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Fuel versus Food

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Abstract

Many countries are actively encouraging the supply of biofuels as a low carbon alternative to the use of fossil fuels for transportation. To what extent do these trends imply a reallocation of scarce land away from food to fuel production? This paper critically reviews the small but growing literature in this area. We find that an increase in biofuel production may have a significant effect on food prices and in certain parts of the world, in speeding up deforestation through land conversion. However, more work needs to be done to examine the effect of newer generation biofuel technologies that are less land-intensive as well as the effect of environmental regulation and trade policies on land allocation between fuel and food.

Key words: *Agricultural Production, Biofuel Economics, Climate Policy, Environmental Regulation, Land Allocation*

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1 Introduction

In 2004, an estimated 14 million hectares worldwide were being used to produce biofuels and their by-products, representing around one percent of global cropland (IEA 2006). In recent years, many countries have adopted policies to encourage the supply of energy from land-based sources. Many factors are contributing to this trend, including the need for cleaner energy sources, a desire for less dependence on foreign countries for vital energy supplies, and the perceived benefits from boosting a domestic agriculture sector that has been dependent on subsidies for survival.

Bioethanol and biodiesel account for the majority of fuel from land. However, these liquid forms of bio-energy only supply a small share of the world energy market – about 1% of world renewable energy supply and 1.8% of the world's transportation fuels. Almost 90% of biofuels is ethanol, and the remaining 10% is biodiesel (Rajagopal and Zilberman 2007).[2] Rajagopal and Zilberman divide the land-based fuels into three main categories: United States ethanol from corn, Brazilian ethanol from sugarcane and German biodiesel from rapeseed. In Brazil, ethanol provides about 22% of gasoline demand, while in the United States this share is less than 3% (OECD 2008). The market is dominated by two countries; Brazil and the United States, who together supply three quarters of the world's biofuels.

Land-based fuel production has received much policy attention in recent years. Nonetheless, its current share is relatively small in most countries, except for Brazil. However, in the future,

[2] Typically, conventional or first-generation biofuels are classified into two broad categories: ethanol and biodiesel. Conventional ethanol in OECD countries is mainly produced from starchy crops like corn, wheat and barley, but it can also be made from potatoes and cassava, sugar cane and sugar beet. In tropical countries like Brazil, ethanol is produced exclusively from sugar cane, while molasses are used in India. Biodiesel is produced from transetherfication of vegetable oils or animal fats. Production of biodiesel can also be obtained from used vegetable oils (Zilberman and Rajagopal, 2007).

government policies that encourage renewable energy sources may result in a larger share of transportation fuels coming from land which historically has been used for food production, forestry, and other critical uses. Pro-biofuel policies have led to a rapid increase in acreage under biofuels in the United States and the European Union, as well as in other countries such as China and India. Policies that encourage land-based fuel production may lead to a reduction in acreage used for food production, with a corresponding reduction in food supply and increase in food prices. Furthermore, land that is not well suited for agriculture, but is currently used for forestry or grasslands may be converted into land for fuel production. This may in turn lead to a leakage of sequestered carbon into the atmosphere, which will reduce the potential environmental benefits from substitution of gasoline by biofuels in the first place.

On the demand side, 99% of energy services in the transportation sector are currently provided by petroleum. Two-thirds of the increment in world liquids consumption is expected to be in the transportation sector by the year 2030 (Rajagopal and Zilberman 2007, IEA 2007). Whereas several substitutes exist for the use of polluting fossil fuels in the electricity sector such as solar, wind, nuclear and other renewables, first generation bio-oils are the only viable substitutes currently available for transportation. Other substitutes, such as second-generation biofuels and fuel cells, are still at the research and development stage.[3]

With the agricultural sector also becoming a provider of clean energy, land availability and food needs can limit the growth in plant-based fuels production. World food requirements are likely to

[3] Second generation biofuels are produced from agricultural or forest residues such as straw, wood chips or grasses and they use the cellulosic parts of the plant. They require much less land relative to first generation biofuels. Third-generation biofuels, which are still at the research stage, would use substances such as algae or biotech feedstocks.

maintain a significant level of growth in the coming decades (FAO 2007). A change in dietary habits towards meat and dairy products is also expected to accompany the rise in per capita income in fast-growing countries (Cranfield *et al.* 1998, Delgado *et al.* 1999). This shift in food consumption preferences increases the demand for land since meat and dairy are intensive users of agricultural land. In addition, there is relatively little unused, arable land left available for a major expansion of current agricultural production (Wiebe 2003, FAO 2007).

