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Mark W. Rosegrant, Mandy Ewing, Siwa Msangi, und Tingju Zhu:
Bioenergy and Global Food Situation until 2020/2050

Externe Expertise für das WBGU-Hauptgutachten "Welt im Wandel: Zukunftsfähige Bioenergie und nachhaltige Landnutzung"

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Bioenergy and the Global Food Situation until 2020/2050

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Siwa Msangi, and Tingju Zhu

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1 INTRODUCTION

A number of coincident global driving forces are converging to bring issues of climate change, long-run environmental sustainability of economic growth, and global food security and well-being to the fore of policy thought and political discussion. Rapidly increasing demand for energy across a number of sectors underlies the steady upward trend in energy prices that is being observed across the world, and is being felt most acutely by those countries which are dependent upon energy imports. A desire to decrease dependence on foreign energy resources, and concerns about global warming are among the key factors that drive continued interest in renewable energy sources and in biofuels, in particular. While fossil fuel consumption still dominates the world energy market (Figure 1), increasing levels of uncertainty about future supplies, declining productivity of some sources, and increasing costs of expanding proven reserves are pushing national energy policy-makers to search for alternative, clean sources.

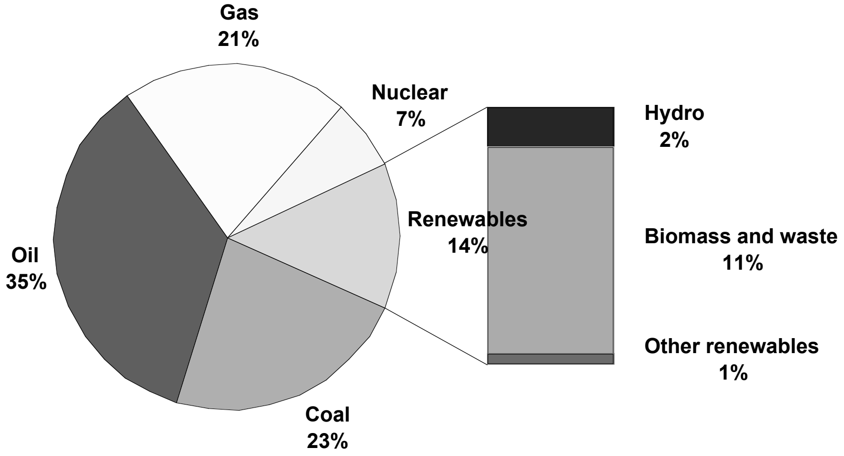

Figure 1. Share of different energy forms in global total primary energy supply at 10,345 mtoe (million tons of oil equivalent), 2002.

Source: IEA 2004.

Coincident with this increase in energy prices has also been a steady increase in world food prices, which has also caused concern. Observing the prices of major agricultural commodity prices since 2002, we see sizable increases, and even signs that food price trends might even be showing an increasing correlation with oil prices (Figure 2).

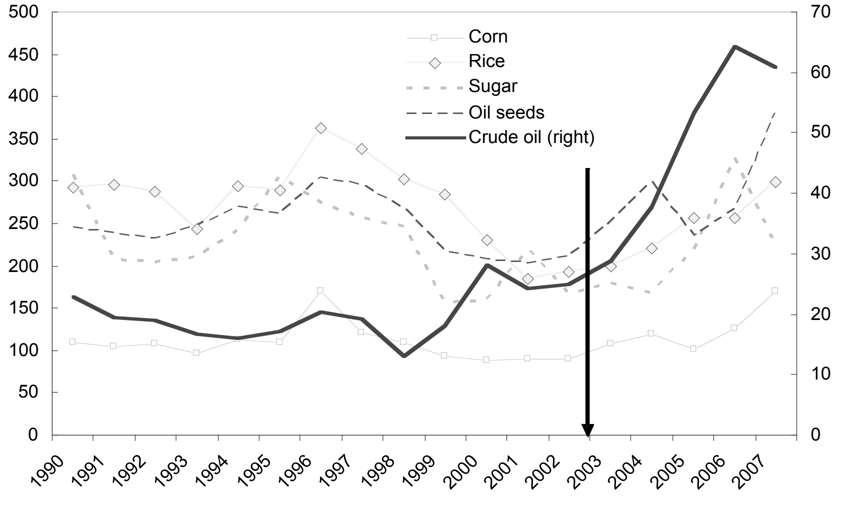

Figure 2. World prices of selected commodities, 1990-2007.

Sources: Data on corn, rice, sugar, and oilseeds for 1990–2005 are from OECD 2005 and for 2006–07 from World Bank 2007 (US$/metric ton). Data on crude oil are from IMF 2007 (US$/barrel on right hand scale of the figure). Notes: 2007 data for corn, rice, sugar, and oilseeds are for January–June 2007 only; 2007 data for crude oil are for January–April 2007 only.

While the reversal of the downward trend in real agricultural prices, that has taken place over the past several decades is certainly welcome news to many large- and medium- scale producers of agricultural commodities, the implied increase in on-farm energy and (fossil-fuel based) fertilizer costs presents an increasing challenge to small-scale farmers – especially those who might still be net purchasers of agricultural food commodities, themselves. Therefore the question of whether the gain felt by some from higher food prices justifies the welfare loss felt by others who are affected by increasing household expenditures for food, becomes an important one for policy-makers. At the same time, the importance of policy choice becomes critical, so that the need for social protection of vulnerable sections of the population can be balanced with the need to maintain incentives for local producers to increase their supply in the face of higher prices.

Another contributing factor to the rise in food prices, however, is expanded biofuel production—something initially viewed as part of the energy solution. Recent projections implicate biofuel production as the principal driver in long-term commodity price trends (OCED-FAO 2006). Accounts of cooking oil scarcity and rationing are emerging in China and Malaysia leaving many analysts to make the obvious link with biofuel production. Intense media interest and the concerns of the public are bringing into question the long-term viability and environmental sustainability of biofuels as an alternative energy source, and policy makers are focusing their attention on the role that biofuels might play in the rise of food prices and pressures on sensitive land. In this report, we examine the impacts that expansion of biofuel production could have on commodity prices in the medium- to long-term, as well as the implications of these price changes and shifts in the global food balance on future levels of hunger and malnutrition.

In addition to the food security impacts, the implications of biofuels for long-run environmental sustainability are also being scrutinized intensely. Despite the potential that biofuels have to decrease the emissions of greenhouse gases, in comparison to traditional fossil fuels, the actual net carbon savings that are embodied in biofuels, from the production process through to final combustion as fuel, is being questioned, especially when production-induced land use changes are considered. In general, the demand that energy crop production has on land resources may compete with other uses, such as biodiversity conservation, animal habitat and carbon sequestration – among other ecosystem services. As a result, it is important to establish guidelines for the expansion of biofuel production so that other environmental goals are not marginalized.

In this report, we investigate the interactions between biofuel demand and production and the demand and production of food and feed crops, in order to better assess how future growth in biofuel production could impact food prices and consumption, food security and other dimensions of overall human welfare. While the scenario-driven quantitative analysis that we do takes on a global perspective, we also consider the various factors that might affect economic and environmental outcomes at the country-level, so that we can better understand how different biofuel development plans might interact with world food markets and affect human livelihoods. The environmental impacts of future growth in biofuels are also considered, along with numerous implications for policy that are drawn from the results and evidence that we are able to produce.

1.1 Drivers for biofuels

Biofuels are an attractive option for offsetting fossil fuels for a number of reasons. First and foremost, they have similar properties to petroleum-based transportation fuels and therefore can be combusted in the same engines, and utilize the same distribution systems. Despite their familiarity, the strive for more efficient conversion technologies has the potential to both decrease biofuel production costs and total GHG emissions, which is an important component of climate change mitigation. Biofuels are also considered by some to be a potentially significant contributor towards the economic development of rural areas (Kammen 2006), and a means of reducing poverty through the creation of employment and improving the quality of lives – leading closer to the achievement of important Millennium Development Goals (FAO 2005). The significant mitigation potential that can come from the agricultural sector in developing countries of Latin America and Sub-Saharan Africa, in particular, represents an opportunity that some see fit to exploit with clean development mechanism-financed projects in biofuels.

The use of biofuels, however, would not in most case be competitive without subsidies and other programs that support industry development. As a result, countries that are highly dependent on fossil fuels such as the US are offering significant tax breaks for ethanol refineries and continued subsides for corn producers. In addition, nations have set consumption targets for biofuels in the transportation sector, solidifying biofuel expansion over the next decade. These policies along with the continuous upward trends in oil prices the principal driving forces in the expansion of biofuel use and production. As a result, policy will play critical role in determining the nature and impact of the biofuel market. In the next three sections, each of these drivers will be fully characterized in order to provide a foundation for the policy experiments that follow.

1.1.1 High oil prices

Although the interest in biofuels stretches back the energy crisis of the 1970s, the persisting upward trend in oil prices has provided a stronger incentive to invest in renewable energy technologies, and take a closer look at the role that agriculture can play in supplying the raw materials that are necessary. The rapidly increasing oils price since late 1990s (Figure 2) strengthens the rationale for seeking cheaper supply alternatives. With oil prices well above the US$60-70 per barrel level, biofuels have become competitive with petroleum in many countries even with existing technologies.

Production costs for ethanol and biodiesel for various feedstocks under different production technologies are shown in Figures 3 and 4, respectively. Brazilian sugarcane-based ethanol has the lowest production costs at US$0.30 per liter of gasoline equivalent (lge). US ethanol from corn costs on average US$0.45/lge, while wheat and sugarbeet derived ethanol in the EU can cost up to US$0.90/lge. State supported molasses-based production in India averages around US$0.65/lge. The cost of production includes growing or purchasing the feedstock, transport, conversation, labor, and capital costs. Across production systems, 60 to 80 percent of total production costs are in feedstocks (Schmidhuber 2006). As a result, feedstock productivity enhancements will be a large factor in future competitiveness of biofuels.

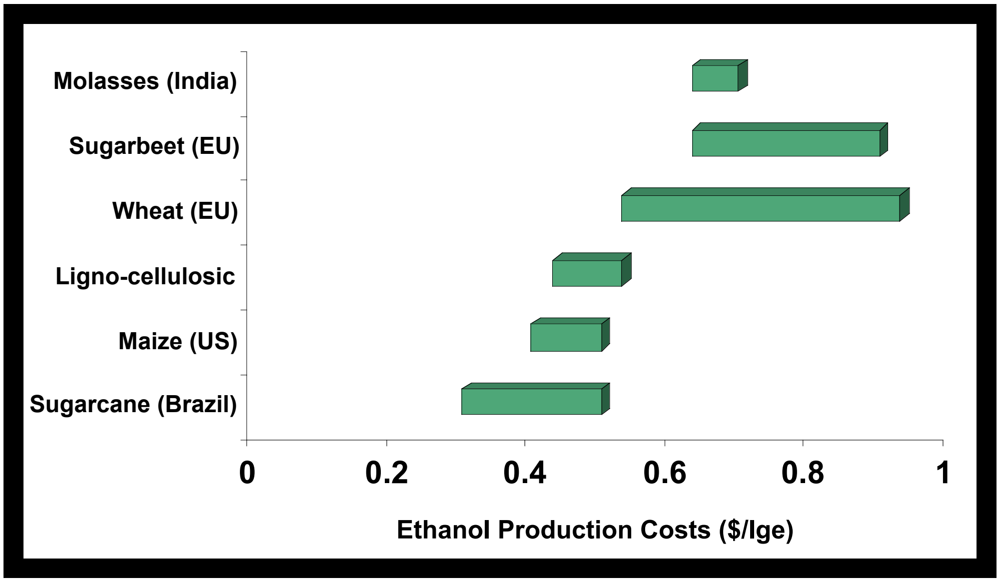

Figure 3. Ethanol production costs, various feedstocks and technologies.

Sources: Indian molasses from Gonsalves 2006; Brazilian sugarcane from IEA 2007; all others from Fulton *et al* 2006.
Notes: Constant 2000 U.S. dollars; lge = liters of gasoline equivalent

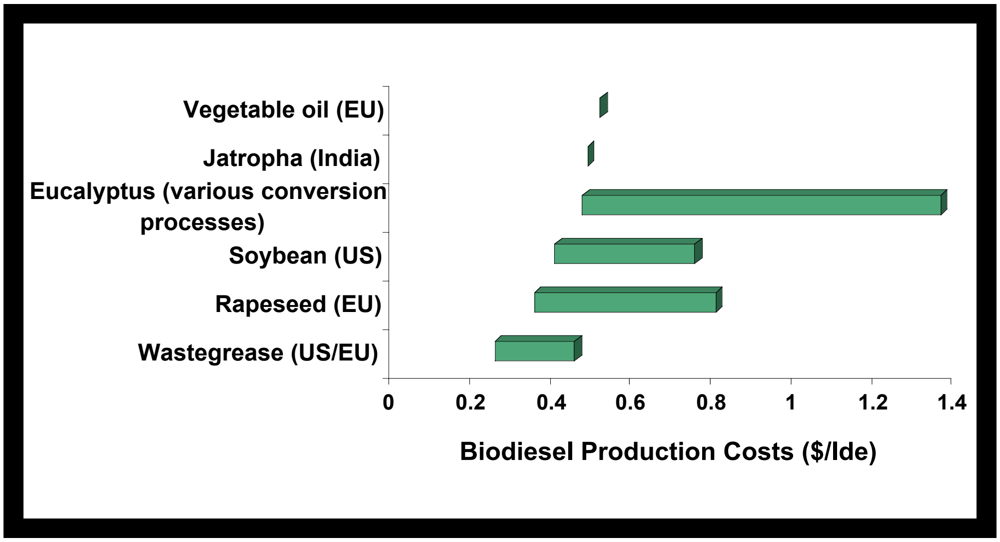

Figure 4. Biodiesel production costs, various feedstocks and technologies.

Sources: Indian Jatropha from Gonsalves 2006; all others from Fulton *et al* 2004.

In the absences of producer subsidies, the timing that biofuel production breaks even with the production costs of gasoline or diesel is dynamic and will depend on trends in production technology and crude oil prices. Figure 5 presents the parity price, or break even price, for feedstocks under differing production systems for different prices of crude oil. According to data from Schmidhuber (2006), the most efficient sugarcane producers in Brazil have a breakeven price at US$28 per barrel (bbl), and under average production conditions around US$35/bbl. Large-scale cassava production in Thailand breaks even at US$38/bbl, palm oil production for biodiesel in Malaysia pairs with crude oil prices at US$45/bbl, and US corn-based ethanol at US$58/bbl. With crude oil prices in early 2008 encroaching on US$120/bbl, biofuels are able to compete with fossil fuels across a wider range of production systems.

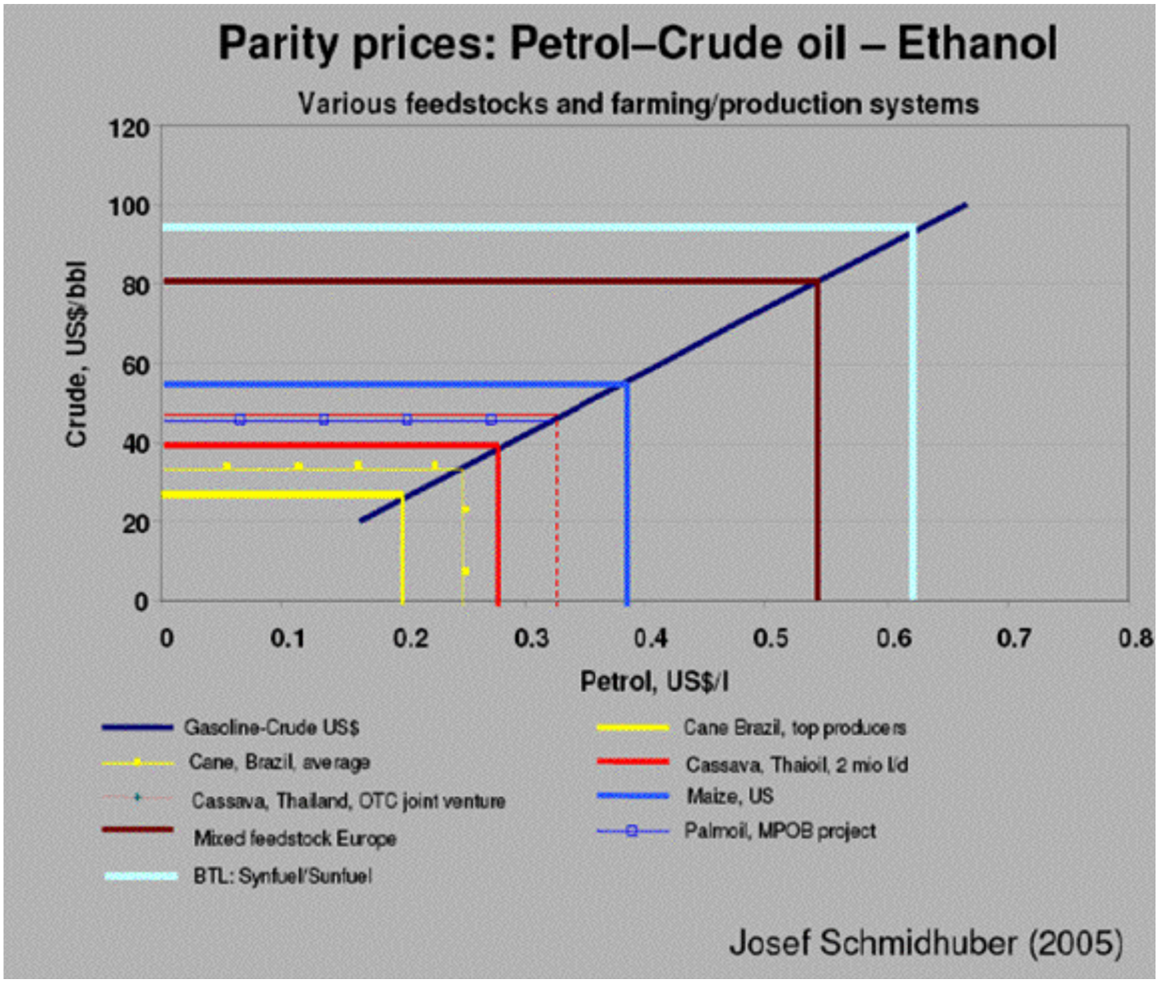

Figure 5. Parity prices of petroleum and crude oil, various feedstocks and production systems.

