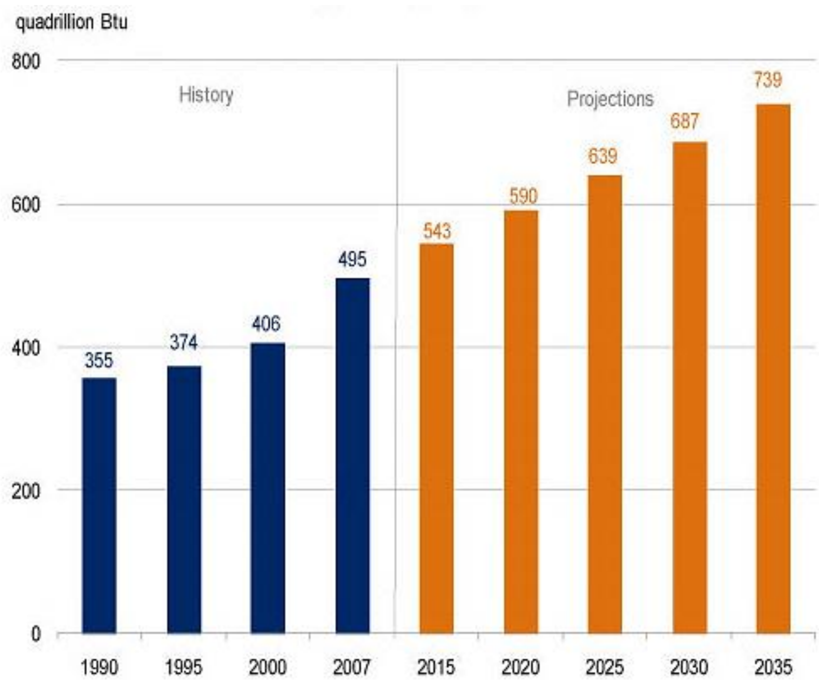


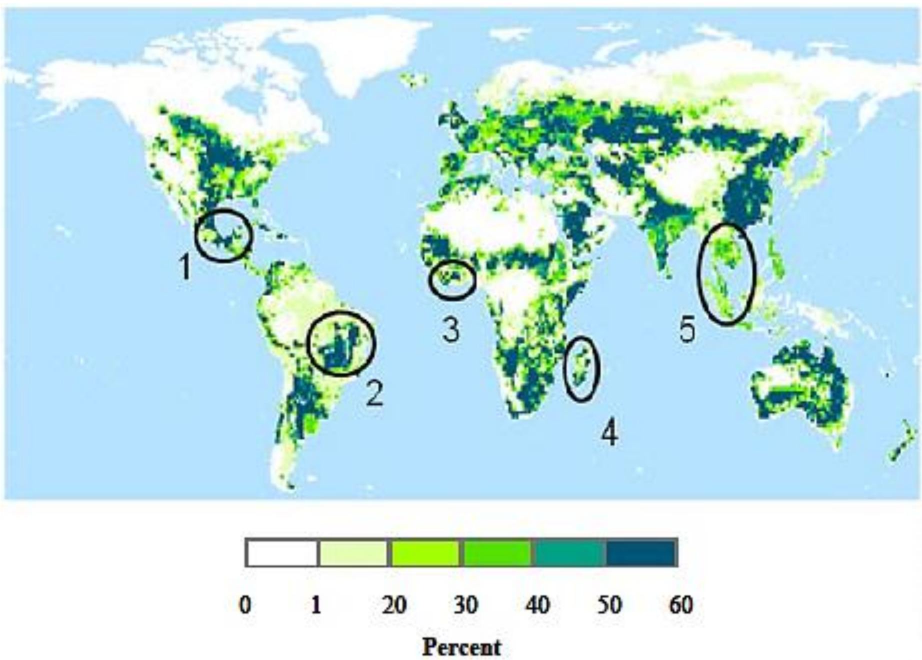
Figure 3. World Marketed Energy Consumption (quadrillion BTU) 1990-2035, Source: (EIA 2010)

One of the major question marks hanging over the biofuel technology is its ability to scale up to the levels needed for the world transportation needs. The economies of China, India, South Africa and Brazil have robust growth in their vehicle fleet and the consequent demand pressure on world fuel supplies on one hand and the increase GHG emissions on the other, are bound to pose significant challenges to food crop based biofuels and technologically underdeveloped advanced biofuels from sources like waste, cellulose and algae.

2.4.2 Environment and Biodiversity

Enactment of RFS and EUD mandates has led to a heightened emphasis on the social and environmental costs of current biofuels technologies as discussed by (Tilman et al. 2006; Fargione et al. 2008; Scharlemann & Laurance 2008; Searchinger et al. 2008; The Royal Society 2008). Increased production of biofuel crops due to mandates has the potential to compete with food production for arable land. In addition, increased biofuels production will require the conversion of natural lands with resulting carbon emissions, threats to biodiversity, and likely increased use of fertilizers and pesticides. At the same time, a growing population will create increasing demand for food, while changes in the climate, CO_2 and tropospheric ozone will affect land requirement and the location of production activities.

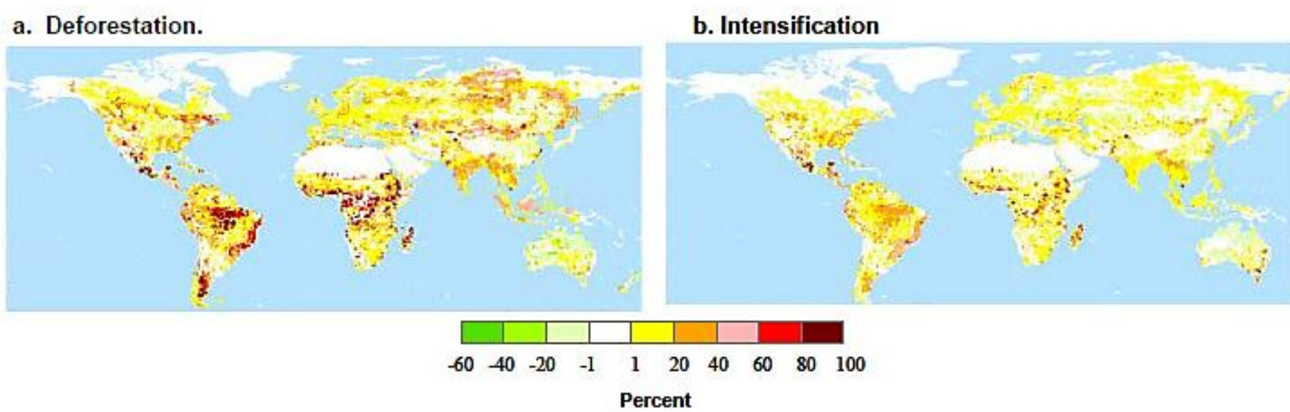
First generation biofuel production requires the use of fossil fuels (natural gas or coal) as an energy source which minimizes the CO_2 benefits, and they also rely on crops such as maize, rapeseed or oil palm for feedstock input which raises questions about sustainability. The competition for these crops and for land significantly affects the food prices and creates additional pressure for deforestation. The effects of land use change are not only limited to crops and forests, but also impact the soil fertility, biodiversity and wildlife habitat as shown in the Figure 4.



*Data shown is for circa 2000 and expressed as the percentage of each ½ by ½ degree grid cell devoted to the crop and pasture agriculture. Several biodiversity hotspots are circled – Mesoamerican forests (1); the cerrado of Brazil (2); the Guinean forests of West Africa (3); Madagascar (4); and the forests of Southeast Asia (5)

Figure 4. Natural areas in many biodiversity hot spots have already been converted to crop and pasture agriculture and limited remaining areas would face more threats from biofuels expansion, Source: (Melillo et al. 2009)

While the first generation biofuels are capped at specific levels, the shortfalls created due to lack of progress in second generation fuels will likely result in the introduction of costly alternative crops like wheat or sugar-beet ethanol or other capital intensive sources like waste treatment, import of sugar ethanol from Brazil and palm-oil from Indonesia and Malaysia. The imports are likely to have a counter effect to the main policy goals of energy security and domestic development. The exports of biofuels from these regions will in turn lead to leakage effects and put land use pressure on forest land in those regions as shown in Figure 5.



*Data expressed as the percentage of each ½ by ½ degree grid cell devoted to agricultural and cellulosic biofuels production

Figure 5. Loss of natural areas due to their conversion to crop and pasture agriculture and cellulosic biofuels between 2000 and 2050 as simulated by the deforestation (a) and intensification (b) scenarios, Source: (Melillo et al. 2009)

Analysts have long understood that there will be food price, biodiversity and environmental consequences even for an industry that is supplying no more than a few percent of fuel use. The potential use of corn stover for cellulosic biofuels, intensive crop production pattern for higher production levels and use of marginal land could result in diminished soil fertility and increased soil erosion.

While the land use implications have a network effect on the global and domestic economies, the effects of the biofuel use and mandates are not limited to agricultural sector only. The demand for high volumes of water and natural gas for biofuel production will likely lead to significant challenges for water resource availability and energy markets. The increased use of chemicals for high yields on crop land may also lead to run-off or leaching in water resources. As shown in Figure 6 the construction of new and existing biofuel production facilities will be highly dependent on generous water supplies and are bound to put significant pressure on water resources.

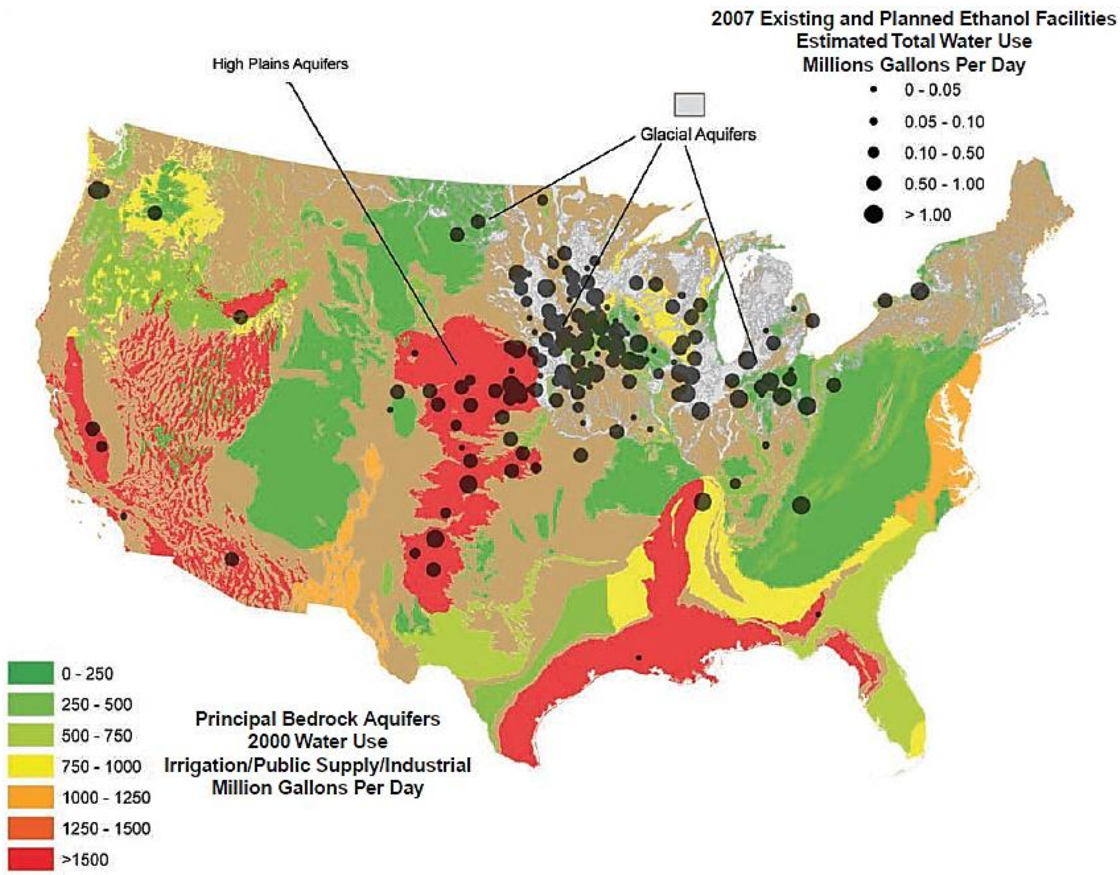


Figure 6. Existing and Planned Ethanol Facilities (as of 2007) and their Estimated Total Water Use mapped with the Principal Bedrock Aquifers of the United States and Total Water Use in 2000, Source: (GAO 2009)

2.4.3 World Food Crop Supply and Feedstock Prices

Rising competition for available cropland between biofuel feedstock and other field crops, along with intensification of agricultural activity on the EU and US cropland to meet the ever increasing demand for food, fuel and animal feed is exerting price pressure on other agriculture markets as described by (Walsh 2011).

First generation biofuels (corn, wheat, soy oil etc.) have a potential to unsettle the agricultural markets, e.g. corn in the US and wheat in the EU will compete with other grains for the land. Animal feed prices will likely increase due to the higher price of feed grains, and agriculture inputs of pesticide and fertilizers will likely have increased demand due to the intensive use of these agents for better crops yields. The land prices and total crop land area will also increase as the demand for feedstock crops rises. In 2001, US national ethanol production was about 7% of the US corn crop but by 2010 the share had jumped to 39% as indicated in Figure 7.

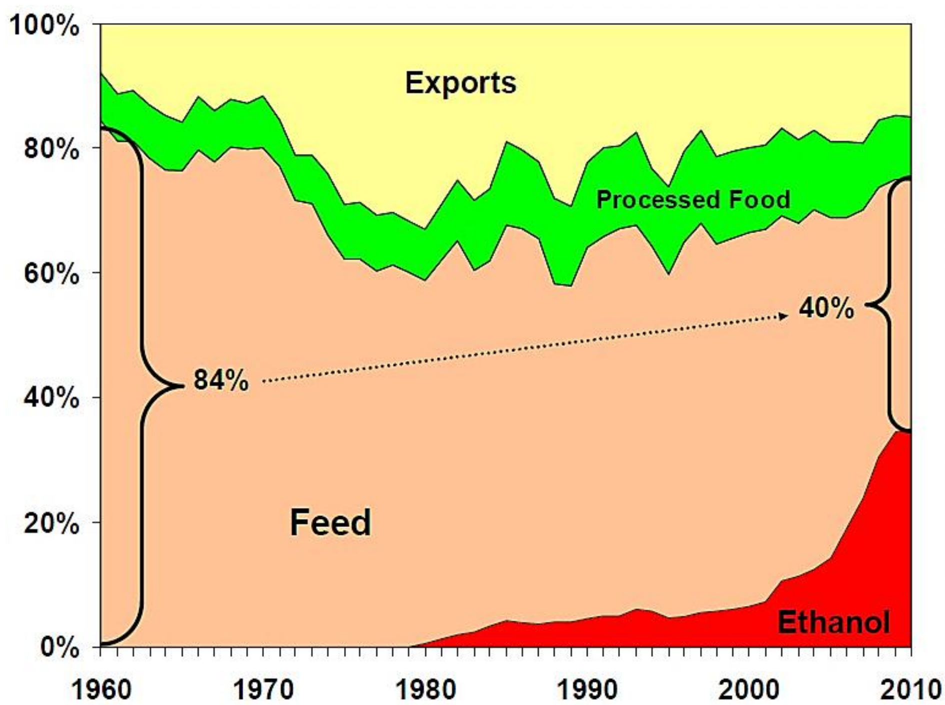


Figure 7. Annual U.S. corn disappearance as a percent of total use, excluding stocks, Source: (Schnepf 2010)