This chapter provides a review of some of the major issues and economic trade-offs between fuel production for transportation and the production of food from land. The remainder of the paper is organized as follows. We start with a brief discussion of the main economic models that have been developed and used to study biofuel production and its economic and policy implications. In section 3, we discuss the allocation of land between food and fuel. The economics of biofuels are presented in section 4. In section 5, we give a brief overview of government policies toward biofuel production, including trade and agricultural policies, and discuss their potential impact on biofuel and food production. We then discuss some of the environmental impacts of biofuel production in section 6. Section 7 concludes the paper.

2 Economic Models of Biofuel

Several models have been developed to study the interaction between biofuels and food. The production of biofuels and the development of the biofuel industry are highly dependent on land availability and food demand as well as on the price of conventional transportation fuel (petroleum). Accordingly, the models that have been developed to study fuel versus food can generally be divided into two main categories, based on whether the models describe only the agricultural sector or the agricultural sector together with the transportation sector. In this section we give a brief overview of some of these modeling efforts.

2.1 Models of the Agricultural Sector

The main modeling efforts at the global level focusing only on the agricultural sector are FAPRI (2007) and IFPRI (Msangi *et al.* 2007). Both studies develop partial equilibrium models to explore the potential impact of biofuels production on food prices, agricultural production, food security, and international trade in the medium term (until 2016 or 2020). In these models all prices are endogenous, but the scarcity of land resources is not considered explicitly and petroleum prices are taken as given. The impact of the development of biofuels is explored by introducing an exogenous demand for transportation. The models are used to project demand and supply for agricultural products, as well as trade between different regions of the world.

Three scenarios are defined and studied by the IFPRI model (Msangi *et al.* 2007). A first scenario focuses on the recent boom in biofuel production, but leaves out second generation biofuels. The second scenario introduces second generation biofuels, while the third scenario also adds improvements in crop productivity. The results are compared to a benchmark model without biofuel production. An increase in food prices in this model also affects caloric availability and child malnutrition in poor income economies. The FAPRI (2007) model considers only one scenario and aims at analyzing the expected impact of biofuel production on agricultural markets until the year 2016.

Other models of the agricultural sector incorporate endogenous demand for land. Schneider and McCarl (2003) have extended the FASOM model (Adams *et al*. 1996), which is a partial equilibrium model of the US agriculture and forest sectors, in order to examine the potential role of biofuel production within a portfolio of land-based carbon mitigation strategies. This is an optimization model, where the objective is to maximize the economic surplus net of the costs of inputs under land-allocation constraints. In order to account for imperfect substitutability between alternative uses of land, available land is divided into different land types, and the model tracks land competition between food, feed, energy and forest since land may be allocated to different crops, pastures and forestry uses.

2.2 Models of Agriculture and Transportation

We divide our presentation of models of agriculture and transportation into two parts based on whether they are partial or general equilibrium models. Most of the models presented below are setup within a general equilibrium framework.

2.2.1 Partial equilibrium models

The nature of land-based fuel production implies that biofuels compete with food production for scarce land resources. Hence, the opportunity cost of land must be taken into account when considering the production costs for biofuel. This is done by Chakravorty *et al*. (2008) who develop a stylized model within a Ricardian-Hotelling framework. In this dynamic framework, land allocation decisions are based on the rent maximization principle. The model focuses on the supply of biofuels in the context of scarce energy resources in which available land is allocated between the food and energy industries. The demand for clean energy is modeled by introducing an exogenous cap on the carbon stock in the atmosphere. Biofuel serves as a perfect substitute for petroleum and is considered carbon neutral.

Elobeid and Tokgoz (2008) develop a partial-equilibrium model of the world ethanol market in order to study the impact of US trade barriers on the US ethanol market. This model distinguishes between six regions; the United States, Brazil, EU15, China, Japan, and the rest of the world, and is used to analyze the implications of a US tariff on ethanol imports as well as a tax credit for US refiners blending ethanol with gasoline.

2.2.2 General equilibrium models

The GTAP model (Hertel 1997), which is a general equilibrium model, has been altered to take into account land scarcity and has been combined with the GTAP-E model (Burniaux and Truong 2002), which is a model of the energy sector (Banse *et al*. forthcoming, Hertel *et al*. 2008.a, Hertel *et al*. 2008.c.). In this revised model, to account for the heterogeneity of land across geographical areas, the global land area is divided into different agro-ecological zones (Lee *et al.* 2005). Each zone is defined on the basis of the length of the growing season, and these zones are in turn subdivided into three climatic zones (tropical, temperate, and boreal). Land-use changes within each zone are determined by changes in relative rents, and the magnitude of these changes is driven by a constant elasticity of transformation. In the model, first generation biofuels are used in conventional vehicles. Conventional gasoline vehicles are compatible with blends up to 10% bioethanol (E10), whereas flexi-fuel vehicles are typically designed for blends of 85% ethanol (E85). To treat biofuels and petroleum as complementary inputs, the altered GTAP model incorporates a CES production function for the transportation sector (McDougall and Golub 2008, Banse *et al*. forthcoming, Hertel *et al*. 2008.c). The model allows for substitution between petroleum products and three types of biofuels; ethanol, biodiesel produced from oil, and biodiesel produced from vegetable oil. To take into account the fact that bioethanol can be produced from different feedstocks, ethanol production is modeled using a