Source: Schmidhuber 2006.

1.1.2 Energy policy

In light of high oil prices, government led support for biofuels has been political feasible and has led to a menu of tax incentives and consumption targets across both industrialized and developing country nations. Targets for the displacement of transportation fuel have recently been adopted in the EU and US. In 2003, the EU adopted a guideline of 5.75 percent of renewable fuel as a share of total transportation fuel by 2010. The United States plans to double ethanol consumption from 2005 levels to 28 billion liters a year by 2012. While Brazil has had blending requirements on the books for many years for ethanol, biodiesel will be required to supply 20 percent (12 billion liters a year) of transportation fuel demand by 2020 (OCED 2006). Other countries such as Argentina, Indonesia, Malaysia, and Thailand also have minimum blending requirements and/or future targets for biofuels on the books.

In the case of the US and the EU, consumption targets will most likely be met through a mix of domestic production and biofuel imports. It has been estimated that the EU would have to utilize 72 percent of agricultural land in order grow enough dedicated crops for energy to displace 10 percent of fossil fuels in the transportation sector (Worldwatch 2006). In the US, this figure is approximately 30 percent. Dedicating this much land to energy crops would marginalize food supplies and grain reserves despite the higher overall productivity in comparison to production systems in developing nations. On the other hand, Brazil can displace 10 percent of transportation fuel demand through dedicated production on 3 percent of agricultural land due to its relatively large land endowments and lower fuel demand. Selecting a judicious mix of cropland expansion, productivity-enhancing technology investments, reserve use, and biofuel imports will require careful consideration and a thorough analysis of tradeoffs. In Section 4, land use potential is discussed in-depth.

1.1.3 Climate change policy

In addition to potentially reducing the reliance of energy-driven economies on limited fossil fuel sources, bioenergy has continued to receive increasing attention from those concerned with promoting agricultural and environmental sustainability through the reduction of carbon emissions, which is an important component of climate change mitigation. In the latest report from the IPCC, if bioenergy supplied 10 to 25 percent of world global energy, 5 to 30 percent of cumulative carbon emissions would be abated (Ferrentino 2007). Specifically for the transportation sector, liquid biofuels are predicted to reach 3 percent of demand under the baseline scenario, increasing up to 13 to 25 percent of demand under alternative scenarios (IEA 2006). This could reduce emissions by 1.8 to 2.3 Giga-ton of carbon dioxide (Gt CO2), corresponding to between 5.6 and 6.4 percent of total emissions reductions across all sectors at carbon prices greater than US$25 per ton of CO2 (Ferrentino 2007).

The potential of biofuels to reduce carbon emissions, however, is highly dependent upon the nature of the production process through which they are manufactured, which ultimately determines the net carbon balance. There tends to be a high degree of variance in the literature over the net carbon balance of various biofuels, due to differences in the technological assumptions that the authors use when evaluating the various processes embedded in the life cycle assessment.

Under life-cycle assessment (LCA) framework, the total GHG emissions reduction compared to gasoline are summed for each process in the fuel chain. For example, the life-cycle of the ethanol fuel chain—from farm to tank—includes crop production, refinement, co-production credits, and the transport of ethanol from the biorefinery. The amount of emissions from each process is highly dependent on the technologies employed. In the U.S. corn ethanol production system, crop production accounts for 38-65 percent of total life-cycle GHG emissions and represents 39 percent of the variability in life-cycle GHG emissions when biorefinery efficiency is held constant (Liska *et al* 2008). In addition, biorefinery types vary from wet to dry mills and coal fired to natural gas powered, which varies the GHG impact. Finally, supplying co-products such as feedcakes for livestock by has a positive impact on GHG emissions by reducing the need for dedicated feedstock production.

Most of the literature analyzes production conditions in the US of corn-based ethanol (e.g. Farrell *et al* 2006; Pimentel and Patzek 2005), soy-derived biodiesel (Sheehan *et al* 2000; Pimentel and Patzek 2005), and fuels from perennial grasses (Tilman *et al* 2006). Other literature is also available on biodiesel from rapeseed oil in the EU (Janulis 2004) and cane-based ethanol in Brazil (Macedo *et al* 2004). Early life-cycle assessments of biofuels found a net carbon benefit, which has contributed to consumer acceptance (e.g. Wang *et al* 1999). Yet, the net carbon benefit in comparison to traditional fossil fuels is being challenged through a number of studies (Pimentel and Patzek 2005), especially when biofuel production requires land conversion from cover with a high carbon sequestration value, such as forests (Searchinger *et al* 2008).

Fewer analyses have been conducted under production scenarios in developing countries. The limited amount of literature available on the environmental impacts of developing country produced biofuels makes it difficult to determine the impacts on the GHG balance. One exception is a recent energy analysis from Thailand, which determines that even without co-production credits, cassava production is more energy efficient than US corn ethanol (Nguyen *et al* 2007)

Despite the lack of peer-reviewed literature, the UK Department for Transport has recently published reporting guidelines for importers of biofuels. This document contains carbon intensities for the majority of biofuel production systems around the world. In addition, the document contains step-by-step emissions from each of the major production processes involved, including land use change. Figure 6 presents the conservative estimates for each biofuel feedstock and country specific production system. This figure indicates that, from a carbon intensity standpoint, sugarcane production in Brazil releases the least amount of carbon through the production of ethanol, and on average offers a carbon savings of 80 percent over gasoline. On the other hand, conservative estimates for US based corn production show an almost 25 percent greater amount of carbon intensity per Mega Joule (MJ) of energy than gasoline. This figure is in stark contrast to recent studies showing a nearly 50 percent carbon savings of US-based corn ethanol production in comparison to gasoline (e.g. Liska *et al* 2008).

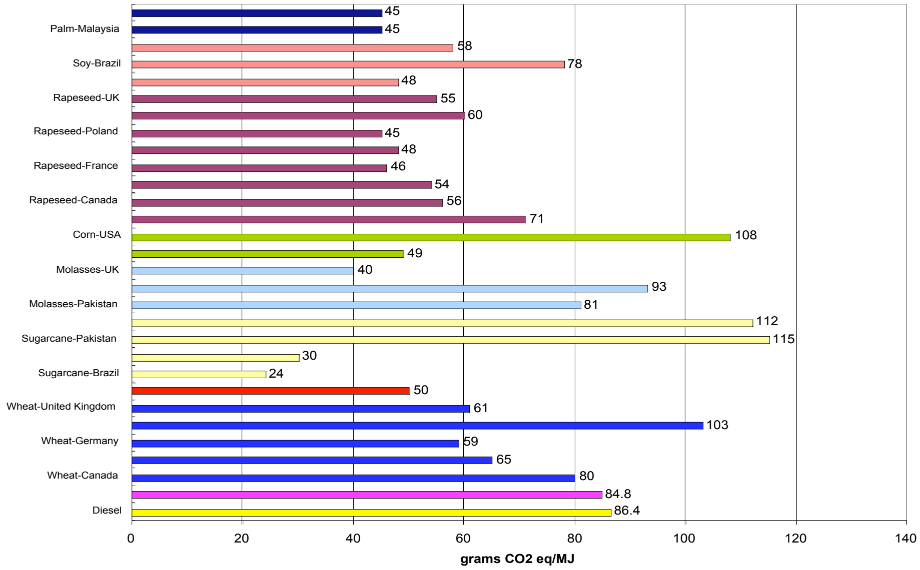

Figure 6. Carbon intensity for biofuel production.

Source: UK Department for Transport, 2008.

The focus of the environmental impacts of biofuels needs to expand beyond their carbon offsetting potential and include human health effects, soil quality, biodiversity, and water resource depletion, among others (Rajagopal and Zilberman 2007). If production is dominated by plantation agriculture that is dependent on petroleum-based fertilizers and heavy irrigation, there will be further environmental implications that may offset any carbon storage value. Nitrous oxide emissions that result from fertilizer application currently produces the largest share of emissions from agriculture (36 percent), with 2,100 Mega tons of CO2 equivalent in the year

2000 (USEPA 2006).[1] In US corn ethanol production systems, 50 percent of crop production emissions and 23 percent of total life-cycle emissions were the result of fertilizer use (Liska *et al* 2008). In addition, the application of fertilizers can require the treatment of agricultural runoff in order to avoid groundwater contamination. Therefore, the agricultural production of energy should be developed synergistically with improved agricultural practices that conserve soil carbon, including conservation tillage techniques.

1.2 Biofuel production trends

The policy developments and high oil prices have been driving expanded biofuel production over the last few years—a trend that is likely to continue over the coming decade. Figures 7 and 8 show global supply of ethanol and biodiesel, respectively from 2000 to 2005. Global production of ethanol nearly doubled over this period from 18 billion liters per year to 34 billion liters per year. While production of biodiesel is relatively low in comparison, its supply has increased nearly fourfold over the five year period to close to 4 billion liters.

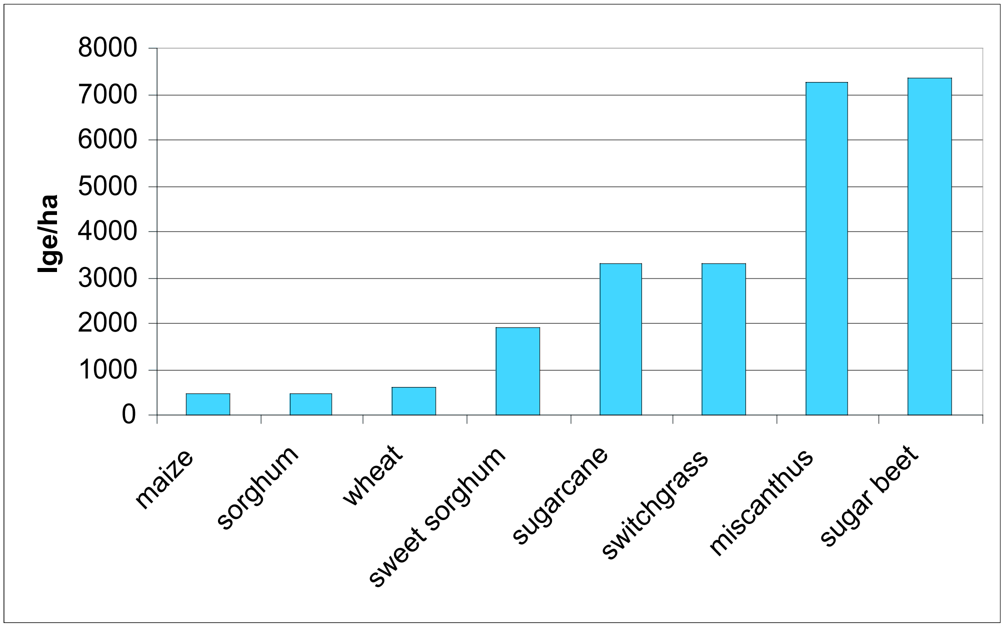

Figure 7. Liters of gasoline equivalent ethanol per hectare (lge/ha), various feedstocks.
Source: Rajagopal 2007 in Rajagopal and Zilberman 2007.

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[1] One million metric tons of nitrous oxide emissions equals 310 million metric tons of carbon dioxide equivalent emissions (1 Mt N_20= 310 Mt CO_2).

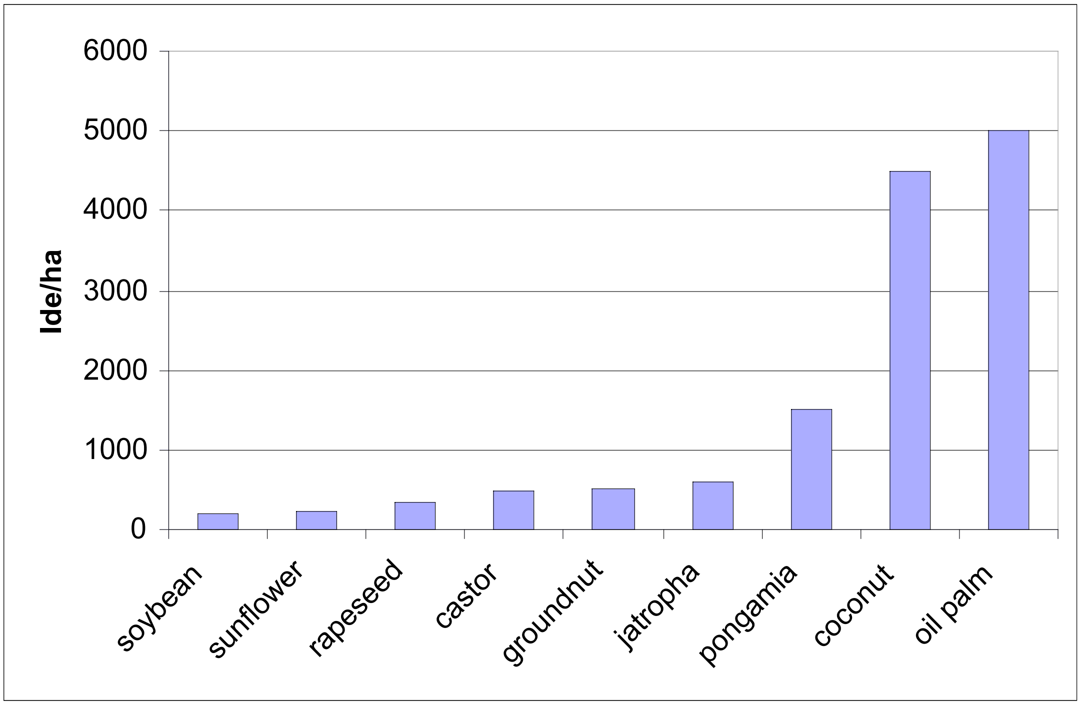

Figure 8. Liters of diesel equivalent biodiesel per hectare (lde/ha), various feedstocks.
Source: Rajagopal 2007 in Rajagopal and Zilberman 2007.

Ethanol production is mostly concentrated in Brazil and the United States, which together accounted for nearly 90% of bioethanol production in 2005 (Licht 2005). Biodiesel production is geographically concentrated within the European Union countries, with Germany and France together accounting for 79 percent of production in 2005 (Licht 2005). In addition to the dominance of Brazil in the production of biofuels, we also see that the global trade in biofuels products is also dominated by Brazil – which remains a major net exporter (Table 1). While the United States will continue to match and even exceed Brazil in terms of total production volume of ethanol, its trade position in the product will continue to be that of a net importer, as the internal demand for transportation fuel far exceeds its ability to supply its own needs, and is likely to continue growing at a rapid pace, in to the future.

Table 1. Brazilian exports of ethanol (million tons of liters).

Importing countries	Exports (millions liters)	Share of total
India	475	19%
United States	426	17%
South Korea	239	10%
Japan	209	9%
Sweden	198	8%
Netherlands	156	6%
Jamaica	133	5%
Nigeria	106	4%
Costa Rica	106	4%
Others	361	16%
Total	2447	100%

Source: Worldwatch, 2006.

1.3 Biofuel feedstock characteristics

Figures 9 and 10 show average ethanol and biodiesel yields per hectare, respectively. On average, ethanol derived from sugar beet has the highest yield per hectare, while oil palm yields the most biodiesel per hectare. According to data presented in Rajagopal and Zilberman 2007, ethanol feedstocks such as maize and sweet sorghum have a shorter growing season than sugarcane, indicating a potential for a dual harvest. Oil seed trees such as jatropha and coconut, on the other hand, will take years to reach maturity in comparison to fast growing crops such as sunflower and soybeans. Of ethanol feedstocks, maize has the lowest water requirement per liter of ethanol, followed by sorghum and wheat. Oil yields per unit of water are lowest for sunflower and soybeans, and highest for coconut and pongamia.

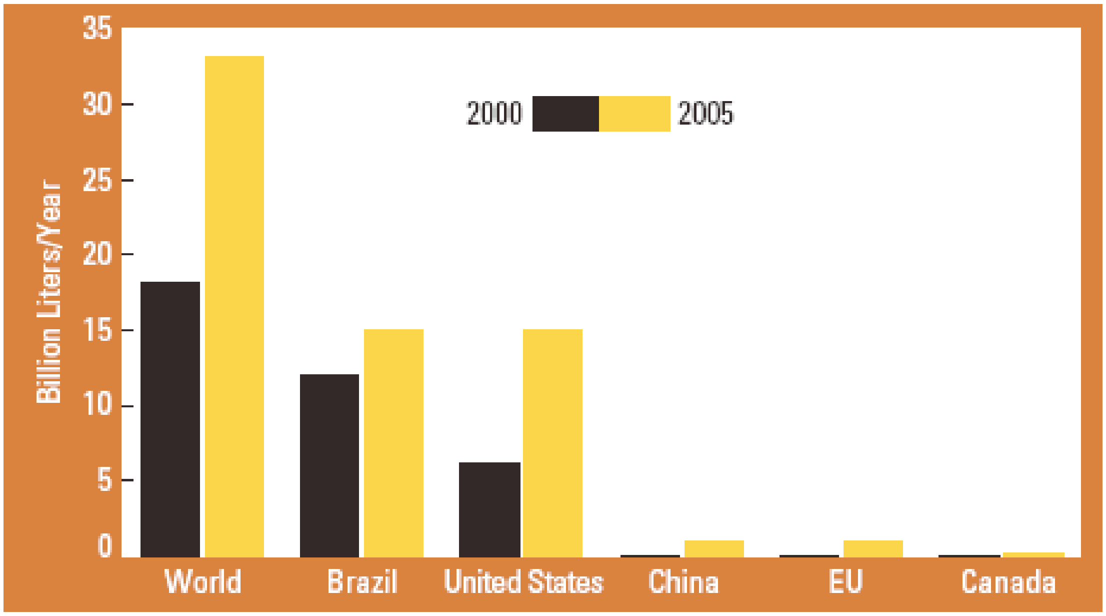

Figure 9. Global ethanol production, 2000-05.