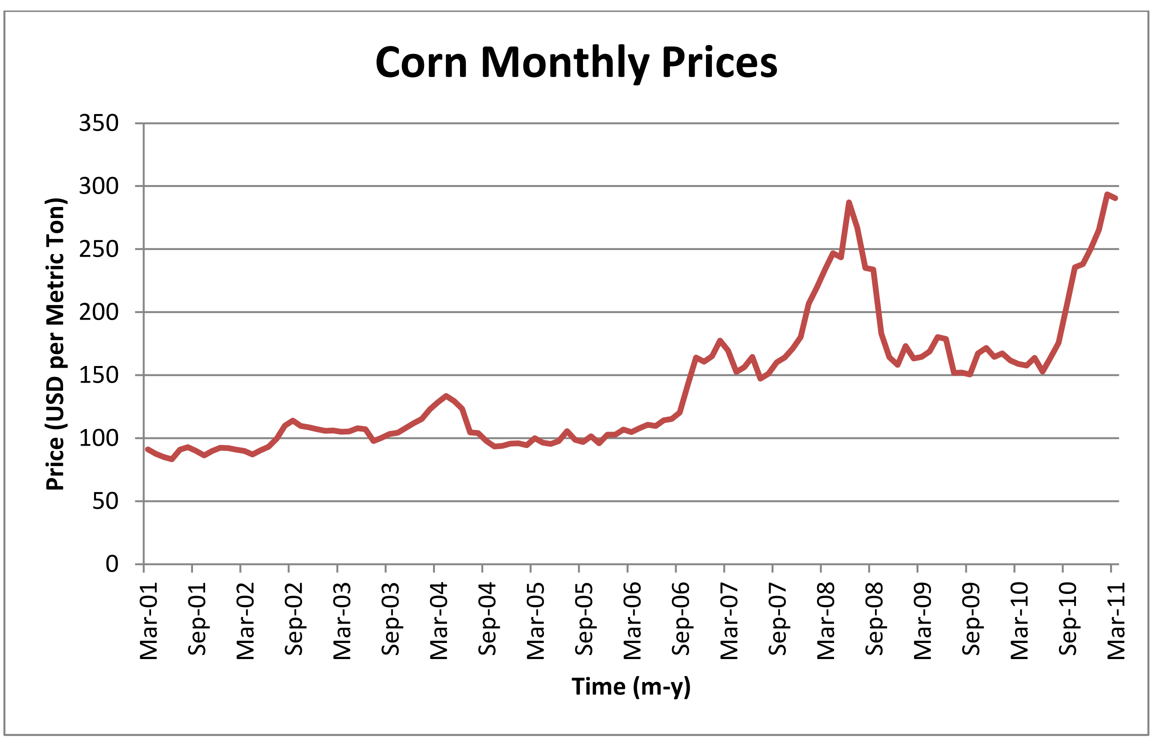


Figure 8. Monthly US Corn Prices 2001-2010, Source: (FAO 2011)

In 2008 the market prices for several agricultural commodities in the US reached record or near record levels. In particular, corn hit record high prices in both spot and futures markets as shown in Figure 8, this has consequences for poorer consumers worldwide. European blending requirements and the demand for biodiesel, in particular have been linked to expanding oil palm plantation and deforestation in Indonesia. The promise of improving farm income has been realized as commodity prices have risen sharply, but the success also illuminates the limits of biofuel technology in providing sustainable domestic supply of energy. Figure 9 summarizes the complex interactions of biofuel related regulatory and economic agents (GAO 2009).

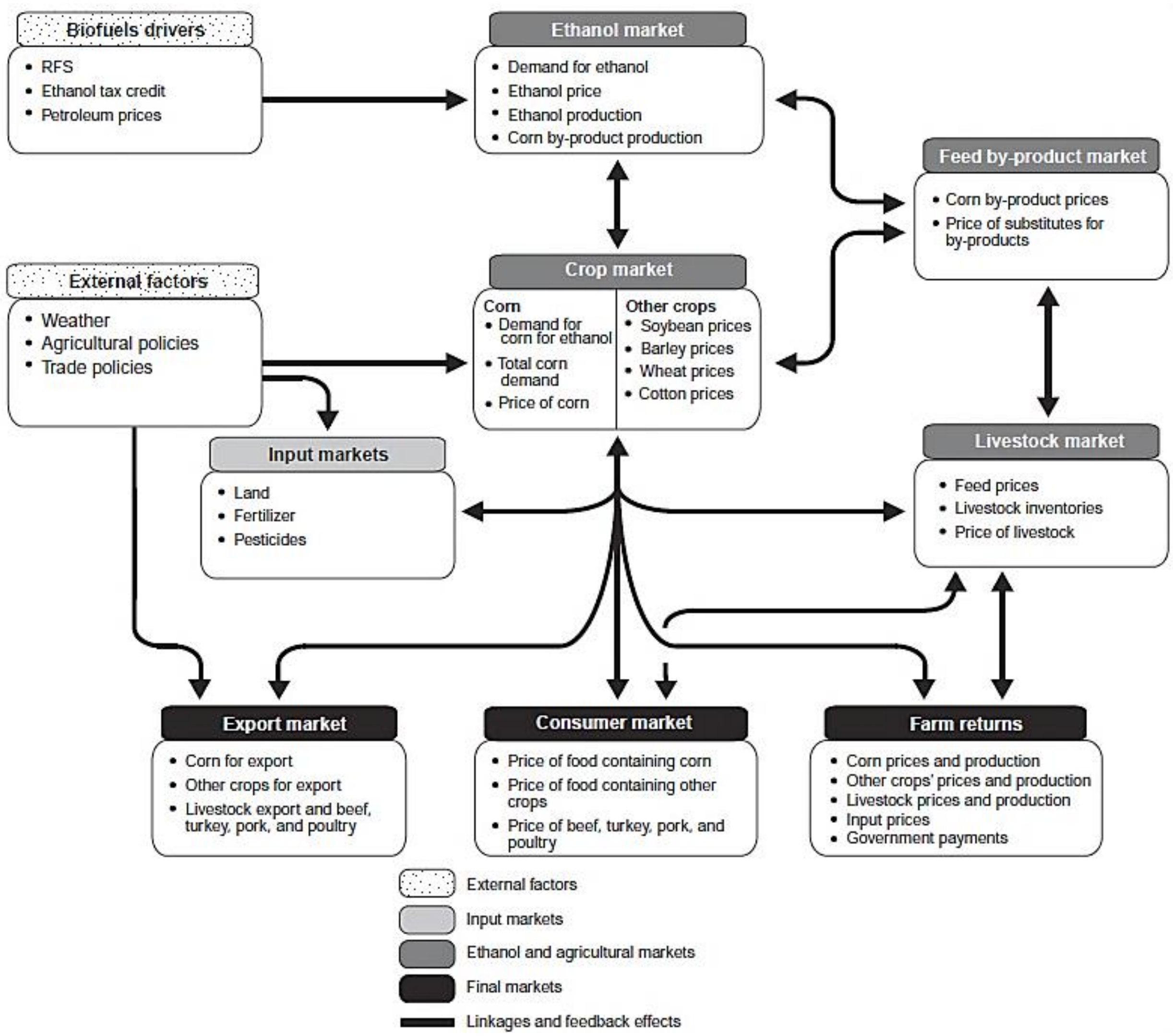


Figure 9. Economic Linkages of Ethanol Production to Food and Agricultural Markets, Source: (GAO 2009)

2.4.4 Technical and Infrastructure Challenges

As first generation biofuels put significant pressure on various markets shown in Figure 9, the slow pace of technological advancements in second generation biofuels (cellulosic, switch grass etc.) is expected to fall short of the expected targets as laid forward by biofuel mandates. Cellulosic crops tend to be heavy and represent significant challenges in terms of harvesting, transporting and storing.

The RFS mandate in the United States calls for a substantial increase in the share of cellulosic biofuels from 3 billion gallons per year in 2015 up to 16 billions of gallons per year in 2022. Such a demand-pull mechanism represents a prodigious challenge to the biofuels industry in light of the fact that no commercial production of cellulosic biofuels yet exists. Such an ambitious target relies on the assumption from the Department of Energy that cellulosic ethanol will be competitive with corn-based ethanol by 2012 (at $1.82/gallon-equivalent gasoline in 2007 dollars). However (Gurgel et al. 2008) report that the breakeven point for the cellulosic conversion is currently closer to $4.00/gallon-equivalent gasoline. Therefore without major breakthrough down the road, the EISA requirement for cellulosic ethanol will imply a substantial amount of subsidies to make cellulosic conversion cost-competitive with starch-based process.

Table 4. Number of US Registered Highway Vehicles 2007, Source: (NHTSA 2001)

Vehicle Type	Number (millions)	Ratio (Percent)
Primarily Gasoline Motors		
Passenger Cars	135.9	53.4%
Flex Fuel Vehicles	8.0	3.1%
Total Vehicles	254.4	100%

One of the major technical challenges with mandates is a limitation with conventional fuel injection engines designed to run on fossil fuel containing no more than 10% of biofuels. Currently most of the car manufacturers will only warrant their engines if they are fuelled with ethanol blend of 10% or less, which is marketed as E10. In fact, blend higher than 10% cannot be marketed as conventional gasoline in the United States (ASTM 2009). This 10% is now an upper bound – sometimes referred to as the "blend wall" - to the level of ethanol that can be introduced in the pool of conventional gasoline. Testing is currently being carried out to examine the compatibility of existing vehicles and distribution facilities with the higher blend, such as E15 or E20 (with 15-20% of ethanol and 80-85% of gasoline). Preliminary results from (NREL 2009) conclude the absence of major modifications in tailpipe emissions, and in the operability of engines with E20 fuel. However, further testing is still needed especially for terminal tanks, tanker trucks, retail storage tanks, pumps, etc.

Moving to E15 or E20 is a crucial issue as it will allow meeting the RFS target with few (if any) modifications to existing vehicles and infrastructure. Otherwise, requirement above 10% needs the expansion of a flex-fuel fleet capable of any mix between E10 and E85 (85% ethanol and 15% gasoline). These vehicles are popular in Brazil where they account for 84% of the sales at the beginning of 2009 according to numbers from (ANFAVEA 2011). In the U.S. these vehicles have been introduced in response to the fuel-economy compliance credits offered by the Department of Transportation since 2001 (NHTSA 2001). In 2007, almost 5% of the 17 million new light-duty vehicles sold in United States were E85 vehicles. The E85 capability adds an estimated $200 to the vehicle cost (Keefe et al. 2007). There are also additional costs associated with the storage and distribution of E85 fuel. Installation of a new E85 pump and underground tank can cost as much as $200 000 (Keefe et al. 2007). IEA estimates that the total infrastructure changes needed for the transport, storage and distribution of E85 add about $0.06/gal to the price of ethanol.

3. ANALYSIS METHODOLOGY

The goal of chapter 3 is to describe the research methodology and explain how it depends on the use of Emissions Prediction and Policy Analysis (EPPA) model. The main focus of the chapter is to describe the implementation of biofuel mandates, first and second generation biofuels and crop production in the model. I will detail the process of generating different production blocks and input shares. I will describe the underlying principles and assumptions and explain how the new modifications are coherent and consistent.

3.1 A Computable General Equilibrium (CGE) Model

The MIT Emissions Prediction and Policy Analysis (EPPA) model described in (Paltsev et al. 2005) has been widely applied to address energy, agriculture and climate change policies. EPPA is a multi-region, multi sector recursive-dynamic computable general equilibrium (CGE) model of the world economy as shown in Figure 10. The model solves for the prices and quantities of interacting domestic and international markets for energy and non-energy goods as well as for equilibrium in factor markets. The model represents the world economy aggregated into 14 sectors and 16 regions. The base year for the model is 2004 and the model simulates the economy outputs recursively at 5-years intervals from 2005 to 2030. Production and Consumption sectors in EPPA are represented by nested Constant Elasticity of Substitution (CES) function, which include Cobb-Douglas and Leontief special cases. The model is written in GAMS software and is solved using the MPSGE language (Rutherford 1995). The model developed for the research to examine land use change and energy policy applications is based on the previous work by (Gitiaux et al. 2009; Gurgel et al. 2008; Reilly & Paltsev 2007).

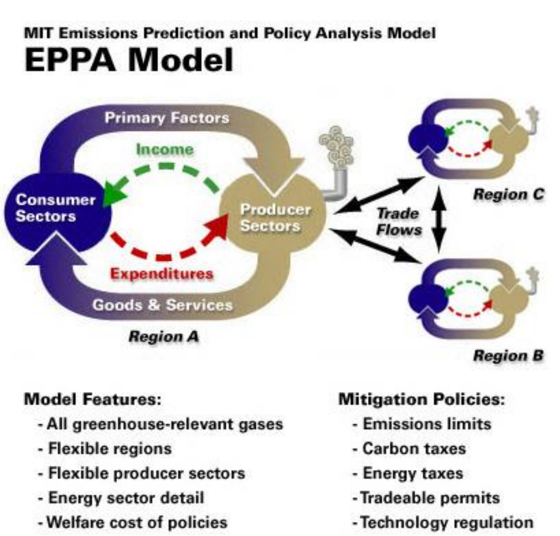


Figure 10. MIT Emissions Prediction and Policy Analysis Model-EPPA (MIT Joint Program 2011)

Table 5. Regions and Sectors in EPPA

REGION	SECTORS	MODIFICATION
United States (US)	Agriculture-Crops (CROP)	**Backstop:**
Canada (CAN)	Agriculture-Livestock (LIVE)	Biofuel Crops
Mexico (MEX)	Agriculture-Forestry (FORS)	Biofuels
Japan (JPN)	Food Products (FOOD)	
Australia and New Zealand (ANZ)	Coal (COAL)	
Europe (EUR)	Crude Oil (OIL)	
Eastern Europe (ROE)	Refined Oil (ROIL)	
Russia Plus (RUS)	Gas (GAS)	
East Asia (ASI)	Electricity (ELEC)	
China (CHN)	Energy Intensive Industries (EINT)	
India (IND)	Other industries (OTHR)	
Brazil (BRA)	Services (SERV)	
Africa (AFR)	Transport (TRAN)	
Middle East (MES)	Savings Good (CGD)	
Latin America (LAM)		
Rest of Asia (REA)		

The model used for the research is an extension of the MIT Emissions Prediction and Policy Analysis (EPPA) model and builds on the Observed Land Supply Response (OLSR) version described in (Gurgel et al. 2008). To represent land use conversion, production of first and second generation biofuels, the model takes account of detailed bottom-up engineering parameters. The parameterization method is described in detail in (Paltsev et al. 2005).

Future scenarios are driven by economic growth that results from savings and investments and exogenously specified productivity improvement in labor, energy, and land. Growth in the demand for goods produced from each sector including food and fuels occurs as GDP and income grow. Stocks of depletable resources fall as they are used, driving production to higher cost grades. Sectors that use renewable resources such as land compete for the available flow of services from them, generating rents. These resource rents together with policies, such as mandate on biofuel use in the US and EU, change the relative economics of different technologies over time and across scenarios. The timing of entry for advanced technology (first or second generation biofuels) is endogenous when it becomes cost competitive or is pulled by the mandated use.

The modifications primarily made in the model are the inclusion of first generation biofuels, feedstock crops and renewable fuel standards. I also make adjustments to second generation biofuel blocks and global biofuel trade structure. The new work builds on the OLSR version.

3.2 Land Use Change Representation

The OLSR version of EPPA model (Gurgel et al. 2008) disaggregated agriculture sector in three different sub-sectors: crops, livestock, and forestry. Land is used as a renewable resource and is also divided among the five types: crop land, pasture land, harvested forest land, natural grass land, and natural forest land. The version assumes the response we see in land conversion in recent years and is representative of the long-term response. The other sectors of the economy are described in detail as in (Reilly & Paltsev 2007).

Each land type is a renewable resource whose quantities can be altered through conversion to another type or abandonment to a non-use category. Land is subjected to exogenous productivity improvements set at 1% per year for each land type, reflecting assessment of potential productivity improvements (Reilly & Fugile 1998) that show historical crop yields to grow by 1% to 3% per year.

Regarding land use transformation, land area of one type can be expanded by conversion of another type of land. For example, natural forestry area can be developed and harvested and then replanted as managed forest land, or cleared for pasture or cropland. The opposite direction can also be observed, i.e. cropland can be abandoned to re-grow secondary forest or reorganized as managed pasture or managed forest land as shown in Figure 11.