CES production function. The value of the elasticity of substitution between different fossil fuels and biofuels reflects the existing technological barriers for displacing fossil fuels by biofuels. Second generation biofuels and other technologies currently at the research and development stage are not considered in this model.These models have been used to explore the impact of different mandatory blending policies on world agricultural production. Whereas some models focus on the impacts of the European directive on the world agricultural markets (Banse *et al*. forthcoming), others explore the consequences of the implementation of both EU and US biofuels policies (Hertel *et al*. 2008.c, Birur *et al.* 2008).

Reilly and Paltsev (2008) develop a model of transportation and agriculture based on the MIT Emissions Predictions and Policy Analysis (EPPA), which is a recursive-dynamic multi-regional equilibrium (CGE) model of the world economy (Paltsev *et al.* 2005). The EPPA model is a bottom-up model built on the GTAP data set, and it gives a detailed representation of energy markets as well as accounting for regional production, consumption and bilateral trade flows. The model estimates the emissions of greenhouse gases, including CO2, as well as other air pollutants. Production and consumption sectors are modeled with constant substitution elasticities. Two biomass technologies are considered: the production of electricity and the production of a liquid fuel from biomass. The demand for land is incorporated in the model, but even though the model is setup at the world level, land is treated as a homogeneous input. The model considers different energy sectors, such as heat, electricity, and transportation. The model also accounts for the price-induced substitution of energy between polluting fossil fuels and the cleaner bioenergy.

The studies presented above consider growth in agricultural yields as exogenous. Keeney and Hertel (2008) develop a model based on the GTAP model, in which yield growth is endogenous.

For example, the recent increase in food prices may induce technological progress in the agricultural sector. Induced innovation studies, such as Hayami and Ruttan (1971), have estimated long-run supply responses of agricultural yields to food prices. Keeney and Hertel (2008) have incorporated such supply response functions into the GTAP model in order to consider the effect of technological progress.

Table 1 summarizes the different approaches taken by the models used to examine the role of biofuels. Most models focus on the economics of biofuels supply and in particular address the issue of government policy and how that can affect biofuels production. A smaller sample of the models explicitly considers environmental impacts from biofuels production. A fewer number of models explicitly consider the role of fossil fuel scarcity and the effect rising prices of energy may have on the supply of biofuels.

Table 1: **Modelling Structure employed by different studies**

		Land-use and land-use changes	Economics of biofuels	Government policy towards biofuels	Environmental impacts of biofuels
Agricultural sector	FAPRI (2007)	no	yes	yes	no
	IFPRI (2007)	no	yes	no	no
	Schneider and McCarl (2003)	yes	yes	yes	yes
Agricultural and transportation sector	Chakravorty *et al*. (2008)	yes	no	yes	yes
	Elobeid and Tokgoz (2008)	no	yes	yes	no
	GTAP models	yes	yes	yes	no
	Reilly and Paltsev (2008)	yes	yes	yes	yes

Note: "yes" means that the model accounts for that factor

We now consider some of the main factors that are behind the increased demand for biofuels and discuss current trends in land allocation between food and biofuels.

3 The Allocation of Land between Food and Fuel: Current Trends

Between 2004 and 2007, when both ethanol and biodiesel production grew rapidly both in the United States and other countries, there was a dramatic increase in food prices for several commodities such as corn, wheat and vegetable oils. This is in sharp contrast to the long-run decline in world food prices of almost 75% over the period 1974-2005 (The Economist, 2007). Short-run increases in food prices were generally caused by supply shortages arising from poor harvests. In a recent study, Martin (2008) suggests that about a quarter to a third of the price increase in recent years can be explained by the increased production of energy from land. Other factors explaining the recent rise in world food prices are droughts and increased demand for agricultural products from highly populated developing countries.

The increase in prices of commodities like corn, which can be used to generate energy, also leads to an increase in the price of meat and dairy products since corn accounts for more than half the cost of animal feed in countries such as the United States (Yacobucci and Schnepf 2007). Large-scale conversion of corn to ethanol will affect the supply of corn in the world market. In this market the United States exports two-thirds of the total quantity of corn, while heavily populated developing countries such as China and Mexico are large importers. In 2004, 11% of the corn harvested by US farmers was used for ethanol production. A shift towards biofuels in the US will result in higher prices of corn in these countries. In fact, the spike in the price of tortillas in Mexico during January 2007 was widely attributed to this phenomenon.