Source: Martinot 2005 in Rajagopal and Zilberman 2007.

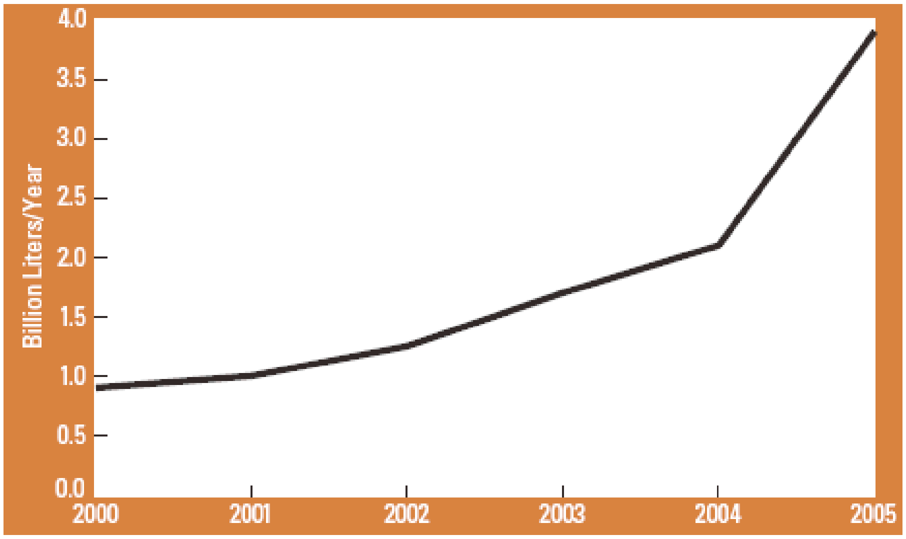

Figure 10. Global biodiesel production, 2000-2005.

Source: Martinot 2005 in Rajagopal and Zilberman 2007.

While these charts are useful in estimating the average global yield of different feedstock crops, local production conditions vary. For example, the sugarcane yields in least developed countries are 49,565 kilograms per hectare (kg/ha) while developed countries can produce over 77,6354 kg/ha (FAOSTAT 2005). Therefore, local production conditions and conversion technology availability will be important factors in the decision to produce biofuels, and in the choice of the feedstock used.

1.4 Biofuel potential

So far the discussion of potential has been limited to the parity price that biofuels become competitive with fossil fuels, or the economic potential, and to some extent the biophysical requirements. It is also important to characterize the theoretical potential of biomass use as an energy source—and not only for the transportation sector. Estimates of biofuel potential are based on the amount of biomass that can be harvested and produced from terrestrial resources after the demand for food, feed, and pastureland is met. Current biomass use (e.g. combustible renewables such as fuel wood and dung) represents approximately 48 Exa-joules per year (EJ/year) of total global primary energy supply (IEA 2005). Only one percent of total transportation fuel is supplied from liquid biofuels, whose production requires around 14 million hectares, or one percent of global arable land (IEA 2006).

There are a number of studies that estimate the amount of biomass that may be available over the next century to meet energy demands. Each study considers the potential contribution of all potential bioenergy sources such as dedicated energy crops, residues from crop and forest harvesting, wood and food processing, as well as animal dung and other unspecified food waste and forest biomass. Across studies, the amount of biomass energy depends significantly on the amount produced through energy crop production. Therefore, model projections are sensitive to the underlying assumptions about yield and land availability. A review of 17 peer-reviewed estimates found that between 100 EJ/yr to over 400 EJ/yr of energy demand in 2050 could be met with biomass resources (Berndes *et al* 2003). More recent estimates have shown that by increasing the productivity of agricultural production to industrialized levels, an additional 0.7 to 3.6 Giga hectares (Gha) of crop and pastureland can be freed for energy crop production, satisfying 215 to 1272 EJ/yr of energy supply in 2050 (Smeets *et al* 2004). Despite differences in projections, these studies consistently show that Sub-Saharan African and Latin America have at least twice as much biomass potential than industrialized regions due to relative land availability and the potential for yield enhancements (Berndes *et al* 2003; Smeets *et al* 2004).

Table 2 presents the results of potential of energy crops across alternative land use categories for year 2050, by region from Hoogwijk *et al* (2005). Abandoned agricultural land is shown to hold the most potential for energy crop production with 409 EJ/yr, followed by savannah, grasslands, and shrubland at 243 EJ/yr, which are considered in the "rest of land" category. This study predicts a total energy crop value of 657 EJ/yr, which is in the range of total biomass projections from other studies. Regional contribution, however, deviate from other studies, with Southeast Asia and the former USSR demonstrating a higher energy crop potential than Latin America. As a result, it is likely that other sources of bioenergy such as agricultural residues and forest biomass could play a significant part of the potential in this region.

Table 2. Table of geographic potential of energy crops across alternative land use categories (year 2050, SRES A1 scenario).

	Abandoned Ag Land		Low Productivity Land		Rest of Land		Total	
	Energy	Area	Energy	Area	Energy	Area	Energy	Area
Unit	EJ/yr	Mha	EJ/yr	Mha	EJ/yr	Mha	EJ/yr	Mha
Canada	14	74	2	30	4	26	20	130
USA	32	168	0	0	19	125	51	293
Central America	8	42	0	0	9	59	17	101
South America	53	279	1	15	32	211	86	505
North Africa	2	11	0	0	3	20	5	30
West Africa	20	105	0	0	29	191	49	296
East Africa	15	79	0	0	24	158	39	237
South Africa	24	126	0	0	17	112	41	238
Western Europe	9	47	0	0	4	26	13	74
East Europe	9	47	0	0	0	0	9	47
Former USSR	97	511	1	15	27	178	125	703
Middle East	2	11	0	0	11	72	13	83
South Asia	12	63	0	0	13	86	25	149
East Asia	79	416	1	15	22	145	102	576
South east Asia	1	5	0	0	8	53	9	58
Oceania	32	168	0	0	21	138	53	307
Japan	0	0	0	0	0	0	0	0
World	409	2153	5	75	243	1599	657	3827

Source: Hoogwijk *et al* 2003.

Estimates of biomass potential are meant to characterize the limits of bioenergy supply and are not to be taken as realistic targets. While food, feed, and pastureland supersedes bioenergy in the demand hierarchy for land resources, other social and environmental considerations such as biodiversity and carbon sequestration are not considered. In Section 4.2, the land use change results will be weighed against these projections so that guardrails for the sustainable production of biofuels can be established.

1.5 Need for study

While there has been considerable attention paid, in the literature, to the biophysical potential of biofuel production, on a global scale – there has not been enough attention on the key socio-economic factors that are relevant to issues of human well-being impact. Many studies have used the abundance of biophysical data that exists on agro-ecological suitability (in terms of soil quality, depth, land topography and slope, and availability of rainfall and ambient temperature conditions), to characterize the zones where key feedstock crops can grow, and the likely levels of yield they can achieve. While this is, indeed, important to determining the viability of large-scale, high-productivity production processes, these do not fully capture the constraints that face emerging biofuels industries, especially in the developing world. The problems of adequate storage, distribution, processing and marketing infrastructure are issues which already constrain the potential of food production systems, in many countries, and which keep the tremendous agricultural potential of much of sub-Saharan Africa from being realized as actual improvements in food security outcomes. The persistence of hunger and malnutrition is, by itself, an indicator of structural factors that will likely prevent the success of crop-based biofuels industries from succeeding, and must be examined further.

The other dimension of socio-economic potential that is still lacking extensive discussion in the current literature, is that of who are the real winners and losers to the expansion of large-scale, crop-based biofuels, within the context of either a first- or second-generation processing technologies. While many believe that the bulk of the benefits of plantation-style biofuel feedstock production and processing expansion will go to large landowners, with some benefits to landless laborers – others are of the opinion that smallholders stand to gain considerable benefits if the production, marketing and distribution networks are designed appropriately. The question of distribution will continue to be one of fierce debate and intense interest, within policy circles, as it touches on issues of social equity and wealth distribution that are of primary interest to civil society groups, and those who are most likely to lobby intensively against the dominance of large multi-nationals in the production of crop-based biofuels.

2 SCENARIO ANALYSIS

2.1 Methodology

To examine the potential impact of biofuel production growth on country-level and domestic agricultural markets, a partial-equilibrium modeling framework is adopted to capture the interactions between agricultural commodity supply and demand, as well as trade, at global level. The model used is the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which was developed by the International Food Policy Research Institute (IFPRI) for projecting global food supply, food demand and food security to year 2020 and beyond (Rosegrant *et al* 2001). The IMPACT model is a partial equilibrium agricultural model for crop and livestock commodities, including cereals, soybeans, roots and tubers, meats, milk, eggs, oilseeds, oilcakes/meals, sugar/sweeteners, and fruits and vegetables. It is specified as a set of 115 country and regional sub-models, within each of which supply, demand, and prices for agricultural commodities are determined. The model links the various countries and regions through international trade using a series of linear and nonlinear equations to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Growth in crop production in each country is determined by crop and input prices, the rate of productivity growth, investment in irrigation, and water availability. Demand is a function of prices, income, and population growth. IMPACT contains four categories of commodity demand – food, feed, biofuels feedstock, and other uses. The model therefore takes into account the growth in demand for the feedstock commodities for biofuel production and determines impact on prices and demand for food and feed for those same agricultural crops. Figure 11 shows how the scenarios for biofuels growth is implemented within the IMPACT model. The utilization level of feedstock commodities for biofuel depends on the projected level of biofuel production for the particular commodity, including maize, wheat, cassava, sugarcane, and oilseeds, as well as commodities such as rice, whose demand and supply is influenced by the price of biofuel feedstock crops.

Biofuel production is only part of the change in the world food balance. Other supply and demand shocks also play important roles. In an attempt to model the recent price developments, changes in supply (from 2000 to 2005) and biofuel developments are introduced to the IMPACT Model. The price results with actual production trends embedded in the 2000-05 time period captures a significant amount of the increase in real prices for grains during this period. A climate change projection based on SRES B2 scenario of IPCC (Intergovernmental Panel on Climate Change) and the results from a climate simulation by HadCM3 model of the Hadley Center for Climate Prediction and Research is embedded into the baseline hydrology of IMPACT, in order to reflect climate change effects over the coming decades.

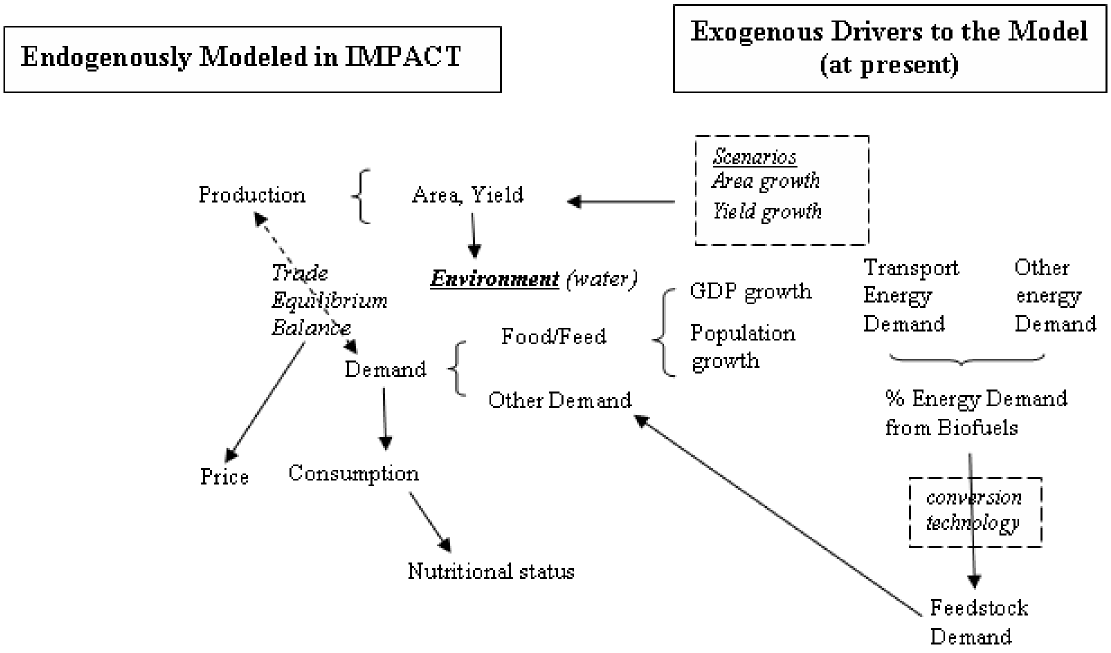

Figure 11. Implementation of Biofuels Scenarios within IMPACT-WATER.

2.2 Scenario descriptions

2.2.1 Baseline scenario

Biofuel demand follows historical patterns through 2006, increases by 1% per year between to 2010 and then for most countries remains constant at 2010 levels. For the United States under this scenario, maize for bioethanol declines after 2010, reflecting either reduced subsidies and mandates for biofuels or early adoption of second generation biofuels that do not require maize as a feedstock. Feedstock commodity demand for biofuel at year 2000 level are taken as 25% of those in 2005 which are real data. This scenario represents a very conservative plan for biofuel development, in terms of both the magnitude and time span of growing demand for biofuel feedstock commodities.

2.2.2 *Biofuel expansion*

This scenario, based on actual national biofuel plans, assumes continued biofuel expansion through 2020, although the rate of expansion declines after 2010 for the early rapid growth countries such as United States and Brazil. Under this scenario, significant increases of biofuel feedstock demand occur at many countries for commodities such as maize, wheat, cassava, sugar and oil seeds. As shown in Table 3, by 2020, United States is projected to put 130 million metric tons (mmt) of maize into biofuel production; European countries will use 10.7 mmt of wheat and 14.5 mmt of oil seeds for biofuel production; and Brazil will use 9.0 mmt of sugar equivalent for biofuel production. In this case, we hold the volume of biofuel feedstock demand constant starting in 2025, in order to represent the relaxation in the demand for food-based feedstock crops created by the rise of the new technologies that convert nonfood grasses and forest products. Crop productivity changes are still held to baseline levels.

Table 3. Projected demand for feedstock commodities for biofuel at 2020 and 2050 (in thousand ton).

Crop	Region	2020			2050		
		Baseline	Biofuel Expansion	Drastic Biofuel Expansion	Baseline	Biofuel Expansion	Drastic Biofuel Expansion
Cassava	ROW	660	6,8	13,6	660	10,6	21,2
Maize	EU	97	1,	2,1	97	1,6	3,3
	ROW	2,	20,5	41,0	2,	30,1	60,2
	USA	35,0	130,0	260,0	35,0	130,0	260,0
Oil Seeds	Brazil	16	153	306	16	197	394
	EU	1,	14,5	29,1	1,	18,5	37,1
	ROW	530	4,2	8,4	530	5,1	10,3
	USA	354	3,	6,	354	3,7	7,4
Sugar	Brazil	834	9,	18,0	834	14,1	28,2
	ROW	163	1,7	3,5	163	2,7	5,5
	USA	265	3,4	6,9	265	5,8	11,6
Wheat	EU	1,	10,7	21,4	1,	15,0	30,0
	ROW	205	2,3	4,	205	3,5	7,1

* Rest of the world.

2.2.3 *Drastic biofuel expansion*

This scenario assumes very rapid growth of biofuel demand and is expected to result in drastic impacts on global food market, food consumption, and malnutrition at country level. In this scenario, feedstock demand for biofuel from 2000 to 2005 are assumed to be the same as in the “biofuel expansion” scenario; 2010 demand is 50% higher than in “biofuel expansion”; and demand in 2015 and 2020 double that of “biofuel expansion”, as in Table 3.

3 RESULTS

3.1 World price implications

Under the "biofuel expansion" scenario, 2020 world prices are 26% higher for maize, 18% higher for oilseeds, 12% higher for sugar, 11% for cassava, and 8% for wheat compared with the 2020 prices in the baseline scenario. The "drastic biofuel expansion" scenario shows dramatic increases in 2020 world prices for feedstock crops relative to the baseline, with the price of maize price 72% higher, oilseeds price 44% higher, cassava and sugar price 27% higher, and wheat 20% higher (Figure 12).