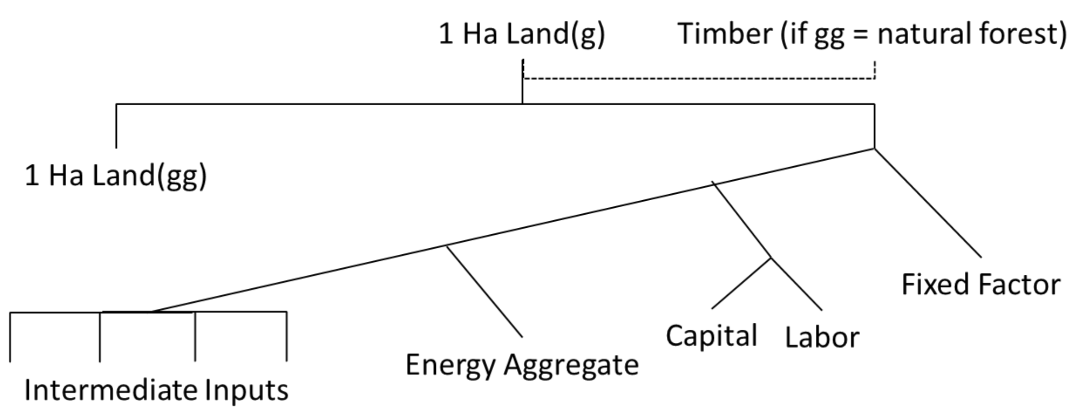


Figure 11. Structure of Land Transformation Functions, Source: (Gurgel et al. 2008)

The land use outputs are based on base year average land rents of the regional cropland. Whereas the land rents for specific feedstock crops (maize, wheat, sugar cane etc.) are different from the average regional rents, this anomaly results in the underestimation of the land needs for biofuel crops. To adjust for the difference I first calculate the land requirements per Exa-Joules of biofuel for each feedstock based on the estimates from (Kavalov 2004) for rapeseed, sugar beet and palm fruit and (BRDI 2008) for wheat, corn, soybean and sugar cane. The energy usage is based on the biofuel production in (Gitiaux et al. 2009) and I manually calculate crop land requirement based on the land-energy ratios as shown in Table 6. I then calculate the adjustment factor by taking the ratio of land requirements per EJ of biofuel from the model and manually calculated land use. The ratio for corn is 4, sugarcane is 1.9, sugar beet is 1, rapeseed is 12, palm fruit is 1.3, soy bean is 7.4 and wheat is 1 as highlighted in Table 6.

Table 6. Land Adjustment Factor and Land-Energy Ratio

Feedstock Crop	Land Adjustment Factor	Land-Energy Ratio (MHa/EJ)
Corn	4	11.74
Sugar cane	1.9	16.64
Sugar beet	1	7.23
Rapeseed	12	6.84
Palm fruit	1.3	21.28
Soybean	7.4	52.75
Wheat	1	5.56

3.3 Second Generation Biofuel Adjustments

As described in (Gurgel et al. 2008), the second generation biofuels structure collapses the crop production and biofuel transformation into a single sector. Accounting for input use at all stages in a single production function and thus implicitly representing a highly producing biomass such as switch grass or hybrid poplar. The firm structure of the actual economy—whether individual stages of production are done by separate firms or the entire process is vertically integrated—does not affect outcomes in a standard neoclassical representation of the economy.

For my purposes I model cellulosic production process and have no particular reason to model a separate production function for the raw biomass and the conversion process for second generation biofuels. This could be done as a separate sector, or as a separate production nests within a single sector. In dealing with advanced technologies that are not fully described, there is limited information on which to establish the values for many different parameters and so elaborating the structure in great detail suggests false precision.

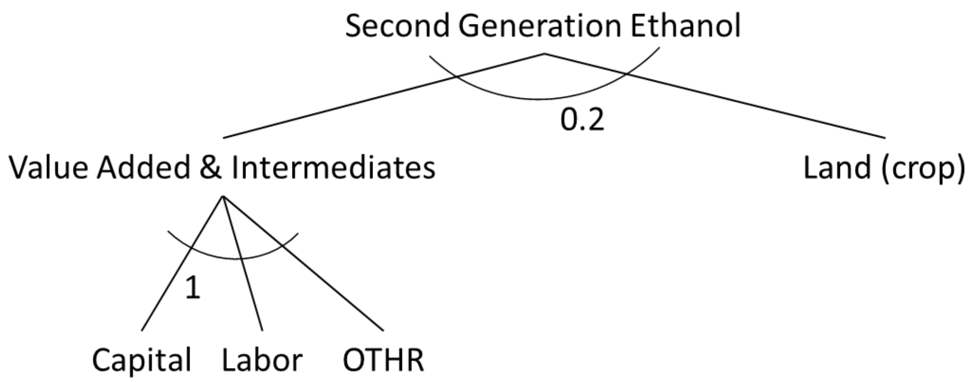


Figure 12. Structure of Production Function for Cellulosic Conversion, numbers shown in the figure are the elasticities of substitution assigned to each input nest

In ascertaining input requirements, the crop implicit in the parameterization is a high biomass producing crop such as switch grass, rather than a sugar, grain, or oil seed crop that is more expensive, produces a lower energy yield per unit of land (FAO 2011), and uses more fertilizer and other inputs. On the other hand, the input costs also reflect the higher cost of conversion than for conventional ethanol production. The most critical parameters in this formulation are the land input share, how process energy requirements are treated, and the overall cost mark-up relative to the existing technology i.e. gasoline.

I updated the cost estimates from (Hamelinck et al. 2003) to 2005 resulting in the US cellulosic conversion to be 1.81 times more expensive than gasoline. I also assume that all the energy required in the cellulosic process is provided by the biomass itself. This is enforced by assuming 40% conversion efficiency from biomass to a liquid energy product. For example, BRA is able to produce biomass at 15 odt/ha/year with a heating value of 20 GJ/odt. This corresponds to 300 GJ/ha/year, what can be transformed to 120 GJ/ha/year of liquid energy product. Internal supply of energy for conversion of ethanol actually reflects the practice for current ethanol production in Brazil where the bagasse provides an energy source for distilling ethanol produced from sugar cane. The reported result for physical biofuel is a volumetric quantity of the final liquid adjusted for the energy content.

The overall approach uses the value of crop land per unit area and the physical productivity of the land in terms of biomass productivity measured in over-dry-tons (odt) which is then directly convertible to gigajoules (GJ) of energy to determine the land value share required for biofuel derived bioenergy. In this way I was able to parameterize the CGE model in a way that is consistent with supplementary physical land data in GTAP (Lee et al. 2005) and energy use tables, assuring that the implied efficiency of production and conversion of biomass and fuels is consistent with agro-engineering data.

In second generation biofuel modeling approach I follow the methodology in (Gurgel et al. 2008). I take land rent data from GTAP database to identify land shares as they are observed among regions and, following (Reilly & Paltsev 2007), normalized input shares to sum to one. When input shares sum to one the technology is competitive with the reference technology (i.e. gasoline) in the model base year 2005. However, I then apply a separate mark-up, a factor by which input requirements are multiplied, in order to represent how the cost differs from the reference technology in 2004 following a convention adopted for the addition of other new technologies in the EPPA model (Paltsev et al. 2005). Given this normalization of input shares among regions, I use different mark-ups to reflect cost difference among regions. As shown in Table 7 the land shares for each region and the shares of other inputs in US reflect the updated shares. Since, by assumption, they sum to one, the input shares for other inputs in other regions can be derived from the US values by scaling them by land input share.

To illustrate what the parameterization means in terms of absolute costs of the fuel, for the USA the parameterization implies that the cellulosic conversion technology is 1.81 times more expensive than price of gasoline in 2005. Gasoline sold for about 2.6 USD per gallon in 2005 according the Energy Information Administration (EIA 2011) implying cellulosic conversion costs of 4.7 USD per gasoline-gallon equivalent gives prices in 2005. Adjusting for inflation and real price of farmland according to Economic Report of the President, breakeven prices would have to be about 5.45 USD/gallon in today's dollars. Thus, even the high petroleum and gasoline prices, the technology will not be competitive today without policy mandates.

Table 7. Parameters used for the production function of cellulosic conversion

		Input Shares			
Technology	**Mark-up Factor**	**Capital**	**Labor**	**OTHR**	**Land**
Cellulosic Conversion	1.81	0.60	0.14	0.19	0.07

Land Input Shares in cellulosic conversion							
USA	CAN	MEX	JPN	ANZ	EUR	ROE	RUS
0.07	0.05	0.14	0.16	0.05	0.11	0.05	0.05
ASI	CHN	IND	REA	AFR	MES	LAM	BRA
0.11	0.05	0.05	0.05	0.02	0.16	0.03	0.03

3.4 First Generation Biofuels Crops

The slight modifications to second generation cellulosic biofuel technology function block lead me to establish first generation biofuel technology in the model. It is expected in the long run technology improvements will make second generation biofuels more competitive and under carbon mitigation policies will crowd out the existing first generation biofuels (Reilly & Paltsev 2007; Gurgel et al. 2008).

The representation of current generation biofuels is, however, only implicit in the OLSR model to the extent that those fuels are contained in aggregate agriculture intermediate inputs of the fuel sector. As current biofuel technologies are more likely to contribute in meeting near term mandates and will hence play an important role in shaping the transition to second generation biofuels, it is necessary to explicitly include these technologies in the model formulation.

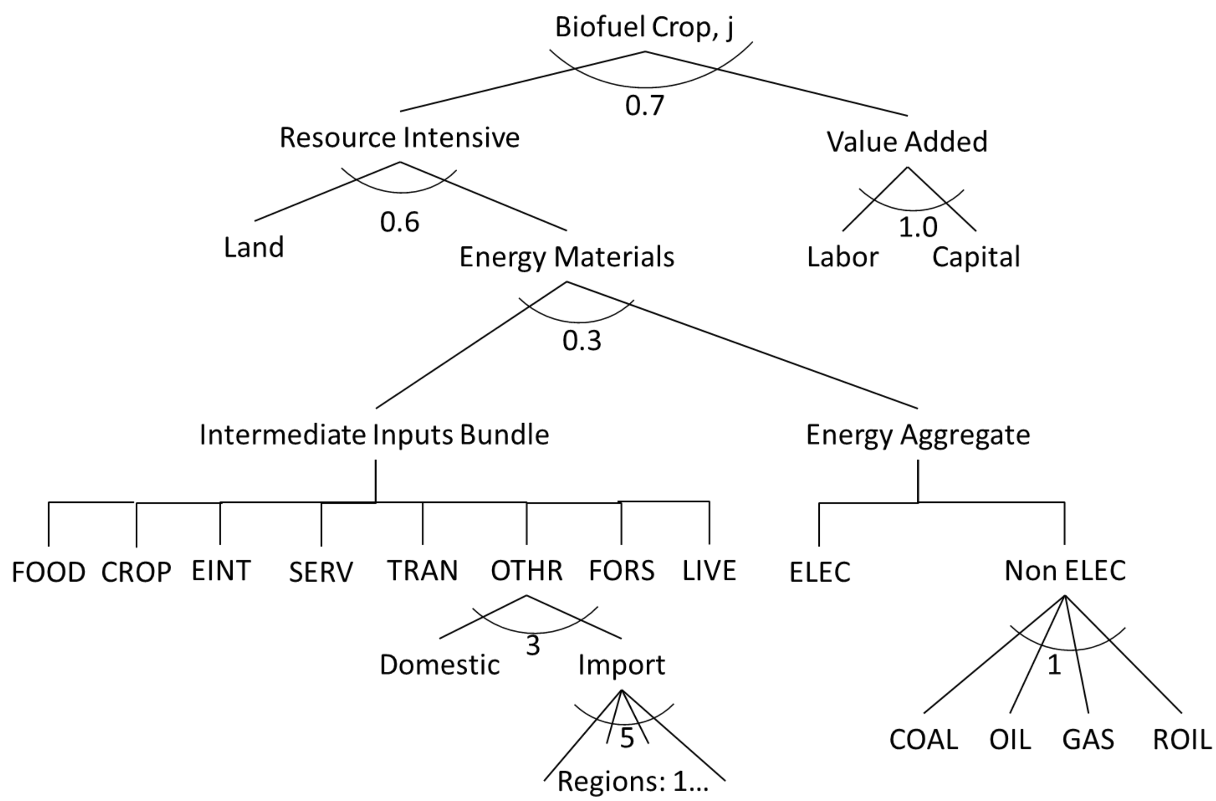
To include these fuels in the EPPA OLSR model I primarily use the methodology developed by (Gitiaux et al. 2009). I use adaptive methodology to integrate the land use production blocks with first generation biofuel technology representation and coalesce this representation with modified second generation biofuel function blocks to work with intermediate energy and final transportation sectors.

Table 8. Distribution of % Acreage between Soybean, Rapeseed, and Palm-plant Production and between Sugar cane and Sugar beet in 2005 (FAO 2011)

GTAP Crop	Feedstock for biofuels	USA	CAN	MEX	JPN	ANZ	EUR	ROE	RUS
Oilseed (OSD)	**Soybean**	98	18	81	99	3	8	43	74
	Rapeseed	2	82	3	1	97	92	57	26
	Palm fruit	0	0	15	0	0	0	0	0
Sugar Plant (C_B)	**Sugar beet**	57	100	0	76	0	100	100	100
	Sugar cane	43	0	100	24	100	0	0	0

GTAP Crop	Feedstock for biofuels	ASI	CHN	IND	REA	AFR	MES	LAM	BRA
Oilseed (OSD)	**Soybean**	14	57	51	6	20	95	99	100
	Rapeseed	0	43	49	94	1	5	0	0
	Palm fruit	86	0	0	0	79	0	1	0
Sugar Plant (C_B)	**Sugar beet**	0	13	0	2	8	100	4	0
	Sugar cane	100	87	100	98	92	0	96	100

I start with adding a production function in the agriculture sector that represents production of the crops to be used as biofuel feedstock. More specifically, I include biofuels based on sugar crops (sugar cane and sugar beet), grains (corn), wheat, and oil seed crops (rapeseed, soybean, palm oil). I utilize data from GTAP input-output tables for the production of grain (GRO), wheat (WEA), oilseed (OSD) and sugar crops (C_B). I further disaggregate oilseeds into soybean, rapeseed, and palm oil, and sugar crops into sugar beet and sugar cane based on acreage shares of these crops in each EPPA region using FAO data for year 2005 (FAO, 2008) resulting in the shares show in Table 8.



*j (j= grain, wheat, sugar cane, sugar beet, soybean, rapeseed, and palm fruit). Vertical lines in the input nest signify a Leontief or fixed coefficient production structure where the elasticity of substitution is zero. Figures below the nests relate to the elasticity of substitution

Figure 13. Production structure of biofuel crop sector

Production of biofuel crop j(j= grain, wheat, sugar cane, sugar beet, soybean, rapeseed, and palm fruit) uses capital, labor, land, intermediate inputs supplied by various sectors of the economy (agriculture, energy intensive industries, services, industrial transportation and other industries) and energy supplied by electricity, gas and refined oil sectors. I derive the share of these inputs from the updated 2005 GTAP data. I represent crop production with nested CES functions as shown in Figure 13.

Land productivity is assumed to improve over time as determined by the land use representation in the model. The land productivity assumed for all the regions in the land use block considers the average productivity levels for crop land; in reality certain regions of the world are more productive for a specific crop than others. As a result I use (FAO 2011) data and adjust the land input share with the productivity factor for each of the crops across all the regions for the year 2005.