About one percent of total cropland globally was used to produce biofuels and their by-products in 2004 (IEA 2006). Brazil has the highest share of acreage devoted to biofuels production; sugarcane is currently produced on 5.6 million hectares in Brazil, which accounts for about ten percent of the country's cropland. Elsewhere, even though the acreage currently used for land-based energy production is quite small, there is not much new land that may be available for energy production. Thus, future growth in biofuels supply will have to come from new technologies or from substitution of current acreage away from food to fuel production.

Looking at the total availability of land, of the world's 13.5 billion hectares (ha) of land surface, forests currently cover 4.2 billion ha while agriculture (croplands and pastures) accounts for 5 billion hectares, of which 1.6 billion ha are cropland. The remaining land areas are urban and ill-suited for agriculture. FAO (2008) considers that an additional two billion hectares are potentially suitable for agriculture. These figures should, however, be treated with caution. First, according to Wiebe (2003), these two billion hectares have low crop yields and are highly vulnerable to land degradation, which undermine their long-term production capacity. Nonetheless, some biofuel crops, such as cassava, castor, and sweet sorghum, can be grown under such unfavourable environmental conditions, but the energy efficiency of these crops is currently low. Second, the world's forests and wetlands supply valuable environmental services such as biodiversity conservation, carbon sequestration and water filtration. As a result, some of these areas will be protected and unavailable for agricultural production. As the total land availability is limited, an increased focus on biofuels will undoubtedly come at the expense of land available for food production.

There is potential to cover some of the increased demand for crops that results from the increasing focus on biofuels by taking advantage of the potential for increased yields that lies in currently available technologies. Even if crop yields are expected to grow at a lower rate than in the past, actual yields are still below their potential in most regions (FAO 2008). For instance, in Malaysia and Indonesia, which are the world's largest producers of biodiesel after the European Union, current palm oil yields amount to four tons per hectare, but could potentially be increased to six tons per hectare with available know-how. In China, the average sugarcane yield is presently only 60 tons per hectare with the potential for going up to 85 tons per hectare.

Land use is closely linked to the production of land-based fuels and food. Most of the modelling frameworks discussed earlier can be used to analyze the implications of biofuel production on land use. We discuss this issue later in the paper.

4 The Economics of Biofuels

There are two important dimensions that need to be taken into account when considering the economics of biofuels; energy yields and production costs. Both are highly dependent on the feedstock used, and local conditions determine what feedstocks can be used in different regions of the world. For instance, in the United States ethanol is produced from corn, which is a far more demanding plant in terms of land quality than sugarcane, which is used in Brazil. There are also large differences in the availability and in the quality of land between different regions (Wiebe 2003). For instance, the availability of land in the United States and in European countries is scarce compared to countries like Brazil and Indonesia. Consequently, to determine where the production of biofuels will occur, it is crucial to consider not only the amount of land available but also the quality of land.

Let us now compare the costs and yields of the major land-based fuel producers; Brazil and the United States. Brazilian ethanol is based on sugarcane and is by far the most efficient, with average yields of 1,665 gallons per hectare. In the US, ethanol from corn yields about 1,045 gallons per hectare (Seauner 2008). The sugar in sugarcane can be converted directly into ethanol, but in corn-based ethanol production, the carbohydrate must first be converted into sugar. Moreover, the cane stalks from sugarcane harvesting (bagasse) are burned to fuel the plant, which further reduces the cost of production. The higher efficiency of the transformation process leads to cheaper ethanol from sugarcane relative to corn. Producing one gallon of ethanol in Brazil costs about US$ 0.83, while the corresponding number for US corn-based ethanol is US$ 1.09 (Lasco and Khanna, 2008). Brazilian ethanol is competitive at crude oil prices of $35 per barrel (FAO 2008). In comparison, biodiesel production in Germany is more expensive with average costs that are about twice the cost of US ethanol. Ethanol can also be produced from other crops such as cereals and beets, but the cost for these crops is even higher (Ryan *et al.* 2006).

In the study by Banse *et al*. (2008), where marginal lands can be converted into agricultural land, increasing food prices are less important than in studies where the endogenous demand for land is not incorporated into the model (e.g. Msangi *et al*. 2007). For instance, Banse *et al*. (forthcoming) report that most food prices follow a decreasing trend. The exception is oilseed, which shows a small price increase of 1%. The IFPRI model (Msangi *et al*. 2007), on the other hand, predicts an increase in oilseed and sugar prices of 18% and 10%, respectively.