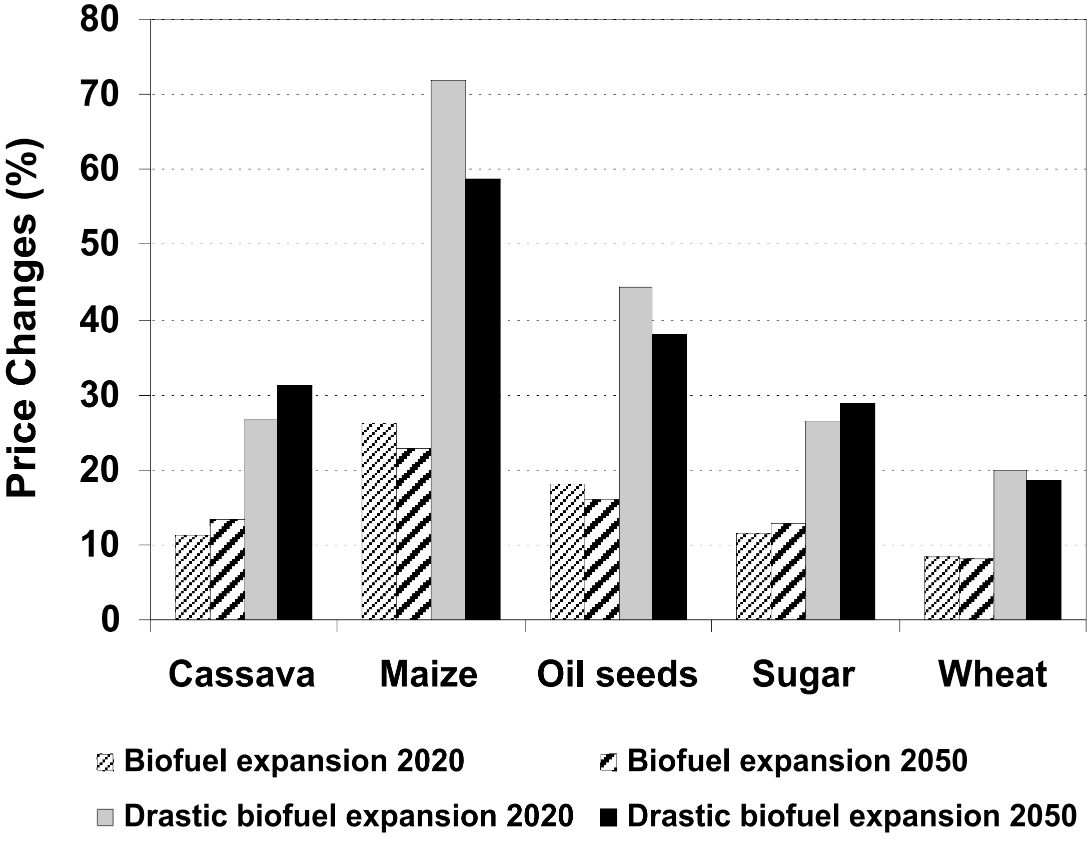

Figure 12. Changes in world prices of feedstock crops and sugar by 2020 and 2050 under two scenarios compared to the baseline levels (%).

The price effects of biofuels development in 2050 are less significant than in 2020 for most feedstock commodities, as shown in Figure 12, mostly because biofuels feedstock demands are held constant starting in 2025 as we assume relaxation in the demand for food-based feedstock crops owning to the new technologies that convert nonfood grasses and forest products into biofuels. Nevertheless, under the "biofuel expansion" scenario, 2050 world prices are 23% higher for maize, 16% higher for oilseeds, 13% higher for sugar, 11% for cassava, and 8.3% for wheat compared with the 2020 prices in the baseline scenario. As in year 2020, the "drastic biofuel expansion" scenario shows dramatic increases in 2050 world prices for feedstock crops relative to the baseline, with the price of maize price 59% higher, oilseeds price 38% higher, cassava price 31% higher, sugar price 29% higher, and wheat price 19% higher than in the baseline scenario (Figure 12).

3.2 Net trade implications

The dramatic rise of maize price is mostly due to the large amount of increased maize demand for biofuels production, especially in United States, as illustrated in Table 4. Biofuel expansion also has important trade implications for agricultural commodities that can be used as biofuel feedstock. As shown in Table 4, United States is a net exporting country of maize in 2020 under the baseline scenario, with a net export of 35 mmt. However, under "biofuel expansion" and "drastic biofuel expansion" scenarios, United States becomes a net importing country of maize in 2020, with net imports of 25.8 mmt and 110.1 mmt, respectively.

Table 4. Projected net trade of agricultural commodities at 2020 (in million metric ton).

Region*	Scenario**	Wheat	Maize	Soybean	Cassava	Oil Seeds	Sugar
EAP	Baseline	-23.5	-47.6	-36.1	14.5	18.1	7.2
	BE	-18.3	-23.1	-35.6	8.3	22.4	9.2
	Drastic BE	-11.7	11.4	-34.9	1.4	27.1	11.4
ECA	Baseline	26.1	-6.7	-19.8	-10.6	-7.7	3.8
	BE	14.8	2.0	-19.5	-10.8	-17.7	5.0
	Drastic BE	0.5	14.3	-19.2	-11.0	-28.7	6.1
LAC	Baseline	-5.2	21.5	34.9	-10.9	6.7	27.5
	BE	-4.4	36.9	34.3	-11.0	8.0	22.3
	Drastic BE	-3.5	57.6	33.5	-11.3	9.5	16.9
MENA	Baseline	-32.4	-19.2	-2.5	-0.1	-5.5	-9.6
	BE	-31.3	-17.5	-2.5	-0.2	-4.8	-8.8
	Drastic BE	-30.1	-15.5	-2.5	-0.4	-4.0	-7.9
N. America	Baseline	54.0	31.3	23.5	-0.5	2.2	-5.1
	BE	53.0	-27.8	23.2	-0.5	1.8	-7.6
	Drastic BE	52.0	-110.0	22.8	-0.5	1.5	-10.3
S. Asia	Baseline	-4.4	3.2	0.6	-1.2	-11.1	-14.7
	BE	0.2	1.9	0.6	-0.8	-8.6	-12.2
	Drastic BE	6.2	1.2	0.7	-0.3	-5.8	-9.5
SSA	Baseline	-14.6	17.4	-0.6	8.7	-2.6	-9.0
	BE	-14.0	27.5	-0.5	15.0	-1.1	-7.9
	Drastic BE	-13.3	41.0	-0.5	22.2	0.5	-6.7
USA	Baseline	34.4	34.9	23.5	-0.4	1.2	-3.9
	BE	35.4	-25.8	23.2	-0.4	0.5	-6.4
	Drastic BE	36.5	-110.1	22.8	-0.5	-0.1	-9.1

*: See figure 2 for regional definition.
**: BE = Biofuel Expansion; Drastic BE = Drastic Biofuel Expansion

With biofuels feedstock demand holding constant after 2025, the United States exports 79 mmt of maize under the "biofuel expansion" scenario, and neither exporting nor importing under the "drastic biofuel expansion" scenario in 2050 (Table 5). The rest of the world responds to the changed role of United States in world maize market by either increasing their exports (e.g. Latin America and Caribbean and Sub-Saharan Africa), or reducing their imports (e.g. Middle East and North Africa), or turning from net importing countries to net exporting countries (e.g. East Asia and Pacific in 2020 and Europe and Central Asia). The only exception is South Asia which reduces its exports under the two biofuel expansion scenarios in 2020 due to rapid increase of biofuel feedstock demand for maize within the region itself. While in 2050, South Asia is a net importer under all the three scenarios, as a result of increased total maize demand in the region.

Table 5. Projected net trade of agricultural commodities at 2050 (in million metric ton).

Region*	Scenario**	**Wheat**	**Maize**	**Soybean**	**Cassava**	**Oil Seeds**	**Sugar**
EAP	Baseline	-41.2	-109.9	-14.6	7.5	35.7	9.3
	BE	-35.8	-90.3	-14.4	-3.3	41.0	12.5
	Drastic BE	-29.6	-62.6	-14.3	-14.8	46.7	15.9
ECA	Baseline	102.4	-7.2	-26.8	-8.0	-11.6	8.1
	BE	89.0	-1.6	-26.4	-8.0	-26.0	9.3
	Drastic BE	73.4	5.9	-26.0	-8.2	-41.6	10.4
LAC	Baseline	0.8	25.3	24.9	-24.0	10.0	65.7
	Drastic BE	1.8	45.3	24.0	-23.3	12.2	58.0
	BE	3.1	71.3	22.8	-22.9	14.7	50.2
MENA	Baseline	-55.2	-37.8	-4.8	-0.1	-9.8	-17.7
	BE	-53.7	-35.7	-4.8	-0.4	-8.6	-16.1
	Drastic BE	-52.0	-32.9	-4.7	-0.6	-7.4	-14.4
N. America	Baseline	81.3	132.2	23.7	-0.4	-0.4	-4.8
	BE	79.9	75.7	24.0	-0.4	-1.4	-9.5
	Drastic BE	78.4	-1.0	24.4	-0.5	-2.4	-14.4
S. Asia	Baseline	-48.0	-10.4	1.2	-1.9	-14.8	-37.5
	BE	-42.6	-13.7	1.2	-1.6	-11.1	-34.0
	Drastic BE	-36.0	-16.5	1.1	-1.2	-7.0	-30.3
SSA	Baseline	-40.0	7.9	-3.6	26.9	-9.1	-23.0
	BE	-38.7	20.3	-3.5	37.1	-6.1	-20.3
	Drastic BE	-37.2	35.8	-3.5	48.3	-2.9	-17.4
USA	Baseline	55.7	137.2	24.6	-0.4	-2.0	-3.3
	BE	57.3	79.5	24.9	-0.4	-3.3	-8.0
	Drastic BE	59.0	1.0	25.3	-0.4	-4.6	-13.0

*: See figure 2 for regional definition.
**: BE = Biofuel Expansion; Drastic BE = Drastic Biofuel Expansion

Likewise, wheat exports of Europe and Central Asia decrease dramatically under the two biofuel expansion scenarios in both 2020 and 2050 due to increased demand of wheat for biofuel in these countries (Table 4). As a result, East Asia and Pacific imports far less wheat in both year levels. In 2020, South Asia changes from a net importing region to a net exporting region of wheat under the "biofuel expansion" and "drastic biofuel expansion" scenarios. In 2050, the wheat net importing status of South Asia is not affected by biofuel development although it imports less under "biofuel expansion" and "drastic bofuel expansion" scenarios, responding to increased world wheat price.

For cassava, dramatically decreased export of East Asia and Pacific leads to increased export of Sub-Saharan Africa, under the two biofuel expansion scenarios in 2020. However, in 2050, East Asia and Pacific changed from a net exporting region of Cassava to a net importing region. As a result, Sub-Saharan Africa exports more cassava to respond to increased import of the East Asia and Pacific region.

Europe is projected to experience the mostly rapid increase of oilseed demand for biofuel (Table 3). The significant increases of oilseed import of Europe and Central Asia in 2020 are accompanied by increased export and decreased import of other regions, especially South Asia and East Asia and Pacific. The changes of oilseeds trade pattern due to biofuel development maintain the same in 2050, however the net oilseed import of Europe and Central Asia is much larger than in 2020 because of the combined effects of demand increases and production decreases of oilseed crops in European countries.

Because of the significant demand increase for sugar in Brazil (Table 3), for both 2020 and 2050, Latin America and Caribbean has dramatic reduction of sugar exports under the two biofuel expansion scenarios. This causes decreased import or increased export of other countries except United States where demand for sugar as biofuel feedstock also increases dramatically from baseline (Table 3).

3.3 Food security implications

In the scenarios mentioned above, the increase in crop prices resulting from expanded biofuel production is also accompanied by a net decrease in availability and access to food. Calorie consumption is estimated to decrease across regions under the two biofuel scenarios compared to baseline levels. For example, as shown in Figure 13, drastic biofuel expansion has negative impacts on calorie availability in Sub-Saharan Africa, Latin America and Caribbean, Middle East and North Africa and the rest of the regions. The same trend holds true for biofuel expansion. The adverse effects on calorie consumption are particularly high in Africa, with a reduction of more than 8%. Moreover Sub-Saharan Africa shows lower level of import for wheat and sugar and higher level of export for maize and cassava under the two biofuel expansion scenarios (Table 4 and Table 5). These cause the numbers of preschool malnourished children of Sub-

Saharan Africa to increase by 1.5 million and 3.3 million in 2020, and 1.4 million and 3.0 million in 2050, for the "biofuel expansion" and "drastic biofuel expansion" scenarios, respectively, compared with the projection in baseline scenario (Figure 14). World total numbers of preschool malnourished children are projected to increase by 4.4 million under "biofuel expansion" and 9.6 million under "drastic biofuel expansion" in 2020. In 2050, world total numbers of preschool malnourished children are projected to increase by 3.9 million under "biofuel expansion" and 8.2 million under "drastic biofuel expansion".

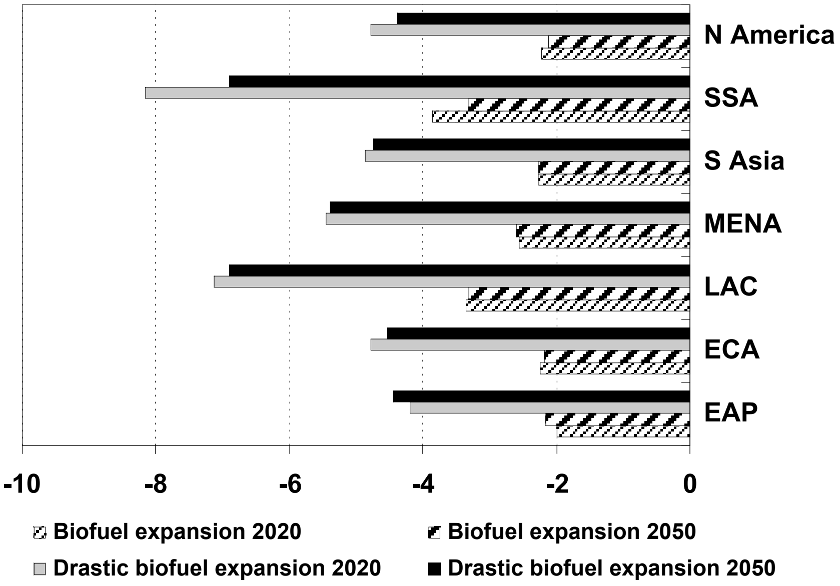

Figure 13. Calorie availability changes projected in 2020 and 2050 compared to baseline (%).

Source: IFPRI IMPACT projections.
Note: N America = North America, SSA = Sub-Saharan Africa, S Asia = South Asia, MENA = Middle East & North Africa, LAC = Latin America & the Caribbean, ECA = Europe & Central Asia, EAP = East Asia & Pacific.

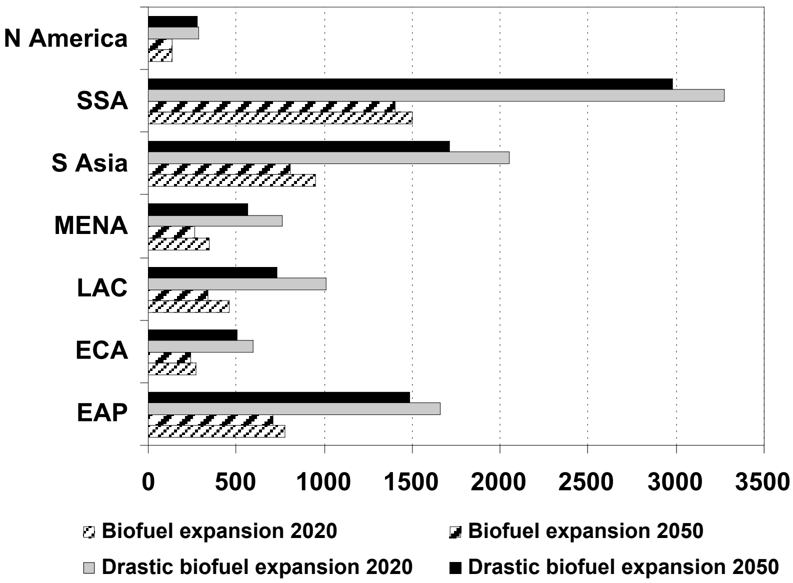

Figure 14. Changes of numbers of preschool malnourished children in 2020 and 2050 compared to baseline (Unit: thousand)

Source: IFPRI IMPACT projections.
Note: SSA = Sub-Saharan Africa, S Asia = South Asia, MENA = Middle East & North Africa, LAC = Latin America & the Caribbean, EAP = East Asia & Pacific.

3.4 Net crop area changes

The area changes for major staples under biofuel expansion for the year 2020 are presented in Table 6. Across all crops considered, there will be an expansion of cropland for the "biofuel expansion" and "drastic biofuel expansion" scenarios. For the year 2020, the baseline crop area is 754 Mega hectares (Mha), which increases one percent to 763 Mha and 776 Mha under "biofuel expansion" and "drastic biofuel expansion," respectively. Latin America and the Carribean will experience 8 percent area expansion over the baseline under "biofuel expansion," which is the greatest area change under this scenario. Sub-Saharan Africa will also experience the large area increases, up to 6 percent over the baseline under the "drastic biofuel expansion" scenario.