Table 9. Normalized Distribution of Productivity Factor for Biofuel Feedstock Crops for all the EPPA Regions
(*** denotes absence of price information for the feedstock in the FAO dataset) (FAO 2011)

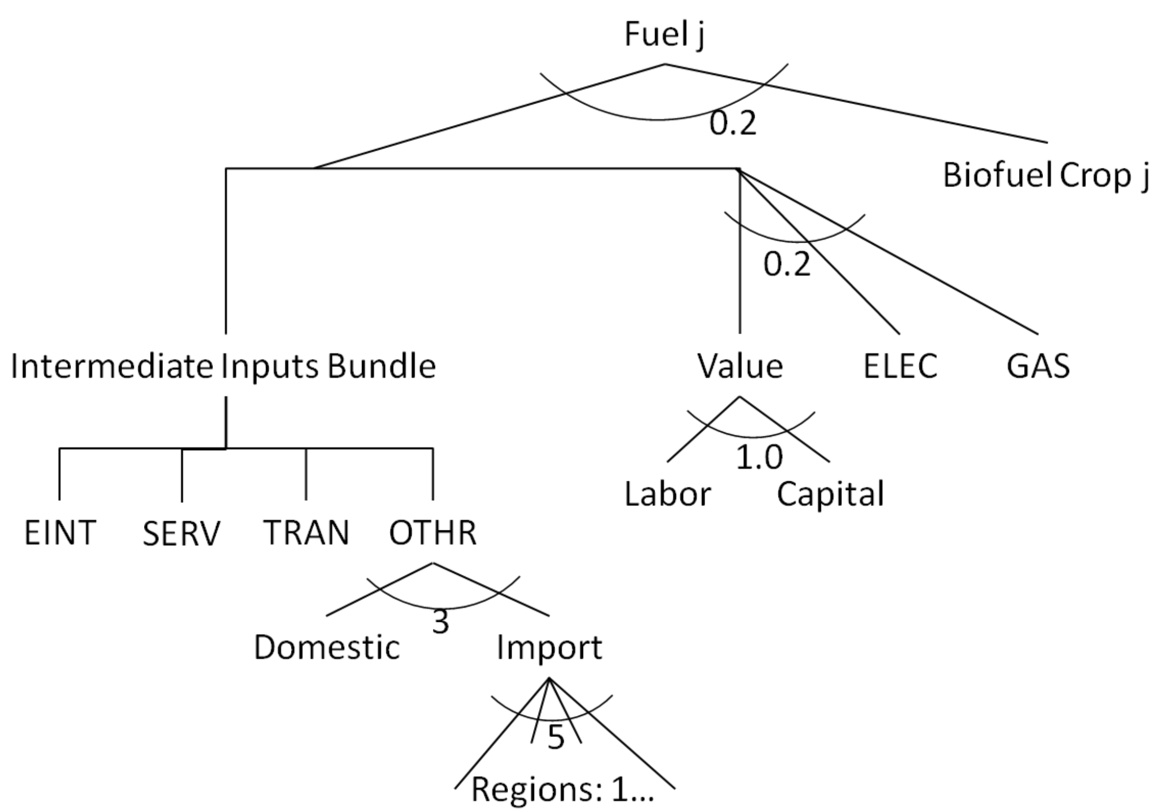
Feedstock for biofuels	USA	CAN	MEX	JPN	ANZ	EUR	ROE	RUS
Soybean	1.21	1.29	1.80	2.08	1.72	1.23	2.53	3.33
Rapeseed	2.02	1.75	2.57	2.57	2.19	1.00	1.49	2.41
Palm fruit	***	***	1.70	***	***	***	***	***
Sugar beet	1.14	1.37	***	1.00	***	1.03	1.98	2.20
Sugar cane	1.29	***	1.19	1.61	1.05	1.29	***	***
Corn	1.00	1.08	3.17	3.71	1.35	1.32	1.94	2.40
Wheat	1.81	1.87	1.08	1.25	2.51	1.00	2.07	2.65

Feedstock for biofuels	ASI	CHN	IND	REA	AFR	MES	LAM	BRA
Soybean	2.58	2.05	3.26	2.16	3.28	1.00	1.48	1.57
Rapeseed	0	1.79	3.10	3.85	2.71	1.88	1.26	1.92
Palm fruit	1.00	1.41	***	***	5.62	***	1.05	2.03
Sugar beet	***	1.66	***	1.94	1.29	1.39	1.24	***
Sugar cane	1.54	1.43	1.42	2.05	1.53	3.51	1.00	1.26
Corn	2.97	1.76	4.79	2.23	5.34	1.86	1.31	3.05
Wheat	3.62	1.20	1.97	2.91	2.43	2.33	1.66	2.59

First I calculate the annual yields for each biofuel feedstock crop for every EPPA region, and then I assign reference regions for each crop based on the yields and current production levels. Finally I calculate productivity factor for each crop and every region by normalizing the crop yields for every region with the yield values of the reference region e.g. for corn, US has the highest per hector (Ha) production yields of 9285.1 Kg/Ha so I used the US value to normalize the yields for every region, hence for corn US will have the productivity factor of 1 whereas LAM with the yield of 7113.6 Kg/Ha will have the productivity factor of 1.31. The productivity factor for each crop and every region is shown in the Table 9. I consider US as a base region for corn, LAM for sugar cane, EUR for rapeseed and wheat, JPN for sugar beet, MES for soybean and ASI for palm fruit. The higher the value of productivity factor compared to the reference region the less productive is the region for the production of the specific crop.

3.5 First Generation Biofuel Production

Production of biofuel j uses an input biofuel crop j together with energy, intermediate industrial inputs (from OTHR, EINT, TRAN, and SERV sectors of the EPPA model), capital and labor as well as ELEC and GAS as shown in Figure 14.

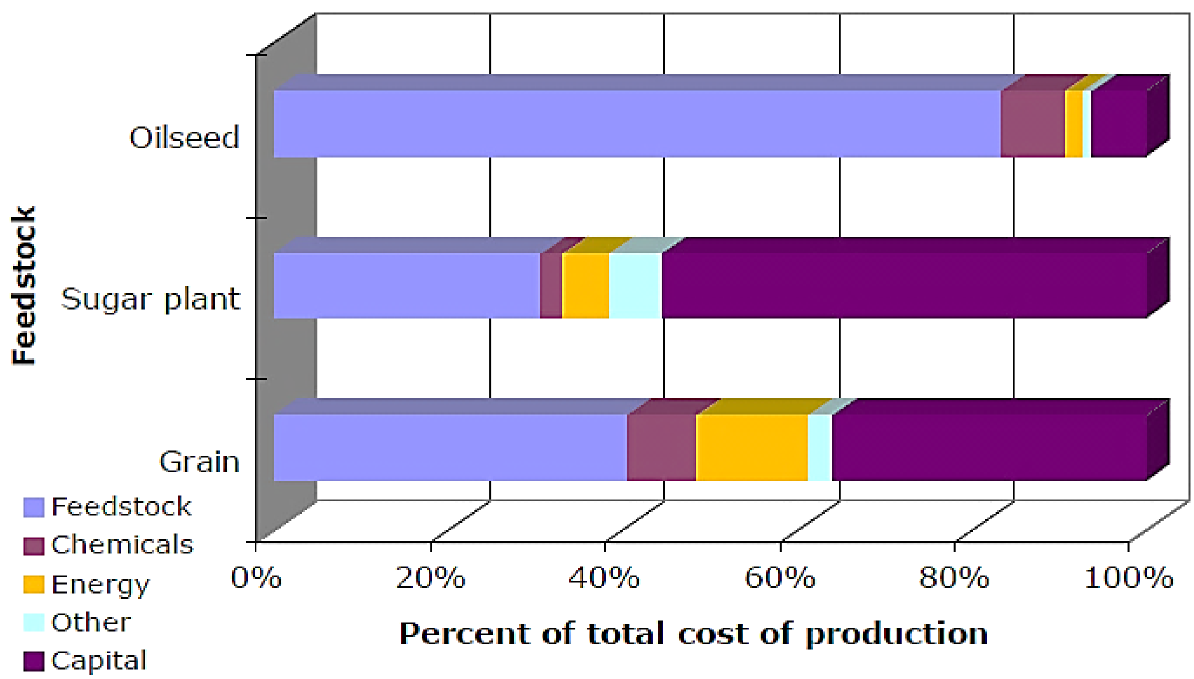


*Biofuel crop *j=grain, wheat, sugar cane, sugar beet, rapeseed, soybean or palm fruit*. Numbers shown in the figure are the elasticities of substitution assigned to each input nest. For *j=grain, wheat, sugar cane or sugar beet,* fuel *j* is ethanol. For *j=soybean, rapeseed or palm fruit*, fuel *j* is biodiesel, both are perfect substitute for ROIL.

Figure 14. Structure of First Generation Biofuel production function in EPPA.

I assume that biofuel technologies are part of the energy mix in the model from the start in 2005. For calibrating cost functions I base benchmark values shares on engineering analysis of production. The explicit technologies for production thus capture expansion of the industry beyond that amount implicitly included in base data set.

For ethanol from grain, I follow the estimates for the cost of production from (Gitiaux et al. 2009) and adjust them for the base year of the model. From the study I determine the cost components and the 2000 to 2005 average cost of production for corn ethanol in the United States, sugar cane ethanol in Latin America and biodiesel from soybean in the United States as shown in Figure 15. The cost of feedstock is between one quarter and one third of the total production cost of ethanol and 80% of the production cost of biodiesel.



*(these estimations are established for ethanol from corn in USA, from sugarcane in Brazil and for biodiesel from soy oil in USA)

Figure 15. Cost structure for biofuel production, Source: (Gitiaux et al. 2009)

When adjusted to reflect the lower energy content of biofuels, costs of production range from 0.39 USD/L for ethanol from sugar cane to 0.55 USD/L for ethanol from corn and 0.57 USD/L for biodiesel from soybean. I extend our cost estimates to other regions following the approach used in (Gurgel et al. 2008). I assume that the conversion technology is the same in all regions but the feedstock shares vary regionally according to the difference in crop prices as reported by (FAO 2011). For example, USA is the reference region for corn ethanol production in my approach, which means that I normalize input shares in the US to sum to one, while in other regions they sum to more or less than one depending on the relative price of corn, as provided in Table 10. In the same fashion, Latin American is the reference region for sugarcane ethanol and USA for soybean diesel. Where there was no crop price information from FAO (e.g. sugar cane in Canada) I assume that little or none of the crop is grown in that region. I then do not allow production of that fuel type in that region on the basis that the country will need to import the crop and that transport costs will favor importing the fuel from countries that can produce the crop rather than the crop itself.

Table 10. Parameters used for the production function of first generation biofuels in the EPPA model: mark-up and input shares

Biofuel Technology	Mark-up Factor	Capital	Labor	Crop	Energy bundle	OTHR
Soybean	1.29	0.06	0.03	0.81	0.09	0.01
Rapeseed	1.53	0.05	0.03	0.84	0.07	0.01
Palm fruit	1.1	0.07	0.04	0.77	0.11	0.01
Sugar beet	1.75	0.27	0.09	0.57	0.04	0.03
Sugar cane	0.89	0.47	0.16	0.26	0.06	0.05
Corn	1.25	0.35	0.03	0.39	0.2	0.03
Wheat	1.54	0.29	0.02	0.49	0.18	0.02

Table 10 provides the regionally specific data for biomass input shares. For example, for ethanol from corn production shares in the US are 0.35 for capital input, 0.03 for labor input, 0.2 for energy, 0.03 for other industries (OTHR) inputs, and 0.39 for biomass feedstock input. I then apply a uniform mark-up multiplier across regions (0.89 for sugar cane ethanol, 1.25 for corn ethanol and 1.29 for soybean biodiesel) to the share parameters in CES production function for all the inputs. This ensures that the price reflects the bottom up estimates of cost for each biofuel technology relative to the price of gasoline or diesel in the reference region for the years 2000-2005.

EPPA follows a standard approach in CGE modeling whereby in the benchmark year all prices are normalized to 1.0 and outputs and inputs are denominated in dollars rather than gallons, tons or some other physical unit. I retain this basic normalization procedure for new technologies and divided the cost per physical unit of new technology relative to the cost of the technology it will replace to estimate the markup. This procedure assures consistency between the economic accounting of the model and supplementary physical accounting for physical units of energy, emissions, or land use.

I extend the cost structures from Figure 15 for wheat and sugar beet ethanol and rapeseed biodiesel produced in Europe, but modify the relative weights between the crop and other inputs bundle to reflect the difference in feedstock prices as done by (Gitiaux et al. 2009). A comparison of the European, US, and Brazilian prices for wheat, corn, sugar beet, sugar cane (FAO 2011) and of rapeseed and soybean (USDA 2005) allows me to estimate the 2000-2005 averaged cost of wheat ethanol at 0.65 USD/L, sugar beet ethanol at 0.77 USD/L and rapeseed biodiesel at 0.68 USD/L.

Table 11. Parameters used for the production function of first generation biofuels in EPPA: input shares adjusted for price difference
(*** denotes absence of price information for the feedstock in the FAO dataset) (FAO 2011)

Feedstock for biofuels	USA	CAN	MEX	JPN	ANZ	EUR	ROE	RUS
Soybean	0.81	0.88	0.82	11.13	1.13	0.97	0.88	0.89
Rapeseed	1.13	0.77	1.02	***	0.89	0.84	0.82	***
Palm fruit	***	***	0.90	***	***	***	***	***
Sugar beet	0.35	***	***	1.09	***	0.57	0.29	0.25
Sugar cane	0.62	***	0.66	3.51	0.39	0.89	***	***
Corn	0.39	0.44	0.72	***	0.82	0.64	0.52	0.42
Wheat	0.42	0.33	0.50	4.62	0.56	0.49	0.34	0.30

Feedstock for biofuels	ASI	CHN	IND	REA	AFR	MES	LAM	BRA
Soybean	1.36	1.56	0.89	0.92	1.22	2.16	0.92	0.78
Rapeseed	***	0.83	1.41	1.12	1.26	1.20	0.79	***
Palm fruit	0.77	***	***	***	5.91	***	1.22	0.44
Sugar beet	***	0.42	***	0.19	0.21	1.24	1.37	***
Sugar cane	0.99	2.52	0.34	0.40	0.98	***	1.21	0.26
Corn	0.65	0.93	0.63	0.68	1.29	1.37	0.91	0.59
Wheat	***	0.57	0.63	0.56	0.87	0.85	0.55	0.48

This estimate results in a mark-up (cost of production relative to refined oil) of 1.54 for wheat ethanol, 1.53 for rapeseed biodiesel and 1.79 for sugar beet ethanol. Following the approach described above, I extend the costs of production across all the EPPA regions in which the crops are produced. As shown in Table 11, I use the same input shares across regions from Table 10, except that for example, in Europe (EUR), the crop share is now 0.64 instead of 0.39 to reflect the relatively higher cost of corn. The same is true for other regions and technologies. The mark-up factor is then applied on top of all the inputs.

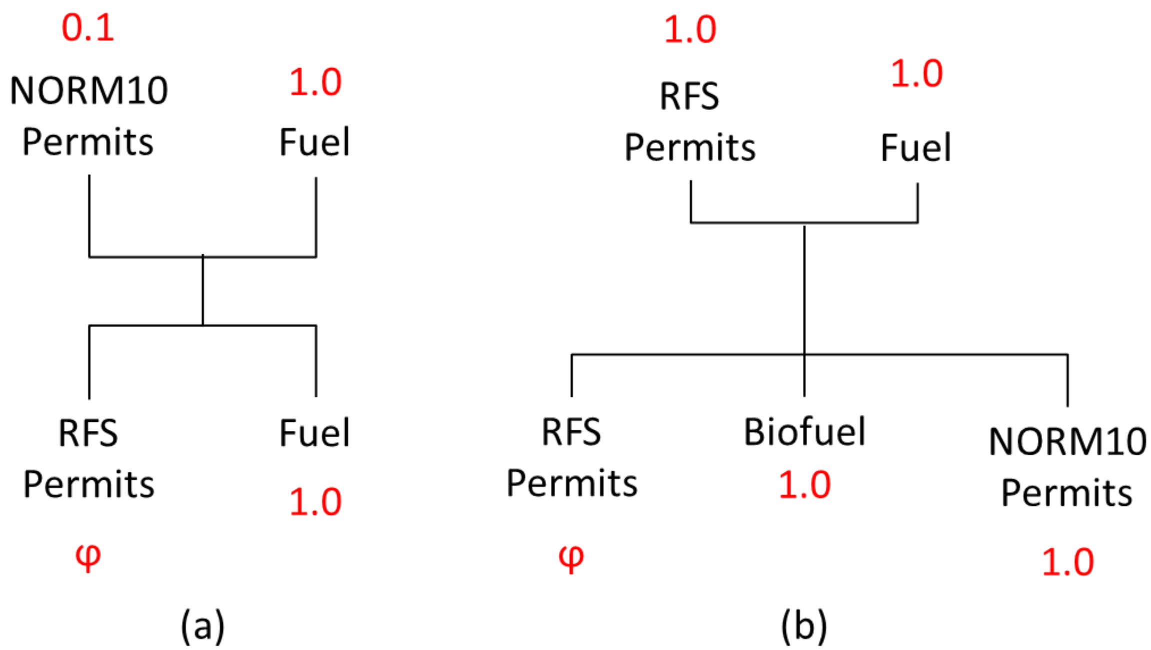
The cost structure of biodiesel from palm oil and its mark-up factor (which is equal to 1.1) are evaluated with the same methodology (Gitiaux et al. 2009) by using the relative price of palm oil compared to soy oil (USDA 2005). Elasticities of substitution in Figure 14 are taken from the refined oil sector in (Choumert et al. 2006)

3.6 Biofuel Mandates Implementation

The approach used for the mandates is a hybrid of quantity constraint and a system of permits previously demonstrated in a model by (Gitiaux et al. 2010). The implementation of permit approach is based on the methodology when firms that produce one unit of renewable fuel receive one Renewable Fuel Standard (RFS) permit. Every unit of conventional fuel or of its perfect substitute requires the surrender of a quantity of RFS permits to meet the renewable fuel mandate, specified as a share, φ, of total fuel. The conventional refineries must acquire permits from the renewable fuel producers. This approach captures the redistribution of funds between conventional refiners and biofuels producers, as fuel sellers must pay a premium (the permit price) to renewable fuel producers.