Several studies evaluate the possible implications of the European Union's biofuel target. To reach these EU targets, Banse *et al*. (forthcoming) find that European imports from land-abundant countries such as South America will increase. They find that this will increase the import share of energy crops from 42% to 53%. We return to this issue below when we look at the implications of government policies towards biofuel production.

The biofuel sources discussed above are typically referred to as first generation biofuels. There is a second generation of biofuels that is derived from agricultural or forest by-products and residues. Second-generation ethanol is produced from biomass such as straw, wood chips or grass, of which the cellulosic, hemi-cellulosic and lignin parts are used. Second-generation biodiesel can be produced from biomass by gasification or Fischer-Tropsch synthesis (Rajagopal and Zilberman 2007, OECD 2008). Other substitutes, such as methanol, hydrogen and synthetic diesel, are produced via gasification from lignocellulosic biomass (Hamelinck and Faaij 2006). These biomass-based biofuels are less land-intensive, but they are at present still in the research and development stage.

Many studies analyze the relationship between biofuels and food prices. This is important as the prices obtained from the alternative use of land (food production) affect the opportunity cost of land. There are also other important consequences of this competition for limited land resources between fuel and food, such as malnutrition and food shortages especially in poorer regions. Analysis using the IFPRI model shows that biofuel production has a substantial impact on world food prices. However, when taking into account second generation biofuels and productivity improvements, the impact is lower. The largest increase in food prices are observed for oil seeds and sugarcane. Only taking into account first generation biofuels, the analysis shows that corn and oil seeds prices rise by 76% and 66%, respectively. When introducing second generation biofuels, these figures fall to 45% and 49%, respectively, and accounting for crop productivity improvements renders the price effect even smaller, although still significant.

The IFPRI model also looks at the effects on calorie availability and child malnutrition in poor income economies, particularly focusing on Sub-Saharan Africa. The results show an 11% reduction in daily calorie availability (275 calories) and a significant increase in the number of children suffering from malnutrition, in the first generation biofuels scenario when compared to the no-biofuels scenario. The effects are smaller when technological progress is considered, such as the advent of second generation biofuels and improvements in crop productivity.

In the analytical model of Chakravorty *et al*. (2008) it is shown that as the exhaustible resource (petroleum) becomes scarcer, its price increases, which makes land-based fuel production (biofuels) competitive. As a consequence, land shifts out from food production to energy production, which leads to an increase in the price of food. Ultimately, the scarce petroleum resource is exhausted and all energy is supplied by land.

The question of what fuel to use, petroleum or biofuels, has also been analyzed in the modified GTAP model. The model accounts for the price increase in crude oil relative to the increase in agricultural prices. The results of the analysis indicate that the demand for energy resources - petroleum versus biofuels - depends critically on the relative price of fossil fuel and land-based energy.

5 Government Policy towards Biofuel Production

A range of different policies and regulation toward the production of biofuels have been proposed and implemented. These include regulations that make it mandatory to blend a certain amount of ethanol with gasoline in transportation fuels (mandatory blending), subsidies to biofuel producers, as well as trade barriers aimed at biofuels imports. Other policies are also highly relevant for the development of biofuels, such as carbon taxes or quotas, although these regulations are not necessarily specific for biofuels, but affect the production of biofuels indirectly. In this section we discuss some of these policies and examine their implications. We start by looking at mandatory blending policies.

5.1 Mandatory Blending

Governments such as the European Union and the United States have established biofuel mandates to be achieved at target dates. For instance, the EU expects its member states to ensure that 5.75% of transportation fuels come from biofuels and other renewables by the year 2010 and 10% by 2020. With an average share of renewables in the EU25 countries of only 2% in 2007 (OECD 2008), these goals may seem unrealistic. In the United States, former President George W. Bush declared that the biofuel production target should be 35 billion gallons in 2017 from the current production of 6 billion gallons (FAO 2008). Also countries such as China, Japan and Australia are planning on implementing policies encouraging the production of biofuels (Rajagopal and Zilberman 2007). Still, in China the government recently decided to slow down its ethanol plant expansion program because of worries that the rapid expansion could threaten the country's food security (Kojima *et al*. 2007).

In terms of future trends in biofuel production, the FAPRI model shows that ethanol production in the United States will expand much more rapidly than mandated by the Energy Policy Act of 2005, surpassing 7.5 billion gallons by 2008 and 12 billion gallons by 2010. However, in the absence of any incentives the European Union is not expected to achieve the goal of a 5.75 percent share of renewable fuels by 2010. The reason why biodiesel production in the European Union is expected to grow slowly is the increasing prices of vegetable oil and the model assumption of stagnant crude oil prices in the future. If oil prices do not rise, then producers of biofuel do not get adequate incentive to supply the energy market.