Table 6. Projected net area change from the baseline of agricultural commodities at 2020

Region*	Scenario**	Maize	Sugarcane	Soybean	Wheat	Cassava	Total (000 ha)	% Change
Brazil	Baseline (000 ha)	14,469	8,743	20,857	2,547	1,768	48,384	*
	high tech	-14%	-20%	-23%	-40%	-10%	38,685	-20%
	BE	3%	2%	-2%	0%	1%	48,717	1%
	Drastic BE	8%	4%	-4%	1%	1%	49,163	2%
China	Baseline (000 ha)	29,669	1,507	8,678	23,687	355	63,896	*
	high tech	-14%	-15%	16%	14%	-8%	64,104	0%
	BE	4%	1%	-1%	0%	0%	65,122	2%
	Drastic BE	10%	3%	-1%	0%	1%	66,808	5%
India	Baseline (000 ha)	7759	4493	6370	26656	266	45,543	*
	high tech	-19%	0%	1%	-1%	0%	44,028	-3%
	BE	4%	1%	0%	0%	1%	45,988	1%
	Drastic BE	10%	2%	-1%	1%	2%	46,583	2%
USA	Baseline (000 ha)	33,577	499	27,546	20,886	0	82,508	*
	high tech	-12%	4%	16%	4%	-6%	83,629	1%
	BE	5%	2%	-2%	0%	0%	83,560	1%
	Drastic BE	11%	5%	-5%	0%	1%	85,073	3%
EAP	Baseline (000 ha)	38,733	5,007	10,117	36,857	3,280	93,994	*
	high tech	-12%	-7%	18%	7%	-4%	93,298	-1%
	BE	4%	2%	-1%	0%	0%	95,596	2%
	Drastic BE	9%	4%	-1%	0%	1%	97,772	4%
ECA	Baseline (000 ha)	13,758	1	1,093	72,561	0	87,413	*
	high tech	-8%	8%	2%	-5%	-3%	82,478	-6%
	BE	4%	2%	-1%	0%	0%	88,152	1%
	Drastic BE	10%	5%	-2%	0%	1%	89,113	2%
LAC	Baseline (000 ha)	30,485	12,815	38,900	10,612	2,824	95,637	*
	high tech	-8%	-9%	-22%	1%	-9%	90,140	-6%
	BE	4%	2%	-2%	0%	1%	102,841	8%
	Drastic BE	8%	4%	-4%	0%	1%	103,910	9%
NAE	Baseline (000 ha)	34,693	499	28,611	30,845	0	94,649	*
	high tech	-12%	4%	15%	4%	-6%	96,092	2%
	BE	5%	2%	-2%	0%	0%	95,788	1%
	Drastic BE	12%	5%	-5%	0%	1%	97,414	3%
SASI	Baseline (000 ha)	9,899	5,722	6,513	38,479	362	60,976	*
	high tech	-16%	13%	1%	-1%	-1%	60,010	-2%
	BE	4%	1%	0%	0%	1%	61,529	1%
	Drastic BE	9%	2%	-1%	1%	2%	62,265	2%
SSA	Baseline (000 ha)	27,578	1,690	1,108	3,181	16,372	49,929	*
	high tech	-8%	-18%	3%	-14%	-7%	45,739	-8%
	BE	4%	2%	-1%	0%	1%	51,250	3%
	Drastic BE	10%	4%	-3%	-1%	1%	53,055	6%
WANA	Baseline (000 ha)	2,133	271	114	28,694	3	31,214	*
	high tech	-11%	-12%	7%	-9%	-6%	28,402	-9%
	BE	4%	2%	-1%	0%	0%	31,297	0%
	Drastic BE	10%	4%	-2%	0%	1%	31,398	1%
				Total		**Baseline**	**754,143**	*****
						high tech	**719,822**	**-5%**
						BE	**763,401**	**1%**
						Drastic BE	**776,086**	**3%**

Source: IMPACT Model results; IAASTD high technology scenario
** BE = Biofuel Expansion; Drastic BE = Drastic Biofuel Expansion; high tech = high productivity growth
CHI= China; IND = India; USA - United States; BRA = Brazil; SSA = Sub Saharan Africa; WANA = West Asia and North Africa; SASI = South Asia; NAE = North America; EAP = East Asia and the Pacific; LAC = Latin America and Caribbean; ECA = Europe and Central Asia

The area changes for major staples under biofuel expansion for the year 2050 are presented in Table 7. Across all crops analyzed, there is an expansion of cropland for both the "biofuel expansion" and "drastic biofuel expansion" scenarios. For the year 2050, the baseline crop area is 691 Mha, which increases 1 percent to 699 Mha and 2 percent to 709 Mha under "biofuel expansion" and "drastic biofuel expansion," respectively. Regions with a higher relative area expansion include China, with a 4 percent increase in crop area in 2050 under "drastic biofuel expansion", and Sub-Saharan Africa with a 5 percent increase under the same scenario. For both of these regions, maize production expands between 8 and 9 percent, with relative decreases in soybean production.

For the area expansion results, an additional scenario was run in order to show the effects of a high rate of productivity enhancing technology development on area expansion. This scenario is represented as "high tech" in Tables 6 and 7, and is based upon one of the positive variants to the reference simulations done for the recent International Assessment for Agricultural Science and Technology for Development. For both years 2020 and 2050, the effect of technology will decrease the amount of land needed to grow food and feed (biofuels are not considered in this scenario). These results are presented in order to demonstrate the land saving effects of technological improvements and will be discussed in more detail in Section 4.1.

Table 7. Projected net area change from the baseline of agricultural commodities at 2050.

Region*	Scenario**	Maize	Sugarcane	Soybean	Wheat	Cassava	Total (000 ha)	% Change
Brazil	Baseline (000 ha)	15,448	13,245	20,226	2,794	1,696	53,408	*
	high tech	-20%	-24%	-15%	-39%	-15%	42,781	-20%
	BE	3%	2%	-1%	0%	1%	53,893	1%
	Drastic BE	7%	5%	-3%	1%	2%	54,485	2%
China	Baseline (000 ha)	23,713	1,487	7,980	19,477	361	53,019	*
	high tech	-14%	-16%	20%	21%	-11%	55,132	4%
	BE	3%	2%	0%	0%	1%	53,873	2%
	Drastic BE	8%	3%	-1%	0%	1%	54,979	4%
India	Baseline (000 ha)	6589	3969	5579	25187	261	41,585	*
	high tech	-21%	-6%	4%	5%	-7%	41,443	0%
	BE	4%	1%	0%	0%	1%	41,942	1%
	Drastic BE	8%	2%	-1%	1%	3%	42,443	2%
USA	Baseline (000 ha)	31,437	612	24,407	17,550	0	74,007	*
	high tech	-12%	3%	23%	12%	-13%	78,046	5%
	BE	3%	3%	-1%	0%	1%	74,745	1%
	Drastic BE	7%	6%	-2%	0%	1%	75,723	2%
EAP	Baseline (000 ha)	31,710	6,326	9,267	30,115	3,049	80,467	*
	high tech	-12%	-7%	22%	13%	-8%	81,983	2%
	BE	3%	2%	0%	0%	0%	81,678	2%
	Drastic BE	8%	4%	-1%	0%	1%	83,215	3%
ECA	Baseline (000 ha)	11,099	1	877	59,752	0	71,729	*
	high tech	-10%	7%	11%	-2%	-6%	69,775	-3%
	BE	3%	2%	-1%	0%	1%	72,280	1%
	Drastic BE	8%	5%	-2%	1%	1%	72,943	2%
LAC	Baseline (000 ha)	30,009	18,975	39,146	11,086	2,767	101,983	*
	high tech	-13%	-13%	-15%	4%	-14%	90,140	-12%
	BE	3%	2%	-1%	0%	1%	102,841	1%
	Drastic BE	7%	4%	-3%	1%	2%	103,910	2%
NAE	Baseline (000 ha)	32,353	612	25,337	25,655	0	83,956	*
	high tech	-12%	3%	23%	10%	-13%	88,435	5%
	BE	3%	3%	-1%	0%	1%	84,771	1%
	Drastic BE	7%	6%	-2%	0%	1%	85,839	2%
SASI	Baseline (000 ha)	8,652	5,425	5,713	33,783	370	53,943	*
	high tech	-17%	21%	4%	8%	-7%	56,648	5%
	BE	3%	1%	0%	0%	1%	54,383	1%
	Drastic BE	8%	2%	-1%	1%	3%	54,995	2%
SSA	Baseline (000 ha)	24,502	2,341	1,141	3,644	20,796	52,425	*
	high tech	-13%	-26%	13%	-12%	-15%	45,220	-14%
	BE	4%	2%	-1%	0%	1%	53,581	2%
	Drastic BE	9%	4%	-3%	0%	2%	55,047	5%
WANA	Baseline (000 ha)	1,711	356	121	23,245	3	25,437	*
	high tech	-8%	-15%	11%	-1%	-13%	24,938	-2%
	BE	4%	2%	-1%	0%	1%	25,520	0%
	Drastic BE	8%	4%	-1%	0%	1%	25,612	1%
				Total		**Baseline**	**691,957**	*
						high tech	**674,542**	**-3%**
						BE	**699,506**	**1%**
						Drastic BE	**709,188**	**2%**

Source: IMPACT Model results; IAASTD high technology scenario

** BE = Biofuel Expansion; Drastic BE = Drastic Biofuel Expansion; high tech = high productivity growth

CHI= China; IND = India; USA - United States; BRA = Brazil; SSA = Sub Saharan Africa; WANA = West Asia and North Africa; SASI = South Asia; NAE = North America; EAP = East Asia and the Pacific; LAC = Latin America and Caribbean; ECA = Europe and Central Asia

3.5 Water resource implications

The water use implications of biofuel expansion were also analyzed with the water management and allocation module of IMPACT, which is defined at the sub-national scale according to how national boundaries intersect with river basins. The results show that, overall, biofuel expansion is not likely to alter the regional- and national-aggregate patterns of water use significantly, as is seen in Table 8 and Table 9.

Table 8. Irrigation water consumption of baseline and biofuels scenarios in 2020.

Region/Country*	Baseline (109 m3)	Change from Baseline			
		Biofuel expansion		Drastic biofuel expansion	
		(109 m3)	(%)	(109 m3)	(%)
Brazil	17.24	-0.08	-0.45	-0.10	-1.05
China	246.02	0.77	0.31	1.04	0.74
India	402.64	-0.31	-0.08	-0.45	-0.19
USA	196.53	2.21	1.12	3.06	2.68
SSA	44.20	0.00	0.00	-0.03	-0.06
LAC	105.02	0.96	0.92	1.26	2.12
EAP	321.41	0.92	0.29	1.21	0.66
ECA	82.72	0.39	0.48	0.51	1.09
MENA	129.17	0.07	0.05	0.06	0.10
S. Asia	471.78	-0.28	-0.06	-0.41	-0.15
N. America	197.99	2.23	1.13	3.09	2.69

Note: See figure 2 for regional definition.

Table 9. Irrigation water consumption of baseline and biofuels scenarios in 2050.

Region/Country*	Baseline (109 m3)	Change from Baseline			
		Biofuel expansion		Drastic Biofuel Expansion	
		(109 m3)	(%)	(109 m3)	(%)
Brazil	17.38	-0.05	-0.28	-0.11	-0.62
China	202.95	0.95	0.47	2.09	1.03
India	400.04	-0.18	-0.04	-0.24	-0.06
USA	170.54	1.17	0.68	2.62	1.54
SSA	54.16	0.07	0.13	0.16	0.30
LAC	106.47	0.90	0.85	2.00	1.87
EAP	271.06	1.25	0.46	2.72	1.00
ECA	73.53	0.19	0.26	0.41	0.56
MENA	107.22	0.04	0.04	0.06	0.06
S. Asia	459.93	-0.15	-0.03	-0.18	-0.04
N. America	171.83	1.18	0.69	2.66	1.55

Note: See figure 2 for regional definition

For both 2020 and 2050, the United States shows some apparent increases in the consumptive use of water, but for some countries, such as Brazil and India, irrigation water consumption levels even decrease slightly under the biofuel expansion scenarios. These changes are mostly caused by the expansion of area under irrigated sugarcane which, in some areas, replaces irrigated rice area that has higher levels of water demand. This result highlights the importance of capturing land use changes, in order to understand how shifting land from an existing food crop towards a dedicated biofuel feedstock crop has the potential to change irrigation water use, and thus the local water availability.

The global impact would be the sum of region- and crop-specific land and water use changes. Conversion towards dedicated biofuel crops or, to be more generic, biomass, will result in increased water use in some cases, while in other cases it would lead to a decrease (NRC, 2007). In addition to changes in water demands, biofuel expansion can have significant implications for trade patterns. For example much of the expansion of ethanol production in Brazil is projected to occur through the reduction of sugar exports – whereas, in the past, Brazil's ethanol output has been known to decrease when world sugar prices are sufficiently high.

Besides the expansion of existing land area under a certain crop, or the substitution away from one type of crop towards another – agricultural production can also adjust to increased biofuel feedstock demand through the intensification of input usage. Water is a key production input that allows agriculture to adapt along the 'intensive margin' of production – such that rainfed area is converted to irrigated area. Even if total area were to remain constant, in this case, there would still be significant implications for water usage. For those land-scarce regions that are unable to adjust along the extensive margin – intensification may be the only option available, and the environmental consequences should be considered.

Figure 15 presents the projected average annual production growth rate in cereals to the year 2050 and the relative contribution of technology versus land expansion across regions. Sub-Saharan Africa will have the highest production growth over the period at 2.3 percent, and also the largest share of growth from area expansion. Latin American countries will also have significant area expansion in cereal production growth, as well as Central-West Asia and North Africa (CWANA). Other regions such as North American and Europe (NAE) and East and South Asia and the Pacific (ESAP) will have higher yield increases and actually decrease the amount of land dedicated to cereals.

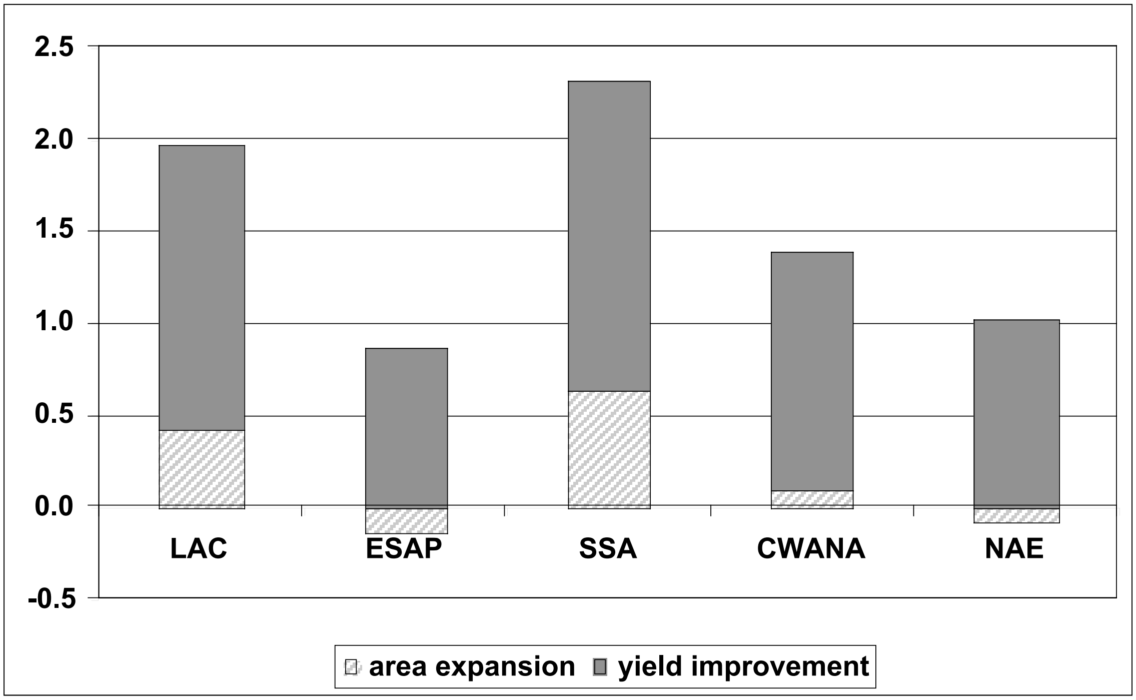

Figure 15: Sources of cereal production growth, reference run, by IAASTD region

Source: IFPRI IMPACT model simulations.

4 ENSURING ENVIRONMENTAL SUSTAINABILITY

In the scenarios that we have considered, in the previous section, we saw that the land use expansion within the various key biofuel-producing regions were of significant proportions, for many of the key feedstock crops that were considered. Besides the impact of land use change on water usage, there are other consequences that could also be considered, that are of both an environmental and economic nature. The implications of bringing extra land under tillage, has implications for green house gas production – especially if it involves the use of land that would otherwise be put under conservation-focused fallowing programs. Currently, land set aside regulations in the EU do not exclude energy crop production, which compromises the conservation goals (Plieninger and Bens 2008). There could also be direct impact on forest cover or species habitat, which will have impacts on biodiversity.

In the next section a theoretical model is presented in order to characterize the land saving capabilities of technological improvements. This model will assist in the understanding and developing of sustainability guidelines that will be develop in Section 4.2.

4.1 The land-saving effects of crop productivity increases

The main land use impact is the direct effect that expanding the area under energy crops has on the total availability of land for other uses – such as food production. By increasing the yield and per-hectare productivity of biofuel feedstock crops, one might not only increase the profitability of the biofuels production process, itself, but also provide direct 'savings' in land, that could be exploited for other uses – such as for habitat, forest, urban uses or other agricultural food or feed crop production.

In the simple illustration, below, we see this linkage manifest itself in the direct displacement of production, and we explore the role that technology has to augment or diminish these impacts. Figure 16 shows a 4-panel schematic, in which the effect of energy production (from biofuels) is linked to land use, and ultimately to crop production and productivity. In this illustration, we consider the impacts of two simultaneous technological shifts – both the technology improvement in fuel conversion technologies, as well as the improvement in agricultural productivity. The shift in fuel conversion efficiency allows a greater amount of energy to be produced for the same amount of land – or, conversely, the same amount of energy with a lower amount of land. The shifts in energy conversion efficiency occur in quadrant I. For a given level of efficiency – take the 'low' case, for example – we see that an increase in energy production (from Q_1^L to Q_2^L), increases the land use requirements (for a fixed yield level) and decreases the amount of land available for food production (L_1^L to L_2^L). The curves in quadrant III represent production isoquants – which are curves along which production of food remains constant. So, in order to stay on the isoquant, yield levels have to increase in response to decreases in land use for food production. So we see that a shift in land use from L_1^L to L_2^L requires that yield levels increase from Y_1^L to Y_2^L in order to maintain food production levels at the same level. Otherwise, production would have to reduce, if yields were to remain at Y_1^L – which is shown by the movement to the dashed isoquant in quadrant III.