To capture the 10% blending wall, and adjust for the presence of only ROIL sector instead of Biodiesel or Gasoline as in the earlier model I divide the biofuel transportation block into US and EU regions separately to reflect the possible different behavior of blending walls in the regions under study.

I introduce another set of permits (which I refer to as NORM10 permits) and two blending processes that complement the conventional refinery sector. The conventional refinery produces conventional fuel. The 10% blending process is a combination of conventional refinery that is mandated to surrender φ RFS permits and of biofuels industry that uses as inputs biofuels and NORM10 permits and produces RFS permits and a perfect substitute for conventional fuel. In this way I allow biofuel production only up to the amount of NORM10 permits available. Conventional refineries produce 0.1 NORM10 permits for every unit of fuel produced. This ensures that the total number of NORM10 permits is only 10% of total fuel production. The structure of the permit approach is represented in Figure 16.



* Vertical lines in the input nest signify a Leontief or fixed coefficient production structure where the elasticity of substitution is zero. Figures below the inputs name are the value of inputs shares. The ϕ is the renewable fuel standard (Gitiaux et al. 2010)

Figure 16. Implementation of renewable fuel mandates in EPPA. (a) Production function of conventional fuel; (b) Production function of blending of biofuels into conventional products up to 10%

I also place a cap on the supply of corn starch derived ethanol at 15 billion gallons in the US and implement a mechanism for a minimal production of cellulosic ethanol. I have used backend calculations to ensure that the energy content adjustment reflects the fuel cap and cellulosic production needs. I impose that by 2015 a specific fraction of biofuels blended in conventional products has to derive from this advanced technology, this percentage corresponds to the 16 billion gallons (out of 36 billion gallons) mandated to be advanced ethanol in the RFS mandate by 2022. From 2010 to 2025, I gradually increase this minimum amount of advanced ethanol from 3 billion gallons in 2015 to 16 billion gallons by 2025. Beyond 2025, it is maintained at the same proportion of the total biofuel blend.

4. IMPLICATIONS OF BIOFUEL MANDATES

In this chapter I will discuss the validity of the research question and test different hypothesis given the simulation results of the model. I will describe the different scenarios implemented and the rational for doing so. The subsequent analysis and commentary in the chapter will discuss the results, research question, and the findings.

4.1 Biofuel Analysis Scenarios

The simulation runs are based on scenarios designed to model policy, economic and technical issues and generate results to study the research questions. A total of seven cases are considered based on the issues raised earlier. The first four scenario cases project the biofuel usage in the regions from 2005 to 2030, based on No Policy (NOP) case with no mandates, European Directive for Biofuel in EU only case (EUD), Renewable Fuel Standard in US only case (USRFS) and biofuel mandates implemented simultaneously in both US and EU (RFSEUD) case. The NOP-NBF case is a no policy-no biofuel production case. The regions of EUR and ROE represent the European Union and the region of USA represents US. The scenarios assume that all the biofuel produced is consumed by the regional household and other vehicle transportation sectors.

Table 12. Scenarios Implemented for Analysis

Scenarios	Case	US	EU	Blend wall	Trade	Productivity
No Policy	NOP	No	No	10%	No	1% annual
No Policy and No Biofuel	NOP-NBF	No	No	10%	No	1% annual
US Mandate	USRFS	Yes	No	10%	No	1% annual
EU Mandate	EUD	Yes	No	10%	No	1% annual
US and EU Mandate	RFSEUD-BASE	Yes	Yes	10%	No	1% annual
US and EU Mandate-Trade	RFSEUD-TRADE	Yes	Yes	10%	Yes	1% annual
US and EU Mandate-BW15	RFSEUD-15	Yes	Yes	15%	No	1% annual
US and EU Mandate-NoProd	RFSEUD-NOPROD	Yes	Yes	10%	No	None

The intent behind scenario design is to observe the individual mandate implementation separately and then together to study any interactive effects which may not be evident if only one of the mandates is implemented. For the remaining scenarios the mandates are enforced in both the EU and US but other parameters are varied, fuel blending wall with either 10% or 15% blending technology for the transportation fleet, global biofuel free trade with no import tariffs or quotas to assess the impact of trade, and crop land productivity with annual 1% or zero productivity improvement to observe the effects of productivity on land use change and global food crop prices. Table 12 shows the implemented scenarios.

4.2 Biofuel Production Projections

The NOP case considers no policy mandates are implemented either in US or EU but allows first and second generation biofuel production. The scenario considers 10% blend wall fuel technology with no biofuel trade between the regions. The production takes place only when the backstop technology is cost effective based on the comparative valuation with the refined oil prices (ROIL) in the region. If one of the biofuel technology pathways is cost effective in any of the regions it will lead to domestic production. The results in Table 13 show that sugar ethanol is cost effective in 2005 in Brazil leading to a production of 2.47 Bgal (billion-gallons) of fuel, whereas corn ethanol becomes cost effective in USA starting 2015 with 19.9 Bgal of fuel.

Corn ethanol production in US in the year 2030 of 39.93 billion gallons (equivalent to 3.55 EJ of energy) highlights that if no cap is placed on the corn ethanol, the entire biofuel market in the US will be taken over by the corn ethanol due to cost competitiveness. The regions of IND, BRA and ANZ produce consistently increasing levels of sugar ethanol, as sugar cane based ethanol is cost competitive with ROIL prices from the base year of 2005. REA and MEX start producing sugar cane based ethanol starting 2020 whereas ASI region is the most suited for palm fruit biodiesel beginning in 2010. Rapeseed based biodiesel becomes economically competitive only in 2030 in EUR. These results are a product of interaction between the markup factor of biofuel technology, the underlying productivity of the crop land for feedstock production and cost competitiveness of regional biofuel prices compared with refined oil (ROIL) prices.

Table 13. No Policy (NOP) biofuel production, values in Bgal (billion gallons)

BIOFUEL	REGION	2005	2010	2015	2020	2025	2030
CORNETHANOL	USA			19.91	36.89	38.36	39.93
SUGARETHANOL	MEX				2.36	2.47	2.59
	ANZ	1.91	1.91	1.91	2.02	2.14	2.14
	IND	3.04	4.16	5.40	6.97	8.77	10.46
	BRA	2.47	2.92	3.26	3.60	3.94	4.16
	REA				2.25	2.59	3.04
RAPESEEDOIL	EUR						14.31
PALMOIL	ASI		5.46	6.05	6.42	6.78	7.15

The remaining cases can be classified as policy scenarios, it is assumed that due to higher costs biofuel production dose not expand in the US and EU beyond the required mandated targets as described in Section 2.2. Table 14 details the results of simulation with biofuel production in billions of gallon (Bgal) for the following cases -US only, EU only and US-EU together- with 10% blend wall, no global trade in biofuels and crop land productivity at 1% per year. The results show policy mandates affect only the three regions, USA due to Renewable Fuel Standard (RFS), and EUR and ROE due to European Directive (EUD) whereas the rest of the regions have the same production as in NOP case. Hence BRA, ANZ and IND produce 2.5 Bgal, 3.0 Bgal and 1.9 Bgal of sugar cane ethanol starting in the base year 2005, whereas MEX starts production in 2020 with 2.4 Bgal and ASI produces 5.5 Bgal of palm fruit based biodiesel starting in 2010.

Table 14. Biofuel Production in billions of gallons (BGals) for the three scenario cases, US only (Renewable Fuel Standard), EU Only (European Directive) and US- EU (RFS and EUD combined)

		2005	2010	2015	2020	2025	2030
Same for US, EU only and US-EU together							
MEX	SUGARETHANOL				2.4	2.5	2.6
ANZ	SUGARETHANOL	1.9	1.9	1.9	2.0	2.1	2.1
ASI	PALMOIL		5.5	6.0	6.4	6.8	7.2
IND	SUGARETHANOL	3.0	4.2	5.4	7.0	8.8	10.5
BRA	SUGARETHANOL	2.5	2.9	3.3	3.6	3.9	4.2
REA	SUGARETHANOL				2.2	2.6	3.0
US and EU Mandates							
USA	bio-oil			2.9	10.5	14.8	14.8
	CORNETHANOL		12.0	15.0	15.0	15.0	15.0
	SOYOIL		1.7	2.7	4.7	5.2	6.3
EUR	RAPESEEDOIL		5.3	7.7	11.4	11.5	14.3
ROE	BEETETHANOL		1.0	1.5	2.2	2.4	2.5
Only US Mandate							
USA	bio-oil			2.9	10.5	14.8	14.8
	CORNETHANOL		11.9	15.0	15.0	15.0	15.0
	SOYOIL		1.7	2.7	4.7	5.2	6.2
EUR	RAPESEEDOIL						14.3
Only EU Mandate							
USA	CORNETHANOL			11.1	37.0	38.4	39.9
EUR	RAPESEEDOIL		5.3	7.7	11.4	11.5	14.3
ROE	BEETETHANOL		1.0	1.5	2.2	2.4	2.5

The differences between the biofuel production levels become evident as we analyze the production in the United States and European Union. In the case of RFS and EUD implemented together (RFSEUD-BASE), the US meets the RFS mandate by producing 15 Bgal of corn ethanol capped from 2015 onwards. The rest of the mandate is achieved through 10.5 Bgal of cellulosic biofuel (bio-oil) and 4.7 BGal of soybean biodiesel in 2020. The following years indicate mandated requirements are fulfilled though a combination of first generation and second generation biofuels in the US.

The increased share of soybean biodiesel in the US can be explained by the better economics of soybean biodiesel than cellulosic biofuel and better cropland productivity for soybean crop. In European Union (EUR and ROE) the 2020 EU requirement of 10% biofuel is met through production of 11.4 Bgal of rapeseed biodiesel and 2.2 Bgal of sugar beet ethanol. This composition of biofuel reflects the better economics and crop land productivity of the EUR and ROE regions for rapeseed and sugar beet respectively.

Analysis of the Renewable Fuel Standard implementation in US only reflects the same level of production in corn ethanol, soybean biodiesel and cellulosic biofuel as detailed in RFSEUD-BASE case earlier but in the EUR region rapeseed biodiesel production starts in 2030 at 14.3 Bgal.

Analysis of the European Directive implementation in EUR and ROE only (EUD) results in the same levels of biofuel production through rapeseed and sugar beet as in RFSEUD-BASE case indicated in Table 14. The one difference is that even though Unites States does not have RFS mandate in the scenario it still has significant production of corn ethanol starting 2015. Since no cap is placed on the corn ethanol production, the levels reach 39.9 Bgal by 2030 in the US. This highlights the importance of placing cap on the corn ethanol use, if left uncontrolled it leads to explosive production levels with consequences for crop land use, food supplies and infrastructure.

4.3 Food Crop Price Effects

In this section I will discuss the effects of policy cases-EU only, US only and US and EU combined- on the global crop prices compared with the no biofuel production case. The important consideration to keep in mind for this section is the dependence of first generation biofuels on food crops as corn, sugar cane etc. Figure 17 shows the results of global food crop price differences (%) between the case with no biofuel production and the three policy cases EU only, US only, US and EU both. In general, the food crop price increases I find are very small, around 1% or less. This result is very different than what has been generally believed. Many recent publications and news article consider ethanol production to be a major driver for food price increases as in (Walsh 2011).

The figure highlights the long term trend in global average crop prices, as biofuel production ramps up the global food crop prices rise with falling rate. In all the cases the long term food crop prices increased by less than one percent (0.75%) rate. The RFSEUD-BASE case has the highest relative increase compared to USRFS and EUD scenarios. The low levels of long term increase can be explained by the fact that biofuel feedstock only consumes a very small proportion of the world total crop production. I find that US biofuel production from corn and soy bean is only 18% of the US total crop value and 1.3% of the global crop value, similarly EU biofuel production from rapeseed and sugar beet accounts for 8.6% of EU and 1.6% of global crop value. The total global biofuel crops accounts for only 4.2% of the total global crop value for the time span of 2010 to 2030, hence the crop price effects are marginal.

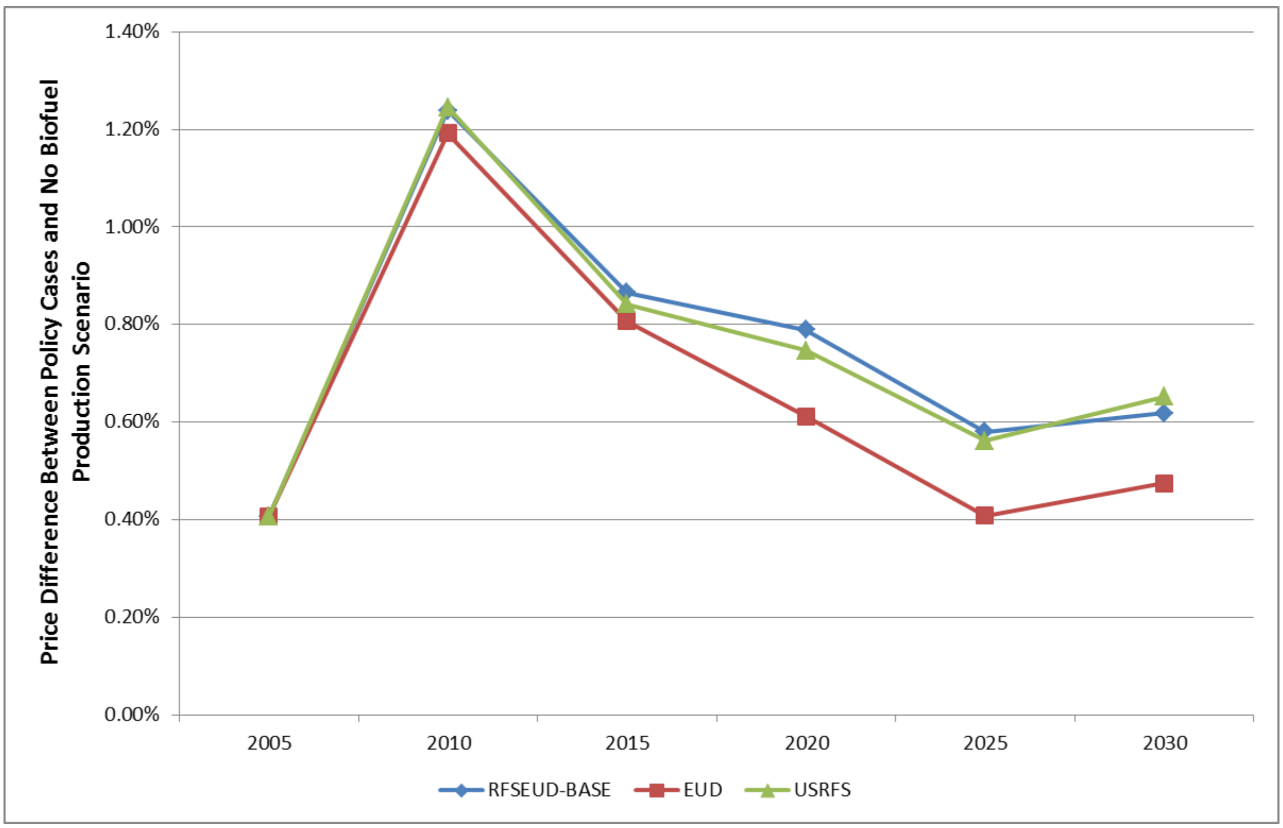


Figure 17. Difference in Global Food Crop Prices between Policy and No-Biofuel cases (percent)

The food crop price trends highlight the relative small contribution of biofuel crops to the global crop production and confirm the hypothesis that biofuel production has a relatively small long term effect on global food prices.