Several other studies also explore the impact on the world agricultural sector of different policies for mandatory blending. Some focus on the impacts of the European directive on the world agricultural markets (Banse *et al*. forthcoming), while other studies explore the consequences of the implementation of both EU and US biofuels policies (Birur 2008, Hertel *et al*. 2008.c). All these studies predict a positive impact on food prices as a result of mandatory blending. The implementation of mandatory biofuels blending in the European Union is projected to slow down the decline in feedstock prices, such as cereals and sugar (Banse *et al*. forthcoming). The effect on world prices is more significant when policies are implemented in both the European Union and the United States. Due to the relative land scarcity in Europe, it is expected that half the crops used in biofuel production must be imported in order to meet the target (Banse *et al*. forthcoming). In the United States, on the contrary, the additional ethanol needed to meet these mandated targets will to a large degree be produced domestically. These studies also find that the impact of mandatory blending on land use will be substantial. This has an indirect effect on climate change, since any conversion of forest lands into agricultural lands, which is predicted as a consequence of the mandatory blending policies, causes carbon leakage and threatens to undo some of the greenhouse gas goals the program is designed to achieve in the first place.

5.2 Carbon taxes and carbon cap

Most countries levy a tax on gasoline and diesel, and excise tax reductions is the most widely used instrument to bridge the gap between the price of conventional and land-based fuels. However, the level of taxation varies across countries. For example, in the United States there is a fixed tax credit of US$ 0.51 per gallon ethanol blended with gasoline and a US$ 1.00 per gallon tax credit for biodiesel (Rajagopal and Zilberman 2007). The excise tax credit may be justified by the presence of environmental externalities that cannot properly be corrected for in end-user prices (Kojima *et al*. 2007). Ryan *et al*. (2006) estimate that the marginal benefit of reducing CO2 emissions would need to be at least US$ 229 per carbon ton of CO2 equivalent (2006 prices), which is much higher than the actual price in 2006 of US$ 17 per ton of carbon. What must also be considered here is the question of energy security. Countries such as the United States have stressed the need to develop the domestic biofuel market so as to reduce their dependence on foreign oil and therefore improve energy security (Taheripour and Tyner 2007). Currently, the United States imports 60% of its oil. The question is how much is the US willing to pay for this added energy security in terms of higher gasoline prices. If energy security is highly valued, that will translate into a strong incentive program for biofuels production.

In addition to policies that are directly aimed at the production of biofuels, other government policies will also have important implications for the development of biofuels. One example is the implementation of a carbon tax that will encourage the displacement of conventional fuels by land-based fuels. This has already been introduced in several countries such as Sweden and Finland.

Schneider and McCarl (2003) explore the potential role of biofuels production in a portfolio of climate mitigation options for the United States. The agricultural sector offers a wide range of strategies to mitigate climate change, including biological sequestration from conversion of agricultural land into forests, the adoption of new strategies for soil carbon sequestration, and the displacement of fossil fuels by biofuels. The authors use an optimization model and for each level of carbon prices they determine the least costly mitigation strategies. Their results show that biofuels should play no role below a carbon price of US$ 40 per ton. However, for carbon prices above US$ 70, their results show that biofuels dominate all other agricultural mitigation strategies. This result emphasizes the role of biofuels in mitigating climate change.

Reilly and Paltsev (2008) analyse the impact of a carbon emission target. The objective is to determine the least costly strategy to reach different carbon targets (450 – 750 parts per million). They find that the development of bioelectricity is expected to be insignificant due to the availability of competitive carbon-free substitutes for electricity (nuclear and solar). However, since other substitutes for petroleum such as fuel cells and hydrogen, are not mature enough at this stage, bio-oil is the only viable substitute on the basis of cost and emissions savings. To meet the target, bio-oil production rises substantially in the model, leading to an increase in world food prices. From 2010 to 2020, world food prices are projected to increase by about 10% in their study. When a mandatory blending target is imposed in the EU and the United States, the increase in prices is expected to be approximately 9% for coarse grains in the US, 10% for oilseeds in the EU and 11% for Brazilian sugarcane.

In a recent study, Chakravorty *et al*. (2008) analyze the impact of pollution regulations on the transition to biofuels and on food prices, within a Ricardian-Hotelling framework. The demand for a clean environment is expressed in terms of a cap on the carbon stock. The immediate implication of this cap is a rise in energy prices, which speeds up the adoption of biofuels and leads to a rise in food prices. The importance of these effects is found to depend on the level of land scarcity, the demand for food, the level of the regulatory constraint, and the abundance of fossil fuels.