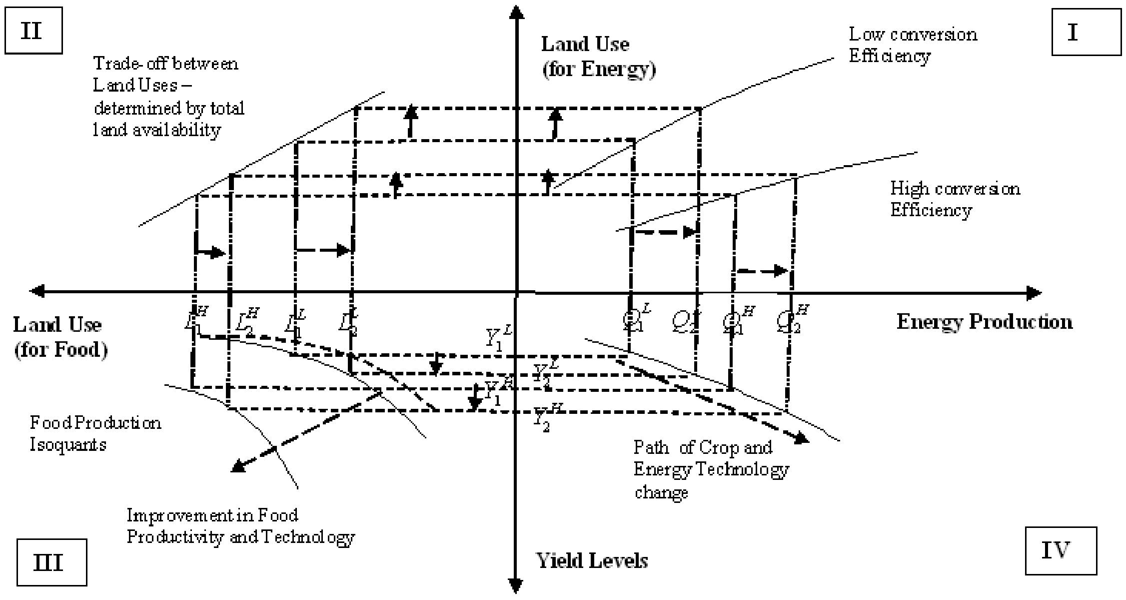

Figure 16. Linkages between land use, feedstock yields, and energy production.

If there was to be a shift in quadrant I to a biofuels conversion technology that was more efficient, then we see that an even greater amount of energy could be made available for even lower levels of land use. A shift from Q_1^H to Q_2^H entails smaller reduction in land than before (L_1^H to L_2^H) and from a higher base level (L_1^H, compared to L_2^L). If this shift to a higher conversion efficiencies were to coincide with an increase in food demand – as is often seen, over time, as income and population levels increase – then an increase in yield (from Y_1^H to Y_2^H) would also be required to maintain food production at the higher level (whose isoquant has been shifted away from the origin, as shown). This yield shift would also start from a higher base level, compared to that required under lower food demand (i.e. Y_1^H compared to Y_1^L).

From this illustration, we see that the concurrence of increasing food production (to meet the needs of growing and wealthier populations) and increasing energy demand places increasing requirements on the improvement of both energy and crop technologies, in order to keep up. Otherwise, a constant or decreasing food supply, due to less land available for food production and static yields, would cause the "food-vs.-fuel" trade-off that is of such concern to policymakers and analysts. The simultaneous improvements in both fuel conversion and crop productivity trace out an expansion path of crop and energy technology that is shown in quadrant IV of Figure 16.

There are clear implications on land use for technology improvements aimed at higher productivity of feedstock crops, which serves to improve both the outcomes for food production as well as that of energy. In the next sub-section, we will discuss other implications of biofuels-driven land use changes.

4.2 Constructing land use guardrails

The area expansion results indicate that under both "biofuel expansion" and "drastic biofuel expansion" scenarios, additional crop area will be required for major staple crops. For example, in 2050, an additional 7.5 Mha will be required when compared to the baseline under "biofuel expansion" and an additional 17.2 Mha will be necessary under "drastic biofuel expansion". In this section, this area expansion will be evaluated against the sustainability goals set by international institutions. Currently, the European Commission has adopted sustainability criteria so that biofuel development does not result in undesired losses in biodiversity. To allow concrete statements on the sustainable amount of land use that can be developed for biofuels globally, 'guardrails' are developed by comparing published sustainable land area figures for biofuel production to the land use expansion predicted by the IMPACT model (Section 3.4).

Eickhout el al. (2008) have calculated the sustainable potential of biofuel land expansion by weighing the biodiversity impacts of energy crop production on various land types to the net carbon benefit of biofuel production and consumption. According to these results, GHG reductions from biofuels will not overcome biodiversity loss for all land types in the short run. In the long run, however, the intensive development of abandoned agricultural land for biofuel production will have positive impacts on avoided climate change—only if they are produced on abandoned agricultural land. The conversion of other land types such as partially restored agricultural land, grasslands, and forests, will have negative impacts on atmospheric carbon and biodiversity. This is because these types of land cover have a higher potential for carbon sequestration than the savings that are embodied in the combustion of biofuels.

The results from Eickhout *et al* are indicative of the relative value of land conversion for biofuels. Therefore, guardrails for sustainable land use may be based on the potential for biofuel production on abandoned and marginal agricultural land only. Eickhout *et al* calculate the theoretical available global land for biofuel production in 2020. With no sustainability criteria, the area of available land is 600 Mha. Yet, if all the sustainability criteria are applied as set out by the EU Commission—including the exclusion of all highly biodiverse grassland—the amount of potential land suitable for arable crops drops to 35 Mha.

The area expansion results for year 2020 from IMPACT indicate an increase in area dedicated to staple crops of 9.2 Mha under "biofuel expansion," and 21.9 Mha under "drastic biofuel expansion." In comparison to the 35 Mha of land that are determined sustainable for biofuel development, nearly 63 percent of sustainable biofuel production will be met in 2020 under the "drastic biofuel expansion" scenario. These results do not include the area that is dedicated to oilseed production for biodiesel, or other crops included in the model. Therefore, it is likely that the actual area expansion would be greater than 21.9 Mha under "drastic biofuel expansion."

It is important to note that the biofuels-focused results from IMPACT do not include the effects of accelerated technological improvements within the agricultural sector. In scenarios where technological advancements in crop productivity are considered, total global crop area decreases by 34.3 Mha. This indicates that double the amount of land—or 70 Mha—could be made available for biofuel production without compromising climate and biodiversity objectives. In conclusion, based on the criteria presented in Eickhout *et al*, the expansion of biofuel production beyond current targets should be not be pursued in the absence of strong technological and productivity gains in the agricultural sector, which is one of the major underlying factors in the success of the Brazilian biofuels sector, and its long-term growth and development.

4.3 Tools available to ensure sustainable land use

A few countries in the European Union are investigating the feasibility of biofuel certification programs (Kojima *et al* 2007; van Dam *et al* forthcoming). These programs, much like FAIRTRADE standards for coffee, will seek to ensure the environmental and social sustainability of any biofuel products. They will do this by limiting market access to producers who do not contribute to deforestation or other unsustainable land practices. While the development of these programs is still in its infancy, it will be important to consider the needs of smallholders—ensuring that certification is not costly or technically difficult. Another possible policy method of ensuring land use would be to incorporate biofuels into the Clean Development Mechanism under the United Nations Framework Convention on Climate Change (UNFCCC). Currently, however, agriculture is not considered in the CDM, which predicates the ability for developing countries to participate.

4.3.1 Protection of forested areas to enhance carbon sequestration

The production of biofuels may cause deforestation directly through land clearing for crop production. The indirect pressure on land resources through the cultivation of energy may induce further deforestation through extensification of agricultural area. The expansion into forests for feedcrop and livestock production is one of the main reasons for deforestation globally (Nabuurs *et al* 2007; Steinfeld *et al* 2006), translating into 9 percent of total global CO2 emissions annually (Steinfeld *et al* 2006). It is estimated that land use activities related to livestock production, including feedcrop production and pasture, account for 70 percent of all agricultural land, or 30 percent of the Earth's land surface (Steinfeld *et al* 2006). Demand for beef is expected to increase as incomes rise, with over 60 percent of meat and milk consumption taking place in the developing world by 2020 (Delgado *et al* 1999). As a result, the indirect impacts of agricultural expansion need to be weighted before perusing the development of the biofuel sector. The concurrent employment of yield enhancing technologies will be necessary to avoid excess pressure on land resources a strike a sustainable balance with forest services.

5 SAFEGUARDING FOOD PRODUCTION

5.1 Crowding out food production

A key issue that underlies the concern of policy analysts and decision makers about the rapid growth of crop-based, first-generation biofuels is that of food security and the impact of biofuels on the global food balance. While most of the literature has focused on the impact on crop prices, which is a key indicator of impacts on food markets, relatively few have looked at the actual impact on consumption patterns and nutrition status of vulnerable people. The discussion in Section 3 has provided a quantitative overview of plausible future impacts of biofuels growth on global food security, even though it has not exhaustively described the degree to which food producing land area might be substituted by land area devoted to the production of energy crops. It is generally understood, among policy analysts and researchers that net food-importing countries are particularly vulnerable to rapid food price increases that are induced by forces such as crop-based biofuels production growth. Land-locked countries which face significant transportation costs for the importation of food as well as fuel products are doubly-disadvantaged by the concurrent increase in both energy and food prices, and are forced to meet increasingly large import bills to meeting their subsistence needs for these goods. The degree to which food or energy products dominate the total value of imports is likely to be a key determinant of whether countries choose to develop capacity in producing fuel, rather than just focusing on self-sufficiency in food.

While much of the analysis done in Section 3 focused on the negative impacts of biofuels-driven price increases on country-level food security outcomes, it is clear that there are gains to be made by the agricultural sector, in terms of land value, production revenue, as well as overall terms of trade, relative to other sectors. However, the net gain that some producers might receive from price increases may not be enough to offset the negative impacts that net food consumers will face – and the overall gains become dependent upon the balance of these two effects, as well as on the distribution of benefits and costs. The ability to purchase food will also be impacted by relative price increase in energy markets as well – especially for those populations which already face high marketing, transactional and transportation costs for food products, that will be pushed even higher by rising fuel costs. For those populations, the market price of food also embeds the cost of getting it to market, of which a substantial portion for food importers is fuel cost. Given our knowledge of household expenditure patterns, based on surveys carried out over various regions and time periods, however, we know that price changes in food commodities have a bigger effect on household budgets of the poor, due to the high proportion that food consumption represents in total household expenditure (e.g. Ahmed *et al* 2007).

5.1.1 Highly vulnerable regions

The characterization of vulnerability, for an economic unit[2] can describe the degree to which there is exposure to variation in key determinants of welfare, or even the absence of resilience or lack of means to buffer the shocks that create large and sudden changes in welfare status. Highly vulnerable regions tend to have a large share of their populations comprised of households that spend the majority of income on food purchases, and are engaged in low-productivity activities; live within conflict zones; subsist on marginal quality land and reside in drought-prone regions, with little access to productivity-enhancing inputs that reduce the variability of output, among other possible characteristics. Figure 17 shows areas of Asia that are subject to various levels of vulnerability to crop failure, under a stochastic simulation of possible climate outcomes. The degree of vulnerability is determined by the combination of both exposure and limited ability to cope with drastic shocks in weather conditions.

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[2] Be it an individual, household or collection of households.

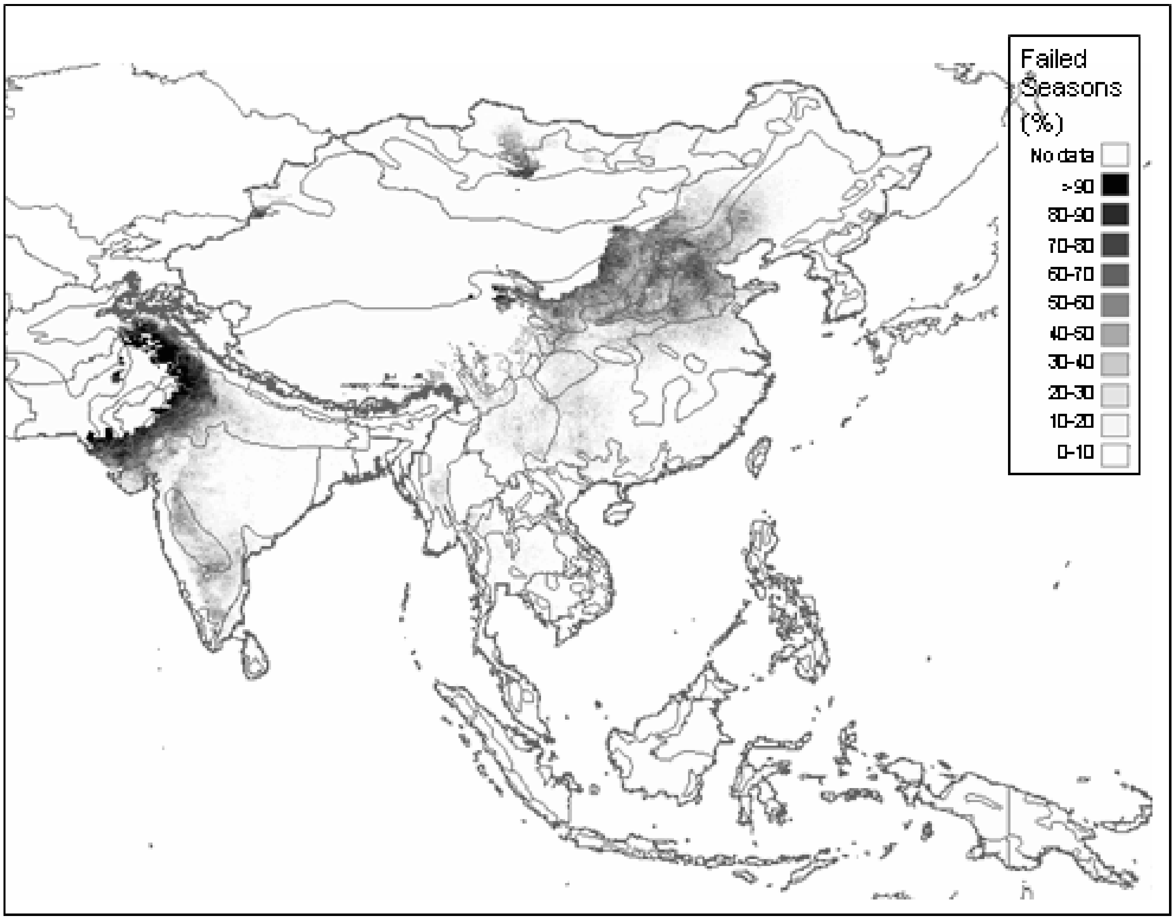

Figure 17. Proportion of failed growing seasons for rainfed cultivation, 100 year weather simulation

Source: Adapted from Hyman, Jones, Fujisaki, Wood and Dixon (2007). Unpublished report.
Notes: The figure illustrates 100 year weather simulation based on historic data analysis

Similar to the way in which we describe the vulnerability of a region to weather outcomes or climatic conditions, we might also think of vulnerability to fluctuations and rapid, sudden changes in economic conditions as the exposure to variability as well as the lack of assets or resources to buffer the shocks. Countries with low levels of grain stocks are unable to stabilize fluctuations in cereal prices in the same way that countries with well-stocked public or private reserves are able to do, and are at a disadvantage when faced with national emergencies which require the rapid release of food stocks to relieve populations faced with acute shortages. The donor community also faces difficulties in providing sustained levels of food assistance, when there are no longer local surpluses from which they can easily source their supplies, and when they have to purchase from highly-variable spot markets with a fixed budget, at the same time when the actual number of people in need of assistance is also increasing. The recent massive budget shortfalls facing the United Nations World Food Program, and the United States Agency for International Development (USAID) food aid program are a testament to the new realities that confront providers of humanitarian assistance in an increasingly tight global economic environment.

5.2 Tools available to ensure food security?

A key challenge remains to improve monitoring systems for human welfare – such as the various hunger early warning systems that are currently used by the United Nations World Food Program (WFP) and the Food and Agriculture Organization (FAO) to detect the early signs of famine. These systems, at present, are best suited towards monitoring the onset of famine events in rural regions, but are not as well adapted to detecting problems occurring in urban areas – which is where a higher numbers of the world's hungry and vulnerable will continue to be found.[3] This will also necessitate the improvement of welfare and humanitarian response mechanisms that can provide well-targeted interventions to maintain and protect the nutrition status of those who are most likely to fall into hunger. An increasing number of the world's vulnerable populations will be found in less-favored areas, and living on marginal quality lands that provide relatively low levels of productivity for agricultural activities. This trend is driven both by pressures on existing land resources, which quickly degrade when subjected to high levels of population pressure and constant cultivation without adequate opportunities for fallowing – as well as by expansion onto lands of lower quality, due to high density in existing areas and limited opportunities for expansion on better land.

All of these socio-economic trends will require concerted policy action, and targeted interventions that we try and outline in the subsequent sub-section.

5.3 Quantifiable level of investment to achieve food security?

While numerous studies have looked at the likely decline of malnutrition and food security outcomes, in the face of growing environmental pressures and rapidly-evolving socio-economic conditions, relatively few of them have attempted to quantify the levels of investment that are needed to maintain or even improve human well-being outcomes. The target levels that are most

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[3] Even though there is agreement, that even into the far future, the majority of the world's poor will continue to reside in rural areas.

often used as a benchmark for comparing evolving trends in human well-being are those of the Millennium Development Goals (MDGs), which are widely-cited and referenced 'goals' for human development, especially among civil society groups, non-governmental organizations and international humanitarian and development-oriented institutions. While many of the goals embedded in the MDGs are admirable, and worthy of aspiration – there are inherent trade-offs that are embedded in the improvement of human well-being and environmental outcomes, that might not allow for a 'multi-goal' objective of simultaneous improvement across a broad range of indicators to be possible.