4.4 Land Use Change

In this section I will detail the land use effects of biofuel production and mandates in the world economy. The land requirements for the biofuel production are calculated based on the technology and economic representation of feedstock crops, land use change and biofuel production blocks in the model. Table 15 shows the land requirements for producing biofuel in the No Policy (NOP) case. The corn ethanol production of 19.91 Bgal uses 7.42 MHa of land in USA in the year 2015 and BRA uses 1.86 MHa of land for the production of 2.92 Bgal of sugar ethanol in the year 2015. The land requirements are generated through the land use function block which uses crop land as an input. The land input share and regional productivity for the feedstock crop results in the land area used which is adjusted for the energy per unit of area for the feedstock as discussed in the Chapter 3.

Table 15. No Policy Case (NOP) land use, values in MHa (mega hectors)

BIOFUEL	REGION	2005	2010	2015	2020	2025	2030
CORNETHANOL	USA			7.42	28.88	28.37	27.61
SUGARETHANOL	MEX				1.50	1.52	1.57
	ANZ	1.62	1.58	1.56	1.53	1.51	1.52
	IND	2.44	2.88	3.35	3.78	4.25	4.68
	BRA	1.71	1.86	1.76	1.67	1.69	1.70
	REA				2.97	3.15	3.31
RAPESEEDOIL	EUR						26.18
PALMOIL	ASI		6.36	6.54	6.55	6.54	6.50

The rest of the section details the land use based on the three policy scenarios of USRFS, EUD and RFSEUD-BASE which represent the biofuel mandate implementation in EU and US separately and then US and EU combined with 10% blend wall and no global biofuel trade. Table 16 shows the land use requirement for the fuel production as shown in Table 14 earlier in the chapter. The output of MEX, ANZ, ASI, IND, BRA and REA is the same for all the three cases as the policies enacted encompass only the USA, EUR and ROE regions.

To observe the land use trend in Table 16, it is shown that the land requirement for production of 2.9 Bgal of sugar ethanol in BRA is 1.85 MHa in 2010 and 1.76 MHa for the production of 3.33 Bgal in 2015, the values indicate as the volume increases the relative land requirement per Bgal decreases, this phenomenon can be explained by the technological innovation and productivity improvement of crop land in the model. The same phenomenon happens in the rest of the regions as the improvements make the crop production more efficient resulting in higher volumes of biofuel produced per MHa of land. In USA the corn production is capped at 15 Bgal from 2015 onwards but the land required to produce the volume continuously decreases from 12.39 MHa in 2015 to 9.64 MHa in 2030. The 1% annual productivity improvement in the crop land as modeled in the system plays a significant role in improved land ratios.

Table 16. Land Used in Mega Hectors (MHa) for the three scenario cases, US only (Renewable Fuel Standard), EU Only (European Directive) and US-EU (RFS and EUD combined)

		2005	2010	2015	2020	2025	2030
Same for US, EU only and US-EU together							
MEX	SUGARETHANOL				1.51	1.52	1.57
ANZ	SUGARETHANOL	1.62	1.58	1.56	1.53	1.52	1.52
ASI	PALMOIL		6.37	6.55	6.57	6.55	6.51
IND	SUGARETHANOL	2.45	2.89	3.36	3.79	4.26	4.68
BRA	SUGARETHANOL	1.71	1.85	1.76	1.67	1.70	1.70
REA	SUGARETHANOL				2.97	3.15	3.31
US and EU Mandates							
USA	bio-oil			1.25	4.12	5.54	5.25
	CORNETHANOL		11.19	12.39	11.11	10.42	9.64
	SOYOIL		12.61	17.90	27.37	28.35	30.99
EUR	RAPESEEDOIL		14.23	17.98	23.50	22.81	26.28
ROE	BEETETHANOL		1.19	1.62	2.27	2.23	2.19
Only US Mandate							
USA	bio-oil			1.25	4.11	5.53	5.25
	CORNETHANOL		11.19	12.38	11.10	10.41	9.63
	SOYOIL		12.60	17.89	27.34	28.32	30.98
EUR	RAPESEEDOIL						26.18
Only EU Mandate							
USA	CORNETHANOL			10.06	28.91	28.41	27.63
EUR	RAPESEEDOIL		14.22	17.96	23.50	22.81	26.28
ROE	BEETETHANOL		1.19	1.62	2.27	2.23	2.18

Under the combined scenario of US and EU mandates significant area of land is required for the production to meet the targets. In 2020 the total land required to meet the mandated threshold both in the US and EU is 68.37 MHa, to give some perspective this land area is as big as the state of Texas. The one difference between EUD case and RFSEUD-BASE case is the use of land for corn production in US (approximately 28 MHa of land from 2020 to 2030) is driven by the absence of usage cap on corn ethanol in the US. The USRFS case land use values are similar to the RFSEUD-BASE case for the US but no land is used in EUR and ROE except 26.28 MHa for rapeseed in 2030.

Next I will make a comparison of the land use change among the land categories of crop land, pasture land, harvested forest land, natural grass land, natural forest land and biofuel feedstock land for the three scenarios with respect to the land use in No Policy (NOP) case. The logic driving the analysis is that land use change happens in the No Policy case due to various economic factors, but the rate may be affected by policy shocks to the economy through the implementation of biofuel mandates and production. The subsequent analysis will look at the land use change for the entire world in NOP, USRFS, EUD and RFSEUD-BASE cases for the years 2010 to 2030.

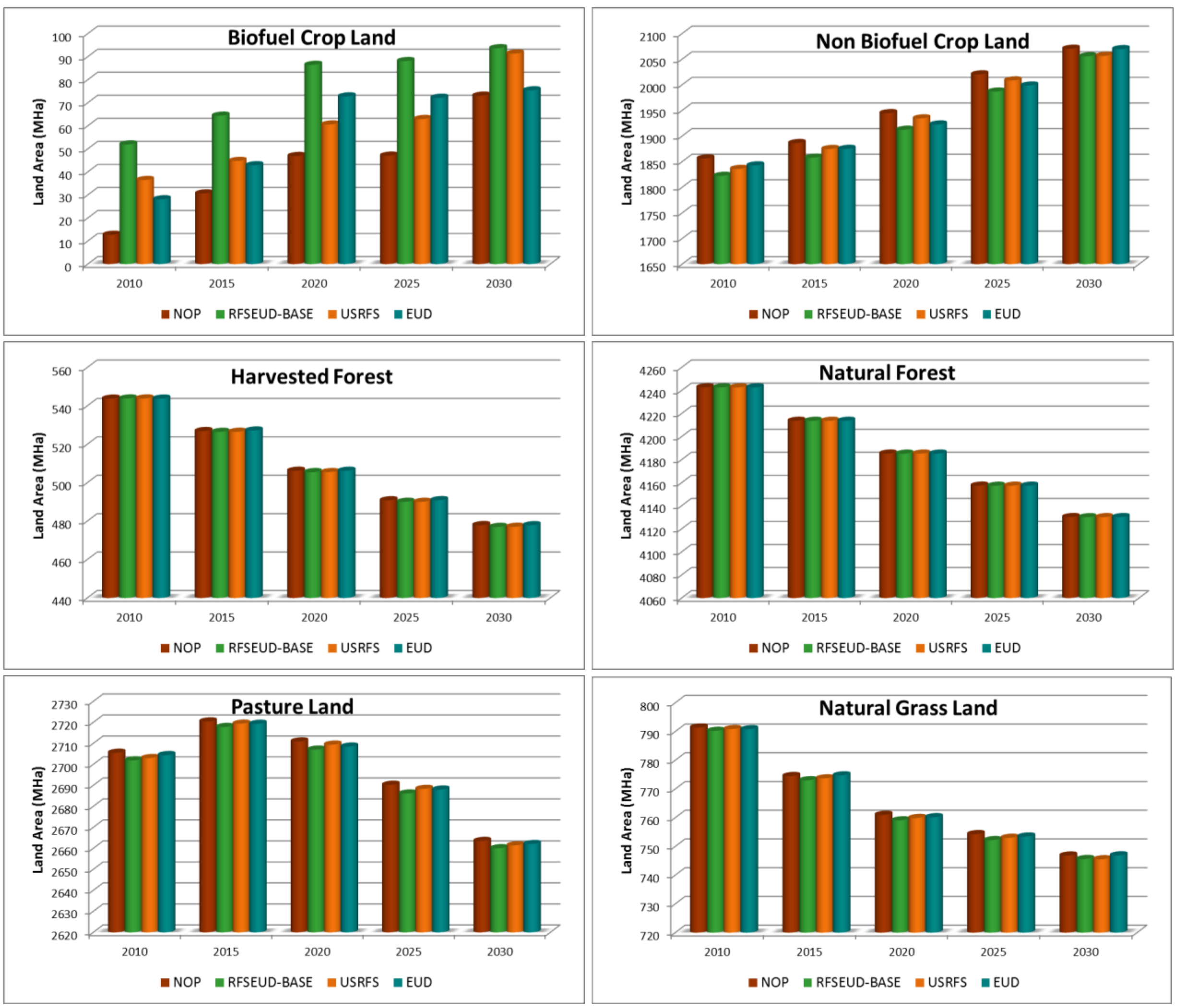


Figure 18. Global Land Use Area (mega hectors) for the land types in No Policy (NOP), RFS only (USRFS), EUD only (EUD) and RFS and EUD combined (RFSEUD-BASE) cases

Results in the Figure 18 show different land categories affected by the implementation of the biofuel policy mandates. The most significant change in land area happened in crop land where policy cases resulted in greater decrease in crop land devoted to non-biofuel feedstock than NOP as more land is dedicated to biofuel production. Even though the crop land area increases with the passage of time due to the increasing demand for crop production driven by economic and population growth the rate is lesser for the policy cases than NOP as more land is dedicated to the biofuel crops. The crop land area for the RFSEUD-BASE case in year 2025 is 1986.65 MHa while for NOP it is 2020.28 MHa. Natural forest land is the least affected by the biofuel mandate implementation but the land area is consistently falling due to the land use conversion. The global land area devoted for natural forest in year 2015 is 4213 MHa whereas in 2025 it is 4157 MHa. The land transformation in natural forest has long term implications for the global greenhouse gas emissions (GHG) and biodiversity.

As shown in the Figure 18, the marginal lands of natural grass and pasture land are not substantially affected by the mandates, with combined RFS and EUD case having the biggest affect. The total land area for both pasture land and natural grass land decreases relative to the No Policy case. Over all the pasture land increases in 2015 and 2020 relative to 2010 levels but continues downward trend starting in 2020 and reaching lower levels in 2025 and 2030. This trend can be explained by the increased demand for marginal biomass and livestock. The area for this land category in RFSEUD-BASE case for the year 2025 is 2688 MHa and in NOP case it is 2690 MHa.

Natural grass land area decreases with the time. Policy cases have a slightly larger drop than the NOP case through the years. The NOP case in the year 2025 has 754 MHa of natural grass and RFSEUD-BASE has slightly less area of 752 MHa in the same year. This indicates that the policy effects on natural grass land are not substantial. Harvested forest land decreases with the time, the policy cases enhance the affect marginally in the years of 2025 and 2030 as shown in the figure. The 2025 level is 490 MHa compared to 544 MHa in 2010.

The total biofuel feedstock land in 2025 for RFSEUD-BASE case is 88 MHa compared to 63 MHa in USRFS case, 72 MHa in EUD case, and 47 MHa in NOP case. The land area has an increasing trend line with higher levels proportional to the higher production levels.

In the Appendix, I provide detailed land use data for Renewable Fuel Standard on US land area compared with No Policy (NOP) and No Policy-No Biofuel (NOP-NBF) cases, European Directive in EUR and ROE land area compared to NOP and RFS and EUD combined compared with NOP-NBF case for the entire world. The graphs show the behavior of all the land categories for the specific regions through the years.

4.5 Free Trade in Biofuels

To the study the effects of the global free trade on biofuels, I simulated the RFSEUD-TRADE case. The main assumption in the scenario is that both RFS and EUD mandates have been enacted in the United States and European Union respectively but the mandated production levels can be met through imported biofuels. This case is contrary to the intention of policy makers to promote domestic agriculture, but enables the study of relative cost competitiveness of biofuel technologies in different regions of the world. Based on free trade theory the more cost effective and efficient biofuel technology will displace the lesser efficient alternatives in the US and EU domestic markets.

Table 17. Biofuel Production in Billions of Gallon (Bgal) with Global Free Trade with RFS and EUD implemented in US and EU respectively

Region	Biofuel	2005	2010	2015	2020	2025	2030
BRA	SUGARETHANOL	39.45	53.37	70.17	71.14	81.25	92.14
ANZ	SUGARETHANOL	8.43	47.00	27.66	31.34	23.30	10.17
ASI	PALMOIL		1.70	4.65	6.48	10.12	16.58
USA	bio-oil			3.55	10.58	14.94	15.12

The free trade assumption is responsible for the production of significantly higher volumes of biofuel in BRA and ASI compared with the case without trade (RFSEUD-BASE). The production of sugar cane ethanol in BRA is 81.25 Bgal in 2025 with trade case compared to 3.9 Bgal of ethanol in 2025 for the case without trade. Similarly the production of palm fruit biodiesel in ASI is 16.58 Bgal in 2030 with trade and only 7.2 Bgal without trade. This highlights the effectiveness of production technologies and higher crop land productivity in BRA and ASI to generate more cost competitive fuels than EU and US domestic markets.

As discussed in earlier sections without trade US relies heavily on corn ethanol and EU on rapeseed and sugar beet based biofuel to domestically achieve the mandated targets. The current policy portfolio is designed to subsidize the domestic fuel production by direct and indirect subsidies for the blenders and producers, through protection of domestic markets by import tariffs and policy mandates (RFS and EUD). The enacted policy approaches impede the trade and have various implications for the global food and biofuel prices, and land use change.