5.3 Trade barriers and other market distortions

Government policies aimed at restricting trade are also of crucial importance to the biofuel industry. This is motivated by a desire for increased energy security and perceived benefits from supporting heavily subsidized domestic agricultural sectors. Trade policies will have a major impact on where biofuels are produced. For instance, the United States currently imposes a 54-

cents-per-gallon (US$) import tariff on ethanol. Brazil is the main exporter of ethanol into the US market, and consequently if this tariff were to be lifted, this would have a major impact both on US and Brazilian production. US ethanol is only economically viable at crude oil prices exceeding US$ 58 per barrel, while Brazilian ethanol is viable at prices that are much lower, around US$ 35 per barrel (Elobeid and Tokgoz 2008, OECD 2008). Hence, trade liberalization may lead to Brazil becoming the world's major ethanol supplier.

The US government protects domestic production by imposing trade barriers and introducing domestic market distortions such as a tax credit to refiners blending ethanol with gasoline. Elobeid and Tokgoz (2008) analyze the impact of trade liberalization by removing US trade barriers and tax credits in the ethanol market and their spill-over effects on other markets such as petroleum and agriculture. They analyze two scenarios: the first scenario involves removing trade distortions in the United States, while the second scenario considers the additional case when the federal tax credit for refiners that blend ethanol with gasoline is removed. The effects are very similar. US domestic ethanol prices are found to decrease by about 14%, which drives up ethanol demand by 4% percent, while domestic ethanol production shows a decline of 7%. The increased US demand results in an increase in the price of ethanol by 24%, and to satisfy domestic consumption, US imports of ethanol go up three times. This has the effect of increasing bioethanol production in Brazil by about 10%.

International trade in food products is highly protected. An estimated 75 percent of total agricultural support to OECD countries is provided by market access barriers (Anderson *et al.* 2006). Liberalization of food markets will impact food and crop prices as well as the competitiveness of biofuels. The European Union and the United States have a range of policies that encourage overproduction of sugar and thereby lower the world market price of sugar. The sugar market is one of the most distorted agricultural markets, and world prices are estimated to be 40 percent below the price level that would prevail in a free market (Kojima *et al*. 2007). These policies have stimulated the production of ethanol in Europe and encouraged Brazil to divert its production of sugar from exports and towards ethanol production. Hence, a liberalization of the highly protected European sugar market is likely to result in increased prices of sugar in Europe, which will lower the competitiveness of European biodiesel.

6 Environmental Impacts of Biofuels Production

Contrary to popular impression, biofuels are not carbon neutral. Life Cycle Assessment studies have estimated the amount of carbon emitted by the biofuel production process from *well-to-wheel* (Peña 2008, Rajagopal and Zilberman 2007). Table 2 shows the direct emissions savings from using biofuels relative to gasoline measured in CO2 equivalent. Savings from ethanol produced from sugar cane in Brazil are higher than the savings from corn in the United States. Furthermore, the savings from second generation biofuels tend to be larger than those of first generation biofuels. Notice that the stage at which most of the carbon emissions occur differs between gasoline and bioethanol (Peña 2008). Whereas most carbon emissions are released into the atmosphere during the combustion of gasoline, for biofuels the majority of carbon emissions occur during the different stages of fuel production. This is important when considering climate policy.

Table 2. Overview of direct emission savings from biofuels compared with reference fossil fuel vehicle (tons of CO2 equivalents per 1,000 gallons).

Biofuel	Generation	Feedstock	Low	Best estimate	High
Bioethanol	1st	Sugar crops	0.7	1.2	2.2
		Starch crops	0	0.4	0.9
		Brazilian sugar cane	2.4	2.9	3.3
	2nd	Lignocellulosic crops	2.6	2.5	2.4
		Lignocellulosic residues	2.7	2.6	2.5
Biodiesel	1st	Oil seeds	0.5	1.3	1.8

***Source**:* Ryan *et al.* (2006)

More recent studies have attempted to calculate the overall change in emissions by also accounting for the effects of land-use changes (Fargione *et al*., 2008, Searchinger *et al*., 2008). This work aims at recognizing the effects of additional acreage coming from deforested lands or from conversion of grasslands into cropland, which releases stored carbon into the atmosphere. Turning grasslands into croplands can release between 134 tons of carbon per hectare in the United States to 165 tons per hectare in Brazil (Fargione *et al*. 2008), while conversion of forest can release between 600-1,000 tons of carbon per hectare (FAO 2008). In a recent study, Fargione *et al*. (2008) found that the carbon lost by converting rainforests, savannas, or grasslands into land for biofuel production outweighs the carbon savings from biofuels. Such conversions release 17 to 420 times more carbon, depending on the crop and ecosystem, than the annual savings from replacing fossil fuels. Furthermore, corn-based ethanol, instead of resulting in a 20% reduction in carbon emissions, as previously thought, may double emissions over a 30-year period.