The Millenium Ecosystem Assessment (MEA 2005), was a large, global, multi-stakeholder, international assessment of fairly broad representation, which documented in a highly detailed fashion, the inherent trade-offs between meeting human needs for food, feed, fiber and fuel, into the future, and maintaining uniformly high levels of environmental quality and integrity of the ecosystem and the various services it provides. Under all of the major "storylines" of future political and socio-economic trends, there were clear compromises between improving poverty and malnutrition outcomes, and maintaining high levels of species biodiversity, environmental quality, natural resource integrity and equality of welfare between regions – albeit to different degrees of severity, and response, across the various key indicators of ecosystem functioning and human wellbeing. The Fourth United Nations Global Environmental Outlook (UNEP 2007) reached similar types of conclusions and was able, in a similar way to the MEA, to quantify how those trade-offs evolve overtime, using a multi-dimensional modeling approach, which links several global models together, in order to illustrate the interactions between the environment and various dimension of the global economy. While both these assessments were comprehensive in the way in which they brought out the interactions between the environment and human well-being, they were not able to bring out the investments needed to meet alternative outcomes, as they were not specifically designed to be goal-oriented, in that way.

IFPRI has carried out a number of quantitatively-based assessments which look at the levels of investment needed to achieve the levels of human well-being specified under certain forward-looking scenarios. The publication of Rosegrant *et al* (2005) showed that the levels of investment needed to achieve the "Vision" scenario of outcomes for agricultural growth and improvement in human services[4] in Sub-Saharan Africa, is US$303.2 billion above the baseline levels – which breaks down to US$95.4 billion for investment in rural roads, US$82.3 billion for education, US$49.1 billion for clean water, US$48.7 billion for irrigation and US$27.8 billion for agricultural research investment. The broad-ranging nature of these investment numbers shows that a fairly comprehensive approach is needed to significantly change the outcomes of human well-being in Sub-Saharan Africa, which has historically lagged behind in the degree to which key sections of the physical and socio-economic infrastructure have been maintained in the past, compared to other regions. Even these levels of investment do not achieve all of the MDG targets for Africa, which is currently on a trajectory that keeps it from realizing most of them by the target year of 2015. Nonetheless, it is illustrative of the mobilization of resources and the level of political will – from both national governments and multi-lateral agencies – that are required to make significant improvements in human outcomes.

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[4] Where crop and livestock yield growth are 50% higher than under the "business-as-usual" levels of investment, GDP growth is significantly higher (6.5% for Nigeria and 8% for the rest of Africa), and female secondary schooling rates and access to water reach 90% and 95%, respectively, by 2020).

6 ENSURING SUSTAINABLE BIOENERGY MARKETS IN DEVELOPING COUNTRIES

In addition to satisfying international demand for biofuels, the creation of energy sources for national consumption can offer a number of benefits. Biofuels can offset energy imports, diversify energy sources, and create employment. For countries where that can produce biofuels without causing scarcity of land, water and food, the biofuel industry will need to have income opportunities beyond producing raw biomass—they should also have a share in the value chain.

Best practices can be drawn from varying country biofuel development models, such as the U.S. and Brazil while tailoring solutions implemented to differing socio-economic conditions. Each country will have to use an analytical framework for assessing the biofuel/food security nexus. A new approach has been developed by the FAO called the Bioenergy and Food Security (BEFS) approach (von Brandt 2008) and is being piloted in various developing countries. The assessment seeks to ascertain the degree of bioenergy potential and food security, while considering the agro-ecology and governmental commitment (von Brant 2008). In Peru the results of the BEFS assessment indicate that while there is potential for the development of agro-ecologically specific feedstocks, substantial market barriers such as the lack of financial tools, technology, and legislation will need to be overcome (Villavicencio Rivera 2008).

A recent study of global biodiesel production potential recently calculated an upper-limit of 51 billion liters from 119 countries (Johnston and Holloway 2006). Figure 18 presents a map of the global biodiesel potential annual production. Of the 119 surveys considered to have production potential, Brazil, United States, Indonesia, Germany, Spain, and Argentina represent the largest potential with an annual production capacity of 1,000 to 15,000 million liters. The researchers also find limited potential in Sub-Saharan Africa and most of Central America, while India and China could produce up to 100 and 500 million liters annually.

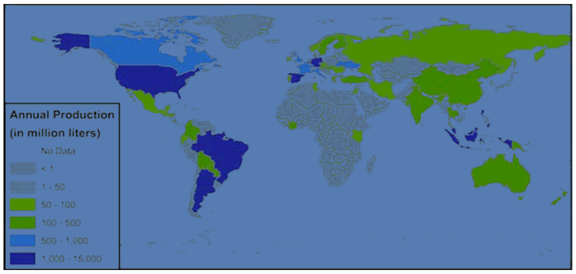

Figure 18. Global biodiesel from existing lipid exports

Source: Johnston and Holloway 2006

There are two principal options for bioenergy production in developing countries: large-scale plantation-based and smallholder-led production. Large-scale development has a lower cost base and therefore a higher export potential; however, land ownership is concentrated and there are often few local opportunities for value added. Current supply chain models will seek to exploit the existing economies of scale in the production of biofuel feedstocks, leaving smallholders and the poor with a limited role (Zeller and Grass 2007). Despite this observation, some see opportunities for smallholder-led production and their ability to retain value added in rural areas when grown on marginal land (Woods 2006). Others, however, warn that the development of marginal lands may limit access to biomass foraging and resources for the landless (Gundimeda 2004).

Considered together, small-scale producers will most likely need assistance in the organizing into groups for improved marketing (Woods 2006) and in advancing in technologically. One policy tool available to ensure assistance to smallholders is public-private partnerships. The public sector needs to set the legal, fiscal and institutional framework for biofuel production in order to maximize the complementarities between the public and private stakeholders. Public-private partnerships can help to ensure that supply chains generate income and employment for small producers and laborers. Specifically, the private sector will play a critical role in technology transfer and related capacity building.

6.1 Bioenergy production for export versus energy poverty reduction

Back of the envelope calculations have shown that less land would need to be dedicated in order to meet rural electrification in India than reducing gasoline dependence significantly (Rajagopal and Zilberman 2007). Calculations such as these beg the question as to whether transportation is the best use for bioenergy. New studies argue that electrification may be a more sustainable use of bioenergy (Eickhout *et al* 2008). In addition, replacing highly polluting and inefficient forms of biomass will have significant welfare impacts for women and children.

Biomass in general can be converted to energy forms to satisfy a range of rural applications that would satisfy local needs rather than the international demand. Local energy needs that could be based on biomass combustion include electrification, small machinery power, irrigation pumping, and food production equipment. In this case, programs for subsidizing the costs of conversion technologies may be most beneficial (Woods 2006).

Figure 19 presents a typology of countries relative to their energy needs and relative food security. The Global Hunger Index (GHI) for non-OCED, non-petroleum exporting countries is plotted on the y-axis, while the ratio total final consumption (TFC) of biomass for residential uses to the TFC of petroleum-based transportation fuel is on the x-axis[5]. The classification of the index is based on relative degrees of severity: scores less than 10 are considered problematic, those between 10 and 19 are serious, from 20 to 29 are alarming, while a score over 30 is considered extremely alarming. For example, Argentina has one of the lowest GHI scores of 1.8, while the Democratic Republic of the Congo has one of the highest, at 40.8. The median GHI of the country group is approximately 12, where as the median ratio between TFC of biomass and TFC of transportation fuel is 0.9. This indicates that 50% of countries have at least a serious problem of hunger and malnutrition, while 50% of countries have an energy demand ratio of 0.9 or greater, which indicates a significant need for residential energy over transportation fuel.

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[5] TFC is presented in units of kilotonne of oil equivalent, which is a net calorific basis. The GHI is based on the average of three variables: percent of population that is undernourished; prevalence of underweight in children under 5; and percent of children dying before the age of five (for background information on the GHI, see Wiessman, 2006).

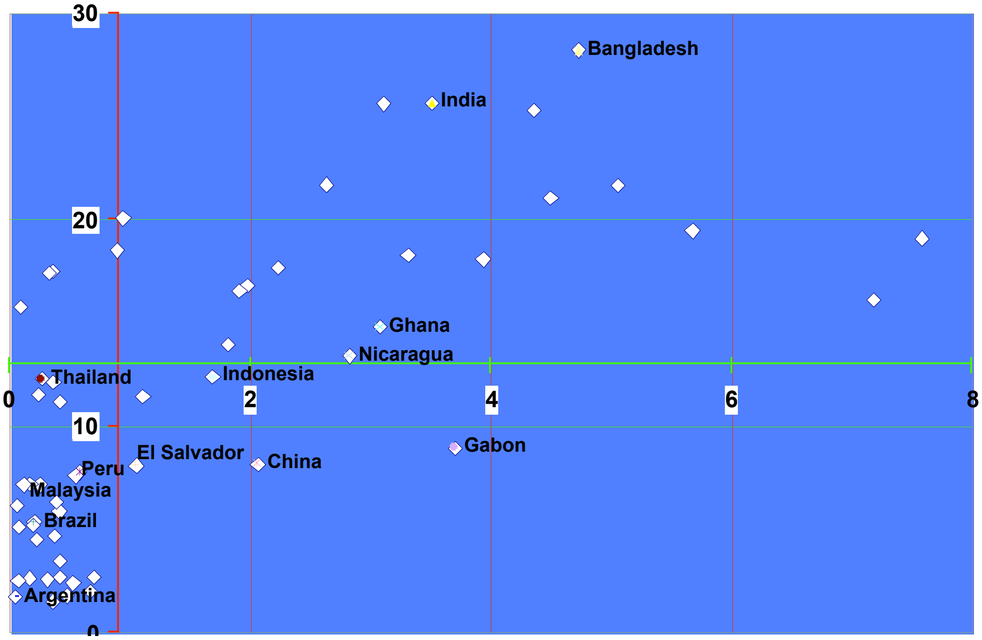

Figure 19. Energy demand and global hunger, non-OCED countries, non-petroleum exporting countries.

Source: IEA statistical database, data for year 2005; Global Hunger Index, data for year 2003

Countries with high biomass demand and high GHI are represented in the upper right hand quadrant of Figure 19, and include Bangladesh, Ghana, and India. Countries in this quadrant have lower access to food and a high consumption of traditional and inefficient energy sources. The development of non-edible energy crops in order to meet village energy needs, as well as generate income, may be most appropriate for these countries—from a food and energy security perspective. Indeed, in later sections we will review current small-scale production models that are being piloted in India and Ghana.

Countries in the lower left-hand quadrant have a high demand for transportation fuel relative to biomass for residential uses, and also have relatively low GHI. Countries in this category include Brazil, Malaysia, Peru, Argentina, and Thailand. A number of these countries are currently expanding biofuel production in order to meet both domestic and international demand. The development of large-scale industries, again from a socio-economic welfare perspective, may bring benefits in the form of lower transportation fuel costs and employment in the biofuel sector, without compromising local food security.

In general, this typology can be viewed as a starting point in analyzing how biofuels are linked to important human well-being impacts like hunger, and how it intersects with energy needs. Further development of this typology could include disaggregating demand between the rural and urban locations in order to differentiate between these regions and allow better spatial planning of biofuel sectors. In addition, it may be important to characterize the relative daily per capita calorie consumption of feedstock crops such as cassava, sugarcane, oils, and maize relative to GHI in order to minimize food security risks that biofuel development may pose.

6.2 Role for technology transfer

By exporting the kinds of key technologies that have contributed success of the Brazilian biofuels sector, some countries might be able to benefit and learn valuable lessons in industrial process design that can be applied within their own national contexts. There are, however, a number of other underlying factors that cannot be easily exported or transferred to other countries and contexts, simply because they are inextricably linked to the context and development of the Brazilian experience with alternative fuel technologies, that have developed since the inception of the ProAlcool program in the 1970s.

Besides the innovations that have been introduced into the industrial production processes of the Brazilian biofuels sector, which allow it to be highly flexible in nature[6], and efficient in character – there are a number of important innovations and advancements that have taken place in the wider agricultural sector itself, which support the industry. The high levels of crop yields that are observed within the Brazilian agricultural sector, even under rainfed conditions, are a result of concerted efforts towards crop improvement and breeding, and production technology advancements, that have accrued over a long period of time, from a long-term trend of investments in agricultural research and development in the sector.

The public sector needs to set the legal, fiscal and institutional framework that attracts the private investments that are the main engine of growth in the emergence of national programs geared towards large-scale biofuel production. These kinds of conditions do not exist in many of the developing countries that are considering the adoption of biofuels processing technologies, and might pose serious barriers to later growth – even in the presence of favorable agro-ecological conditions for cultivating the necessary feedstocks and biomass. Clear and coherent

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[6] Brazilian ethanol processes from sugarcane, for example, are largely designed in a way that allows them to switch easily between ethanol production and refined sugar production, depending on the season or prevailing economic conditions in the market. Most of the industry also operates with co-generation of electricity from crushed cane stalk that supplies most of the power needs and further contributes towards a favorable energy balance and reduction of greenhouse gas emissions.

institutional frameworks are also necessary to maximize the complementarities between the public and private stakeholders, and foster the kind of public-private partnerships that can help to ensure that supply chains generate income and employment for small producers and laborers. Specifically, the private sector will play a critical role in technology transfer and related capacity building, and the government and public sector needs to create the conditions to enable this to happen. This goes beyond just the adoption of technology, but requires the transfer of good governance and institutional culture, that has proved elusive in many under-developed countries, and remains a barrier to the development of commercial or agro-industrial ventures of any kind – whether they're based on crop-based biofuels or some other type of product.

6.3 Effects of industrial country policy on developing country export potential

While we have discussed some of the requisites for good policies that the less-developed countries should adopt, in order to foster the growth of national biofuels production potential, in the previous sub-section – we still have to address the kind of policy reforms that are needed in the developed countries, that also play a part in the global economics of biofuels, and its emergence as a renewable energy sector. One of the major avenues of influence that industrial country policies have on the global biofuel economy is that of trade policy towards biofuels products themselves. The existence of import tariffs that exist in a number of OECD countries, including Australia, the US, Canada and the European Union (among others), hinders the free entry of cheaper biofuels products from other countries – and when combined with blending targets and mandates, may even cause a perverse tendency to increase the consumption of fossil-based fuels like gasoline (de Gorter and Just 2007). Trade policies towards biofuels are made even more complicated by the fact that the classification of ethanol and biodiesel, under the harmonized system, is not uniform and causes one to be classified as an agricultural product, while the other is classified as being industrial in nature (Mosoti 2007).

The other kinds of industrial-country policies that would have large impacts on the viability of emerging biofuels industries within other less-developed regions would be that of trade policy towards the feedstock commodities themselves. Direct tax credits that are aimed at the manufacturers of biofuels products – such as those which are given to blenders within the US – act directly to offset the operating costs of such industries, and maintain their level of competitiveness even in the face of inherently unfavorable economies of cost. Not only do these kind of interventions run the risk of creating environmental externalities in the producing country (through the increased application of productivity enhancing inputs on the landscape, or the overuse of limited natural resources, such as water), but also create international externalities, which are felt through the over-production of the commodity itself, and the impact that it has on the world market prices, and the gains that are realized by other producing nations.

While the effects of full trade liberalization are not explicitly modeled in this paper, we can argue that liberalized biofuel trade is likely to increase demand for biofuels by reducing prices in previously protected markets. Yet, even the removal of tariffs may not create uniformly positive benefits for the developing world, as many small-scale producers would still remain net food buyers and would continue to be subjected to increases in the prices of key commodities that are used as feedstocks, or are closely linked with them (Kojima *et al* 2007). We would expect a high degree of heterogeneity in welfare outcomes that would be dependent upon the nature of the feedstock crops used the types of production technologies that are employed.

7 ENSURING PRO-POOR BIOENERGY DEVELOPMENT

7.1 Impacts on employment

Among the benefits of expansion of large-scale benefits that are frequently cited, are those of employment generation, and increases in the levels of agricultural wages that emanate from the creation of additional value-added activities within the agricultural sectors. The type of feedstock crops that will be favored for first-generation crop-based biofuels production will require fairly robust labor markets to service them, in the absence of high investment levels of capital that can provide labor-saving on-farm machinery. Where harvesting has been mechanized, however, labor requirements can drop sharply. Labor studies in the Brazilian state of Sao Paolo show that labor requirements dropped nearly 60 percent when the sugarcane harvesting became mechanized in the early turn of this century (Smeets *et al* 2008). Many of the GTAP-based, general-equilibrium policy models that look at the impact of biofuels expansion also cite the increases in land rental values that are likely to translate to increased value per worker, and greater accumulation of value within the production chain that supports agricultural production of key feedstock crops. This will lead, in turn, to increases in the wages in the agricultural processing sector, and within other related industries, given that the production of biofuels will likely require a fairly extensive configuration of processing operations. This is supported by data from the Brazilian sugarcane sector, which indicates that wages are higher in sugarcane harvesting than for other crops, while skilled wages at ethanol refineries are also higher than in other comparable industries (Smeets *et al* 2008).

The likely plantation-scale configuration of biofuel feedstock agricultural production will entail working conditions that are common among large-scale, labor intense, plantation operations. Namely, extensive fields in which highly repetitive types of manual labor activities take place – especially in cases where there do not exists high levels of capital investment needed for labor-saving machinery and equipment. In these kinds of environments, standards of worker safety and welfare tend to be low, and in some countries with particularly weak institutions that advocate for workers and their living and working conditions, there could even be instances of outright exploitation – especially where large population of migrant workers are involved. Many parts of Sub-Saharan Africa lack the kind of extensive agricultural labor markets that exist in many of the more-developed OECD countries, where higher wage levels attract high-levels of inmigration from neighboring countries. The type of feedstock crops that will be favored for first-generation crop-based biofuels production will require fairly robust labor markets to service them, in the absence of high investment levels of capital that can provide labor-saving on-farm machinery.