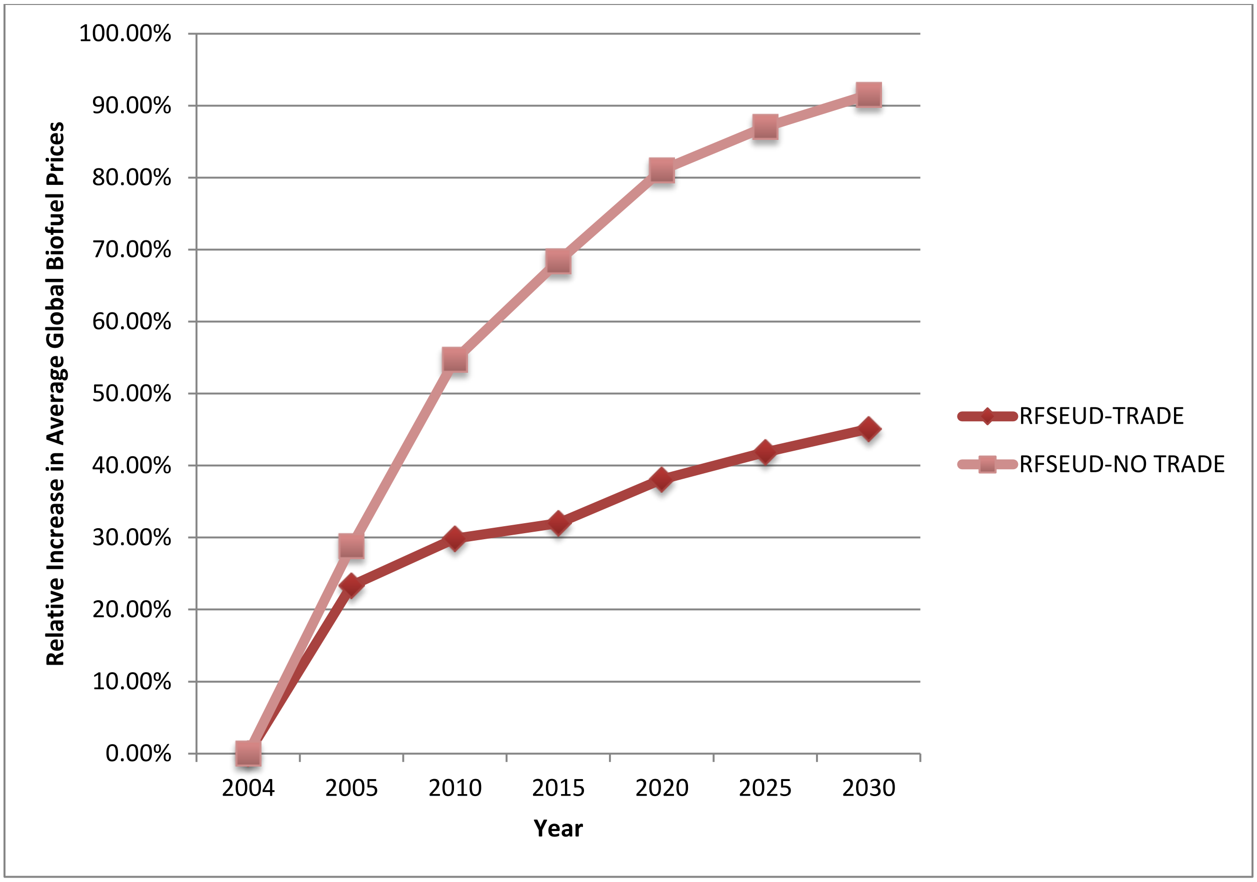


Figure 19. Long term trend in the Average Global Biofuel Prices relative to the Base Year Prices in 2004 for RFSEUD case (RFS and EUD implemented in US and EU combined) with and without Global Biofuel Free Trade

Figure 19 shows that under the case of RFS and EUD implementation with no biofuel trade, the increase in the rate of biofuel price is 30% higher than 2004 base values and trend to be 55% in 2010 and 70% in 2015. If global free trade is allowed the prices increase to only 30% higher than the base year prices in 2005 and only 32% in 2015. The underlying global average price increase in both the cases can be attributed to higher demand and cost increase in production inputs. The trend clearly indicates that if free trade is allowed in the global biofuel market, the long term price increase will be substantially slower relative to the no trade case. The increase in 2025 is projected to be 87% for no trade case whereas only 42% for free trade case.

In Table 17 it is obvious that most of the global biofuel production takes place in Brazil. I will analyze the land use implications for the region of BRA given free trade.

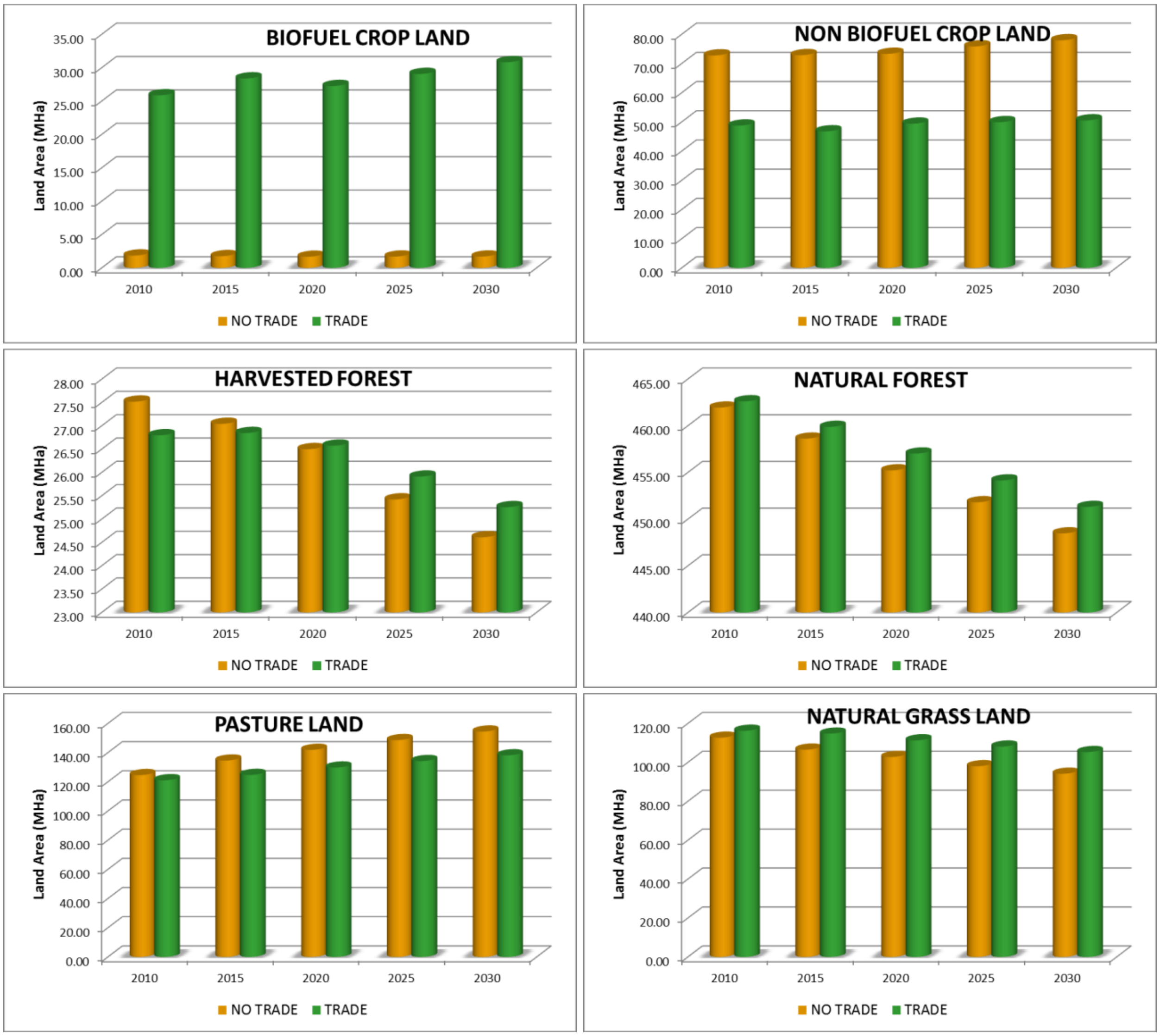


Figure 20. Land Use Area (mega hectors) for the land types in Trade and NO Trade cases for BRA region with RFS and EUD combined (RFSEUD-BASE) policy scenario

Figure 20 shows biofuel exports by BRA will have significant impact on regional crop land. The total crop area in the trade scenario is significantly less than the area in no trade scenario as land devoted to non-biofuel crops is devoted to sugar cane production. The 2025 level for crop land in no-trade case is 76 MHa and in trade case it is 50 MHa. The pasture land also decreases from 148 MHa in no-trade case to 134 MHa in trade case for 2025.

The natural forest and natural grass land area is higher in the trade scenario compared with the no trade scenario. This can be explained by the fact that in trade case Brazil tends to specialize more toward sugar cane ethanol due to higher margins through biofuel exports, and away from livestock. This results in reduced demand for livestock land relieving the pressure on the natural forest and natural grass land which otherwise might have had been converted to pasture land for the livestock industry. Instead more livestock is produced in the US (pasture land area increases in US over time as shown in Appendix), rather than being crowded out by ethanol production, and thus a very surprising result that increased sugar ethanol production actually decreases deforestation in Brazil.

4.6 Effects of Fuel Blend-wall Increase

The vehicle fuel blend wall is an important technical consideration for biofuel usage and growth in transportation sector, the issue was highlighted in detail in section 2.4. For all the previously considered scenarios I used 10% blend wall but as EPA has recently begun a process of allowing a 15% blend wall in the US I simulate a scenario of RFS and EUD implemented simultaneously in the US and EU respectively with blend wall increased to 15% (RFSEUD-15).

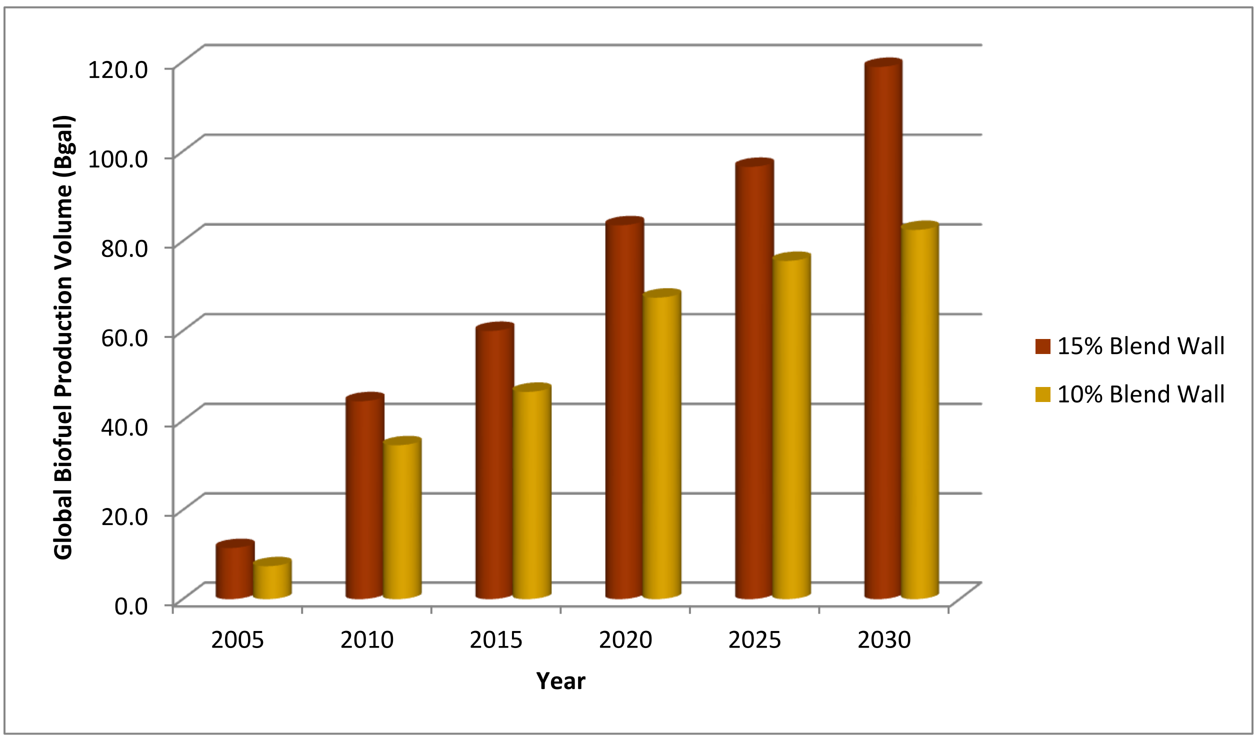


Figure 21. Global Biofuel Production in Bgal (Billion Gallons) for the RFS and EUD combined with 15% Blend Wall (RFSEUD-15) compared with RFSEUD-BASE case with 10% blend wall

The Figure 21 shows the difference in global biofuel production if the vehicle fleet is capable of 15% biofuel blending technology. This technological change will enable the domestic economies to produce more biofuel as a percent of total gasoline and diesel consumption in the transportation fleet. The figure demonstrates that in addition to price and policy constraints on biofuel production blend wall level acts as an implicit constraint. If I increase the blend wall to 15% and keep all other variables constant with no global biofuel trade, the production increases to 60 Bgal in 2015 compared to 46.4 Bgal in 2015 with 10% blend wall.

The difference between the two cases increases with the time highlighting the presence of blend wall implicit constraint on domestic production. Even if the domestic sector is capable of producing high volumes of biofuel it can only produce the levels needed to meet the 10% volume requirement of domestic consumption and excess capacity is wasted if the fuel trade across regions is cost prohibitive. An important corollary is that the volumetric targets in policy mandates can only be as high as the blend wall driven proportion of the total domestic fuel consumption. The take away from the analysis is the presence of implicit technical and infrastructure constraints on biofuel production in addition to the economic and regulatory limits.

4.7 Land Productivity Effects

First generation biofuels use crops such as corn, sugar cane, soy oil etc. as a feedstock inputs, hence the fuel production is affected by crop land productivity. If the land is more productive it will lead to better economics for the first generation fuels. Land productivity improvement dampens the pressure on food prices as the land displaced for biofuel crops is compensated by productivity improvement in non-biofuel crop land with more feedstock production per unit of area. To observe the effect of land productivity on production I simulate the scenario RFSEUD-NOPROD with no productivity improvement in crop land over the years with implementation of RFS and EUD in USA, EUR and ROE. I will compare the results of this scenario with the similar case with 1% annual land productivity.

Figure 22 shows the global food price difference between the two cases considered for the analysis. The figure indicates that global food prices increase by 2.15% more in the case with no productivity improvement than the case with 1% productivity in the year 2015. The difference reaches 4.37% in 2030, highlighting the rising price differential between the two cases. This phenomenon indicates that productivity improvement has a dampening effect on the global food prices by mitigating the land use effects through higher crop yields.

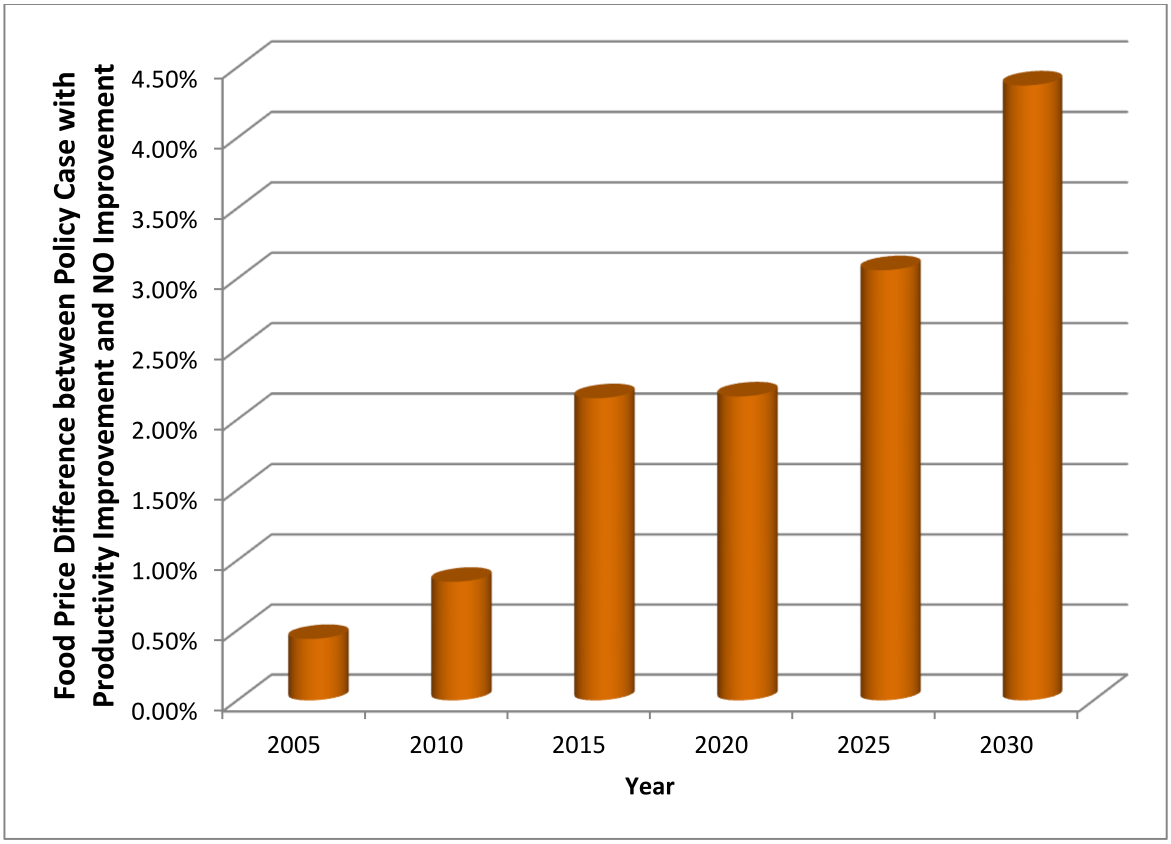


Figure 22. Global Food Price Difference between RFSEUD policy with 1% annual Productivity improvement and No Productivity Improvement

The takeaway from the above analysis is that if the land productivity does not increase as projected by the economists and policy makers, impact of biofuel mandates and production on global food prices will be higher and will increase over time.