Another negative environmental impact that has been discussed as a result of the increasing production of biofuels is deforestation. There have been specific instances when the demand for biofuels has been cited as a factor responsible for an increase in deforestation. One example is

Indonesia, where increased deforestation has been attributed to a 70% rise in palm oil prices during 2007 (Yacobucci and Schnepf 2007). Deforestation has negative implications for carbon sequestration and the protection of biodiversity.

The production of biomass relies on water resources, which are becoming increasingly scarce in many regions. With an increase in the land used for agricultural production as a consequence of increased production of biofuels, irrigated land areas may expand. This may reduce water available for other uses, such as food production, and increase the price of water. Moreover, the reduced availability for water resources may cause a decline in agricultural yields and slowdown in the growth of food production (Rajagopal and Zilberman 2007). This issue is all the more important in countries that already suffer from water shortages like India and China (Berndes 2002, de Fraiture *et al*. 2006). Schneider and McCarl's (2003) also include an analysis of the potential role of biofuels, along with other climate mitigation options such as biological sequestration by converting agricultural land into forests and soil carbon sequestration.

7 Concluding Remarks

The future of the biofuel industry seems to be an increasingly important issue in the decades to come. The demand for transportation is projected to double by 2030 (IEA 2007). Nuclear power, solar energy and wind energy can substitute for petroleum and coal to meet demand for electricity and heating. These resources have some advantages: they are mainly non-exhaustible and carbon neutral. However, the only viable substitute for transportation energy in the near future is first-generation biofuels. The production of this resource is limited by the availability of land, which is also used for food production. Serious concerns have been raised regarding the carbon benefits of biofuel production and use. It is well-known that carbon is released into the atmosphere during the production of biofuel. However, policies that encourage biofuel production may lead to encroachment into forest lands, thereby speeding up the rate of deforestation, and releasing more carbon into the atmosphere. These trends, if significant, may offset the reductions in carbon emissions that the large-scale adoption of biofuels was intended to achieve in the first place.

Even in the absence of regulation to encourage the production of biofuels, biofuel supply is expected to have a positive impact on food prices. Models show that corn and oil seed prices may increase by 65-75% by the year 2020. However, when more advanced second generation of biofuels that use less land are introduced, these figures decline to 45-50%.

Many policies have been introduced that aim at increasing the production and use of biofuels. Mandatory blending requirements have been implemented in the United States and countries of the European Union. These policies are projected to induce substantial increases in world biofuel production in the near future. They are also expected to adversely impact agricultural production in the rest of the world since these domestic biofuel targets can only be met through large-scale imports from land-abundant countries such as Brazil which enjoy a comparative advantage in producing low-cost biofuels from sugarcane. Trade in biofuels may induce significant land-use changes and deforestation in the developing countries. However, protectionist policies in the developed economies will likely reduce these adverse environmental impacts. Most existing economic studies fail to take into account the increase in the carbon footprint of biofuels because of land-use changes, which may, according to some estimates, release much larger amounts of carbon into the atmosphere than the carbon savings from the displacement of petroleum by biofuels.

Most studies find that relative to other climate mitigation options for the agricultural sector, the substitution of fossil fuels by biofuels is still expensive. Modeling studies suggest that displacing fossil fuels by biofuels can be a competitive climate mitigation strategy if the price of the carbon is above US$ 70 per ton. Next generation biofuels may be superior in terms of their land use requirements, but they may also be more costly to produce.

From the point of view of economic research, the issue of fuel versus food is a promising one. The allocation of land away from food production to the production of biofuels will depend on an array of factors, some of which quite uncertain. For instance, although current biofuel technologies are land-intensive, newer generation biofuels may be more efficient users of land, and therefore the impact of biofuel supply on food production may be limited. Secondly, protectionist policies that limit imports of clean energy based on trade and national security considerations may to some extent have a positive environmental effect, in terms of limiting land conversion and deforestation in developing countries such as Brazil which have a cost advantage in the supply of biofuels. Thirdly, the price of nonrenewable resources such as crude oil will determine how quickly consumers switch to the cleaner alternative. This will also be determined by government cap and trade programs and investment decisions such as providing subsidies and tax credits to fueling stations that cater to flexible fuel vehicles. Modeling the effects of these policies will require economic models that build on the limited number of important studies that have already been done and integrate approaches from agriculture and resource economics as well as industrial organization.

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