5. CONCLUSIONS

The use of biofuels in domestic transportation sector in the United States and European Union is attributed to a portfolio of policies enacted over the years. The most significant hence the most debated and studied are the regulatory mandates on biofuel use. Renewable Fuel Standard (RFS) in the US and European Directive on the Promotion of Renewable Energy (EUD) in the EU place binding targets for domestic biofuel use. These mandates have triggered production of first generation fuels at large scale. These fuels primarily rely on food crops for feedstock input while the second generation fuels which rely on cellulose or waste material have not been successfully scaled up to the desired production levels at feasible price threshold. This raises important questions, what will be the implications of policy mandates and biofuel production on land use change, global food crop prices and transportation fleet as the binding mandates will rely mainly on first generation fuel technologies for the foreseeable future.

I explored the research questions through computable general equilibrium framework which allows for the capture of the full economy-wide costs and impacts of policy mandates. Most analysis of policy mandates and biofuel production technologies leave out the land use change impact assessment. I have developed a mechanism to integrate the first generation technologies with land use functionality in the framework and have also adjusted the transportation sector and second generation technologies for policy impact analysis. I simulated the policy mandates through a permit trading system which is constrained by the blend wall technology of the underlying vehicle transportation fleet.

Using the updated model, I simulated several scenarios: No Policy case without mandates but with the capability for first and second generation technologies, US Renewable Fuel Standard implemented alone, EU Policy Directive implemented alone, US and EU mandates combined, the scenarios considered 10% fuel blend wall and no trade. I find that EU-US combined required 44% more land than the NOP case, whereas US only needed 28.4% and EU only required 27.2% more land over the 2005-2030 time frame. The increased demand for feedstock land is met primarily by land use change in non-biofuel crop land-1% for US-EU combined and 0.5% for both EU and US only cases for the 2005 to 2030 time span- and relies partially on pasture land, natural grass land and harvested forest (less than 1% for all the cases).

I find that policy cases impact the long term global food crop prices at the margins with less than 1% increase relative to the price trend in case of no biofuel production. The margin decreases with time as land productivity improvements dampen the impact. I analyzed the effects of enabling biofuel free trade in US and EU combined policy scenario and observe that

Brazil experiences a 19 times increase in sugarcane ethanol production over the time span of 2005-2030 compared to the case with no trade while the production in US and EU is no longer economical and leads to no domestic production of first generation biofuels. The most important finding is that this explosive growth in biofuel production reduces the rate of deforestation in Brazil and results in saving 7% of natural forest land. The global biofuel prices are on average 33.5% less if the trade is allowed compared with no or minimal trade which is a realistic depiction of the existing trade barriers in the EU and US.

I simulate a scenario to analyze the impact of fuel blend wall raised to 15% with the US and EU policy mandates implemented and find that global biofuel production is 32% higher over the 2005 to 2030 time frame. This demonstrates that fuel blend wall is an implicit constraint on the biofuel production as transport sector only consumes the fuel blend with approved level which limits the overall volumetric usage of biofuels.

To study the relationship of crop land productivity with land use change and food prices, I simulated a scenario with EU and US combined policy but with land productivity kept constant at 2004 levels compared to the similar scenario with 1% annual productivity improvement. I find that land requirement for the crop land is marginally higher (less than 1%) and the food prices on average are 2.1% higher (2005 to 2030) for the scenario with no-productivity improvement.

It is important for the policy makers to clearly articulate the tradeoffs involved in biofuel mandates and apply the insights gained from the thesis to design optimal portfolio of renewable energy policies. Future analysis may refine the transportation sector and mandates permit trading system to allow for the inclusion of more advanced vehicle and biofuel technologies in the model.

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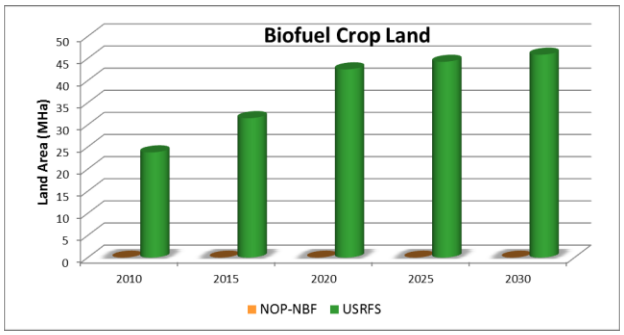
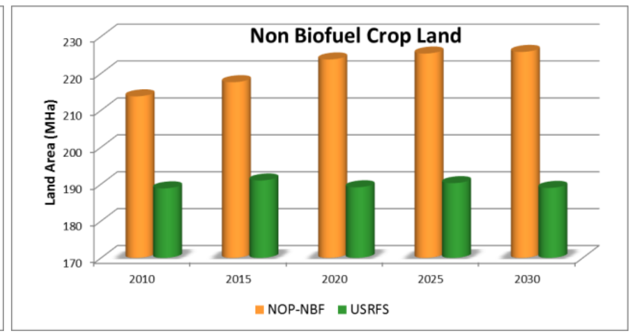
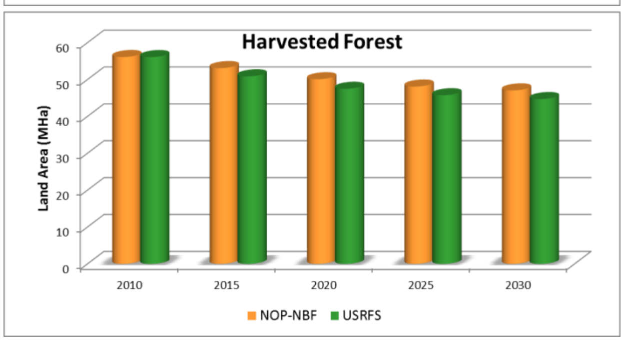
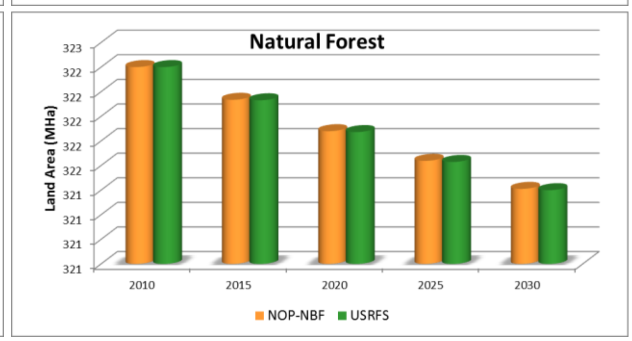
7. APPENDIX

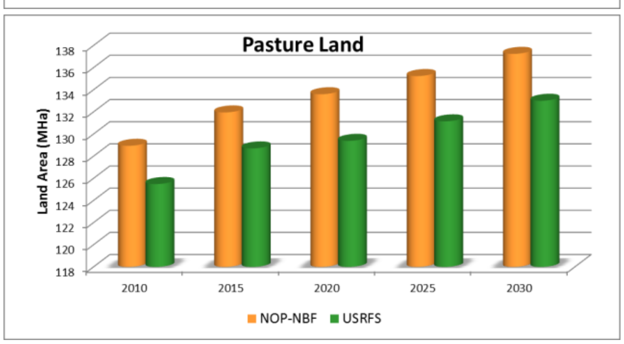
Land Use Area (mega hectors) for the land types in in No Policy-No Biofuel (NOP-NBF) and RFS only (USRFS) cases for the United States (USA)

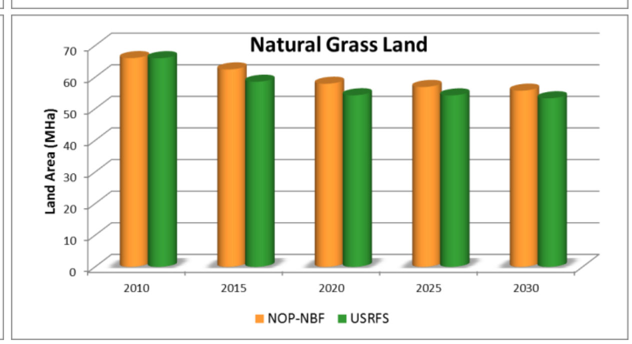




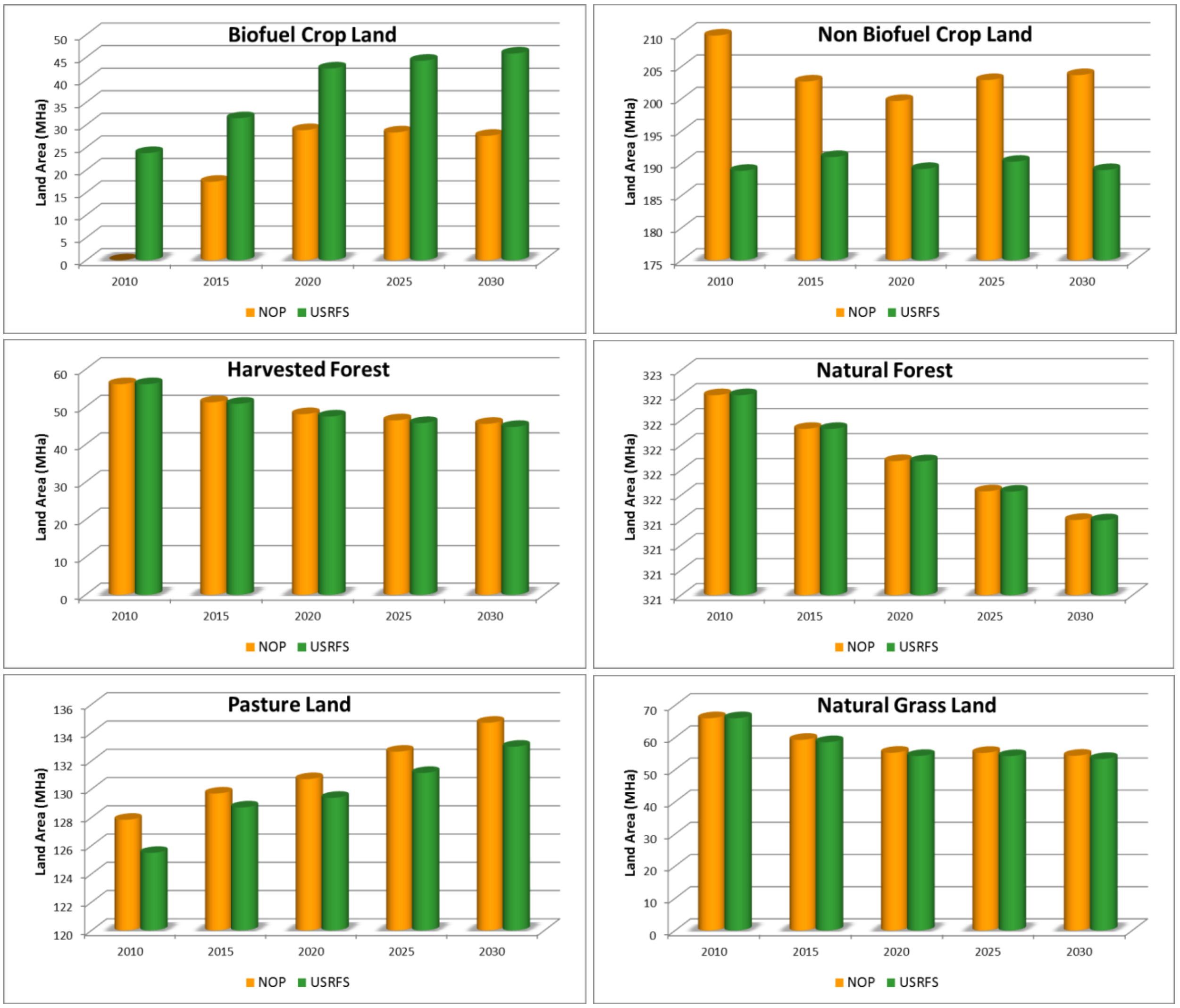




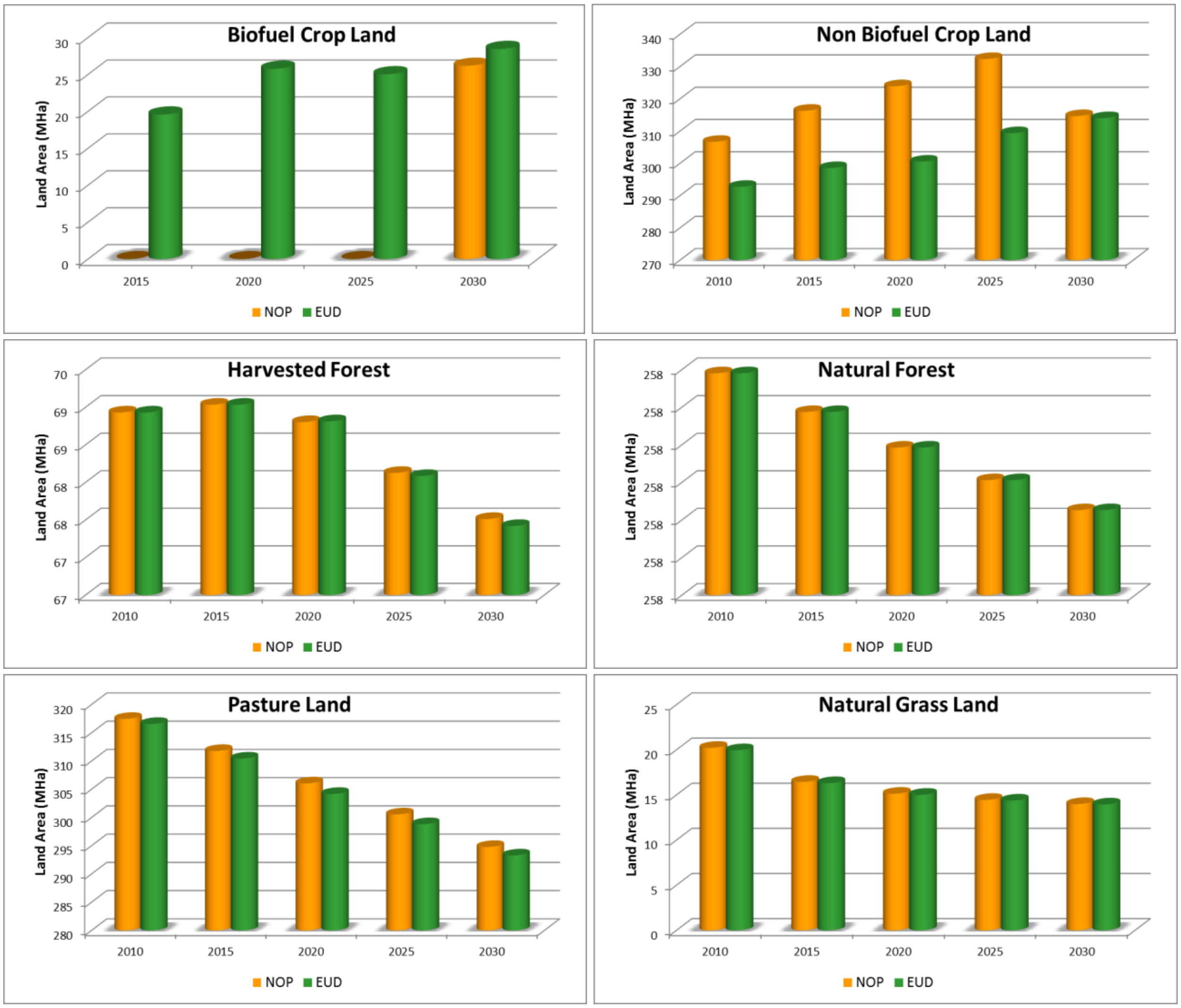




Land Use Area (mega hectors) for the land types in No Policy (NOP) and RFS only (USRFS) cases for the United States (USA)



Land Use Area (mega hectors) for the land types in No Policy (NOP) and EUD only (EUD) cases for the European Union (EUR and ROE regions)



Land Use Area (mega hectors) for the land types in No Policy-No Biofuel (NOP-NBF) and RFSEUD-BASE cases for the entire World