Rajagopal and Zilberman (2007), upon examining the labor intensities that are required, also expect to see an expansion of employment and job creation, as a result of biofuels growth. Other authors see more limited roles for smallholder farmers, given the tendencies of current supply chain models of production, which seek to exploit the existing economies of scale that are embodied in the production of biofuel feedstocks (Zeller and Grass, 2007). The main benefits that may accrue to smallholders, from biofuels growth, may emanate from the higher prices of agricultural commodities, and the improvement of local transportation, distribution and marketing infrastructure within the agricultural sector, in general, rather than from direct income-generation possibilities from the cultivation of the feedstock crops themselves. A considerable level of effort would need to be put into the conscious design of production systems such that smallholders can directly benefit from the opportunities that biofuels may offer to the agricultural sector. We will discuss some of these factors in more detail, in the sections which follow.

7.2 How can landless and ultra-poor participate in boom?

The distributional effects of growth in the biofuels sector are of key concern to those policy makers and analysts who are concerned with the welfare impacts that rapid growth in 1st generation-based biofuel technology adoption might bring. If the bulk of the revenue and benefits from value-addition are concentrated within large-scale, plantation-style cultivation schemes, then the question remains of how smallholders (and even those who are landless) can benefit from the growth in this emerging sector. In the previous sub-section, we mentioned the likely impact that biofuels development will have on agricultural wages, and even wages within related processing industries that are associated with the agricultural storage, marketing, packaging and distribution processes that support the biofuels industry. These type of impacts can provide benefits for the landless laborers who might seek employment within these sectors – although we know that there are likely to be considerable inequalities in wages between workers of different genders, as often happens in agrarian economies, and even more developed economies that lack the enforcement mechanisms to oversee working conditions and compensation within their agricultural sectors.

For those who find themselves in the category of the ultra-poor (i.e. those who live on less than $0.50/day), the gains to growth in the biofuels sector might be even harder to capture – especially considering the nature of the forces that already keep such people in extreme poverty. If consolidation of agricultural land holdings were to take place, in order to form large-scale commercial farming operations that are geared towards the production of biofuels feedstock and higher-level processing – the ultra-poor, who might even be landed, would be at the highest risk of displacement and marginalization, and may not even be able to capture the employment benefits that slightly more advantaged or skilled workers might be able to find within the sector. Not only would such populations be exposed to greater risk of changes in their nutritional status, if the prices of agricultural goods were to increase as result of national-level expansion of biofuels production, but the increase in land values within the sector might even price them out of the land markets – or even increase the incentives to displace them from their land, especially where land tenure institutions and enforcement mechanisms for property rights are weak. There is concern that marginal land development may decrease access to fuel wood (Gundimeda 2004; Rajagopal 2007; Karekezi and Kithyoma 2006).

There is renewed interest in capitalizing on the intense interest in biofuels to draw attention to non-transportation uses of biomass, including electrification and cooking. In fact, some proponents see this as the main purpose of biofuels in developing countries, with energy needs for transportation being less of a priority, and more important for the medium and long-term development priorities. Pro-poor bioenergy products (such as fuel gels suited for cooking and heating) could meet important human needs such as cooking fuel, heating and lighting, for which the ultra-poor often have to rely on harder-to-find and 'dirtier' forms of biomass. These types of benefits could even outweigh the welfare increases that could come from the creation of employment opportunities – although they are not likely to offset the welfare losses that come from high food prices, since the poor and ultra-poor spend a much higher percentage of their income on food-based goods, compared to energy-based goods (von Braun 2007). In the following section, we explore more in-depth the potential of small-scale, bioenergy production that can benefit rural producers and also energy consumers.

7.3 Role of the small-scale producer

Small-scale production models, like those large-scale models, will generate employment and income opportunities in the growing and processing of feedstocks. The main difference, however, between these models is that production is aimed at satisfying a range of local demands rather than for export revenue. As a result, examples of small-scale production models found in the literature tend emphasize a wider set of welfare gains, especially in regards to gender equity and sustainability. In particular, case studies show the promotion of gender equity, local participation and community involvement, new sources of energy and electricity, and the development of enterprises related to co-products, such as soap and organic fertilizer cakes.

One small-scale technology that has substantial welfare impacts is using modern biofuels to meet rural energy needs. Biomass in general can be converted into energy forms to satisfy a range of rural applications including electrification, small machinery power, irrigation pumping, and food production equipment. In addition, bioenergy development for improved cookstoves, such as ethanol-based gelfuels, can provide significant time savings for women and children by eliminating the need to search and collect fuelwood. For example, the analysis of rural household transportation surveys from Burkina Faso, Uganda, and Zambia show that women and girls could save nearly 900 hours a year through the creation of centralized woodlots (Barwell 1996). In addition, the displacement of these traditional sources of energy has positive health impacts, reducing the level of indoor air pollution and related illness. In general, time savings gains for women through the provision of rural services has been linked to higher productivity and income generation, especially in micro enterprises (Verhagen *et al* 2004).

Small-scale production models can also minimize food security impacts by focusing on non-edible energy crops that can be grown on marginal lands. Biofuel production on marginal land may be particularly suited for poor farmers who do not have access to high quality lands (Binns, 2007). One crop well-suited for areas with low rainfall and low soil quality is jatropha. This crop is currently being piloted in a number of small-scale biodiesel development projects in Sub-Saharan Africa and India, and is the focus of a number of case studies reviewed below. Sweet sorghum is another crop that is ideal for drier areas that has similar properties to sugarcane in producing ethanol. In addition, declining demand for sweet sorghum as food as well as its co-production value as a livestock feedcake, lessen its threat to food security (ICRISAT 2007). A final promising variety similar to jatropha is pongamia. Although there are fewer case studies surrounding its production, this tree has been found to produce over twice as much oil per hectare in comparison to jatropha (Rajagopal and Zilberman 2007).

Despite these benefits, there are considerable barriers to small-scale bioenergy development in rural areas. A considerable level of effort would need to be put into the conscious design of production systems such that smallholders can directly benefit from the opportunities that biofuels may offer to the agricultural sector. At the local level, the technical know-how related to feedstocks and conversion, capital availability for start-up costs, lack of private sector capacity and support, market development, and secure land tenure are often cited as limitations to small-scale agricultural development. In addition, a common critique of jatropha-focused biofuel production is that of its rather low yield if it is grown on marginal lands without irrigation, and the disadvantage that entails in terms of cost competitiveness with fossil-based fuels. It must also be borne in mind that most industrial processes require economies of scale and high levels of extraction efficiency, if they are to remain economically competitive, which raises the question of whether small-scale jatropha can survive in the long-term without subsidies in the form of producer credits or protective tariffs on competing products.

Despite these challenges, a number of small-scale biofuel production projects have been launched across Africa and Asia that are providing examples and generating knowledge of the possibilities and constraints surrounding sector development. Small-scale demonstration projects have been conducted in a number of rural communities in Ghana, Mozambique, Zambia, and Mali to develop supply chains for jatropha-based biodiesel, including pilot plantations in order to raise awareness and build capacity (UNDESA 2007). These projects have drawn attention to the range of applications of the jatropha crop, including a fuel source for electricity and energy generation, soap making, lamp oil, and as a organic seedcake fertilizer. In India, a large-scale public-private partnership has been launched to promote the profitable participation of small-scale famers in the cultivation of sweet sorghum feedstocks for ethanol production. A private business partner—Rusni Distilleries—is providing farmers with sweet sorghum seeds and feedstock supply contracts to local processing facilities in order to create a village-based supply chain model (Binns 2007). Also in rural India, a women-led pongamia oil project used to run small generators for household electricity is being replicated by the state government in nearly 100 villages (ICRISAT 2007).

These small-scale projects have had significant impacts on rural welfare and livelihoods, especially for women. Specifically, a jatropha project in Tanzania resulted in the training of over 1,500 community members in management techniques, empowered 17 village women's groups in soap making and jatropha seed breeding, and also implemented plantations to supply local refineries (UNDESA 2007). Initial figures indicate that over US$10,250 in biodiesel sales benefited the local economy and over US$20,533 was generated from soap making. Another study in Tanzania reported on a multi-functional platform that power machinery for oil seed extraction, crop processing such as dehulling and milling, and battery charging and general household lighting(UNDESA 2007). In Mali, jatropha is providing the oil for a 300 kW power plant that will provide electricity for over 10,000 people for 15 years (UNDESA 2007). In the case of Rusni Distilleries in India, the operation of their refinery for sweet sorghum is creating 40,000 labor days (ICRISAT 2007).

Perhaps the most gender-specific welfare benefit that modern biofuels can bring is related to improved cookstove technology. Ethanol-based gelfuels are being piloted in Africa through a public-private partnership called the Millennium Gelfuel Initiative (MGI), to disseminate this clean burning cooking technology to rural households. As a result of the partnership, plants are operating in South Africa, Malawi, and Zimbabwe, and there are planned private sector gelfuel or ethanol production facilities in Benin, Ethiopia, Madagascar, Malawi, Mozambique, Senegal, and South Africa (Utria 2004). The production of gelfuels, however, is primarily dependent on local capacity to produce and distribute ethanol. In addition, the combustion of gelfuel in the household for cooking requires specific stoves, which can be too expensive for poor women. Ongoing research as a part of the MGI is seeking to lower the related costs of switching to this technology (Utria 2004).

8 SUMMARY AND CONCLUSIONS

In this report, we have addressed a large number of issues that surround the topic of biofuels and the global agricultural economy, and which underlying the intense and growing interests of policy makers and analysts who monitor this rapidly expanding sector. While we have not been able to address a completely exhaustive list of issues and fully discuss the complex interactions between biofuels, the environment and the wider ecosystem – our analysis has shown that the tension between the provisioning of food, feed, fiber and fuel from the agricultural landscape, in order to meet growing global needs, poses a fundamental tradeoff with the health and quality of the wider ecosystem and the diverse services that it provides. This was one of the conclusions of the Millennium Ecosystem Assessment, and is an inescapable conclusion of our analysis, as well. Even looking at the global agricultural economy within a partial equilibrium framework, we were still able to see the clear impacts that rapid growth in biofuels demand has on agricultural prices, the consumption levels of key staple commodities and the resulting impacts on food security status and nutrition. The land-saving impacts of improving agricultural production technologies through greater yield increases was also seen, even though we weren't able to directly model the impacts that intensification of production might have on the environment, in terms of increased input usage (including energy and fertilizer), degradation of soil quality, and depletion of other natural resources like water. We were able to show that the impacts on water usage might not be uniformly negative[7], if the land use patterns were to change in favor of less water-consumptive crops. This illustrates the importance of embedding explicit modeling of land use change, when carrying out an analysis of biofuels growth, as it allows us to see the implications on water use more clearly – as well as on the carbon balance, and the net changes that occur in the sequestration of carbon over time. Many of the current studies which carry out life cycle assessments of biofuels production processes try to incorporate this dimension.

We have not been able to explore the implications for second generation biofuels technology fully, in this study – mainly due to the fact that these technologies have not been applied on a scale that would allow us to formally simulate the implications that could result from widespread, industry-level adoption. Nonetheless, the policy considerations that are relevant to encouraging the research and development work that is necessary to make their

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[7] In terms of increased consumptive use of water and resource depletion.

widespread application possible, are still relevant, and should be explored further by national level policy makers to the extent that is possible. While some authors speculate that incentives to switch to second-generation technologies might be lessened if the current growth of the biofuel sector is heavily grounded around ethanol and biodiesel (Holt-Gimenez 2007), we believe that the economic benefits that would be realized under technology innovations in biofuels processing technologies (or their absence) would be the greatest motivator of private sector investment, and would be the main determinant of adoption at the industry level.

There remains uncertainty regarding the environmental benefits of biofuels for transportation (e.g. Searchinger *et al* 2008). The environmental footprint of oil seeds and ethanol feedstocks grown in developing countries has not been sufficiently evaluated (Ragajopal and Zilberman 2008), and requires further research to fully draw out the long-term implications for environmental sustainability. Certification measures imposed by importing countries, while seeking to ensure sustainable production, add an additional layer of bureaucracy that small producers will not likely be able to afford. Therefore, the coordination of world bodies in designing low-cost systems that poorer countries can participate in, will be important in creating a global biofuels economy that is self-sustaining, and un-biased in the way that it distributes benefits among the countries which participate in production and trade of biofuel products. Currently, there is much discussion over how the clean development mechanisms can be designed in a way that brings about exactly these kinds of benefits.

While much of the global commerce in bioenergy products will center on transportation uses, there is increasing recognition that non-transportation uses of biofuels are relevant and important for developing countries, and the poorer populations who lack access to clean and reliable sources of energy for domestic uses. The combustion of locally produced biofuels for electrification could provide an additional option toward meeting rural energy needs in many non-industrialized areas.

The scenario results of this paper clearly show a “food-versus-fuel” trade-off that any national plan for biofuel expansion would have to take into account. Continued rapid expansion of biofuel production, whether mandated through blending requirements or planned according to self-sufficiency goals will, indeed, have significant impacts on the food sector, as we have shown within our scenarios. These impacts include substantial price increases for food commodities, reductions in the availability of calories, and increased levels of malnourishment at the regional level, particularly in Sub-Saharan Africa. Rapid biofuels expansion also has significant impacts on international trade, particularly for the global trade balance of maize. The more drastic scenario further exacerbates these effects, imposing an additional challenge for food security of the developing world. Groups vulnerable to food insecurity in countries that lack food self-sufficiency or rely on exports of agricultural commodity for foreign exchange are expected to face a worsened food situation, under biofuel expansion. Intensified biofuel production would likely increase the number of malnourished persons, even in developed economies.

Our results indicate that expansion of biofuels would increase the stress on regional water supplies only marginally. However, a significant acceleration of biofuels expansion in areas requiring additional irrigation water from already depleted aquifers could cause much greater water scarcity problems (NRC 2007). In such cases, appropriate policies need to be identified to enhance the benefits and reduce the adverse environmental effects of biofuels expansion. These issues, along with the potential socioeconomic impacts, demand the full attention of policymakers, as they contemplate and balance the pros and cons of rapid adoption of biofuel technologies. Underlying this are complex linkages that give rise to tradeoffs between environmental sustainability, overall economic gains and the welfare losses for the poorest persons who are most vulnerable to global economic and environmental change.

Overall, we agree with the emerging consensus that national biofuel strategies should be context specific, while seeking to draw from the lessons and experiences derived from the Brazilian or U.S. production models where appropriate. In addition, national biofuels strategies should take into account not only the bio-physical potential of biofuel production, but also the socio-economic conditions—especially patterns of land ownership—that are present. By looking at the socio-economic and environmental linkages underlying bioenergy and agricultural systems in a more complete way, we can increase the likelihood of deriving better-suited and higher value-yielding types of biofuels production systems that can best meet the goals of environmental sustainability, economic development and human well-being improvement. These are the kind of objectives that underlie the national energy and food security policies of many of the world's countries that are now looking closely at the adoption of large-scale biofuels production, and are trying to evaluate the inevitable tradeoffs between trying to meet the growing demand for food, feed, fiber and fuel, and the health and sustainability of the underlying ecosystems that support the agricultural systems we depend upon so heavily.

9 REFERENCES

Ahmed, A.U., Hill, R. V., Smith, L. C., Wiesmann, D.M., Frankenberger, T., Gulati, K., Quabili, W., Yohannes, Y. 2007. The world's most deprived: characteristics and causes of extreme poverty and hunger. 2020 Discussion Paper 43, International Food Policy Research Institute: Washington, D.C.

Barwell, I. 1996. Transport and the village: findings from African village-level travel and transport surveys and related studies. Discussion Paper No. 334, Africa Region Series. The World Bank: Washington, D.C.

Berndes, G., M. Hoogwijk, and R. van den Broek. 2003. "The contribution of biomass in the future global energy supply: a review of 17 studies," Biomass and Bioenergy (25) 1 – 28.

Binns, P. 2007. Sowing the seeds of prosperity: developing bioenergy technology to alleviate smallholder farmer poverty. Proposal to the Bill and Melinda Gates Foundation, Unpublished.

de Gorter, H. and D.R. Just. 2007. The economics of US ethanol import tariffs with a consumption mandate and tax credit. 2007. Working paper WP 2007-21, Department of Applied Economics and Management, Cornell University, Ithaca, NY.

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, C. Courbois. 1999. Livestock to 2020: The Next Food Revolution. Food, Agriculture, and Environment Discussion Paper #28, International Food Policy Research Institute: Washington, D.C.

Eickhout, B., Van den Born, G.J., Notenboom, J., Van Oorschot, M., Ros, J.P.M., Van Vuuren, D.P., Westhoek, H.J. Local and global consequences of the EU renewable directive for biofuels. Testing the sustainability criteria, Report no. 500143001

Farrell, A. E., R. J. Plevin, B. T. Turner, A. D. Jones, M. O'Hare, and D. M. Kammen."Ethanol Can Contribute to Energy and Environmental Goals," Science 311, 5760 (2006):506-508.

Ferrentino, C. 2007. Potentials for Bioenergy to Mitigate Climate Change: A Summary of recent findings from the IPCC and the IEA, Global Bioenergy Partnership, GBEP Secretariat.

Food and Agriculture Organization (FAO). 2005. Bioenergy and the Millennium Development Goals. Forestry Department, FAO, Rome, Italy. Available at http://www.fao.org/docrep/008/j5135e/j5135e01.htm (accessed on December 10, 2007).

Fulton, L., T. Howes, and J. Hardy. Biofuels for Transport: An International Perspective, Paris: International Energy Agency, 2004.

Gonsalves, J. 2006. An Assessment of the Biofuels Industry in India. United Nations Conference on Trade and Development: Geneva.

Gundimeda, H. 2004. How 'Sustainable' Is the 'Sustainable Development Objective' of CDM in Developing Countries like India? Forest Policy and Economics 6 (3/4): 329-343.

Hoogwijk, M., A. Faaij, B.Eickhout, B. de Vries, and W. Turkenburg. 2005. "Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios," Biomass and Bioenergy (29) 225–257.

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). 2007. Pro-poor biofuels outlook for Asia and Africa. Working Paper, March 4.

International Energy Agency (IEA). 2006. World Energy Outlook. Paris.

International Energy Agency (IEA). 2007. IEA Energy Technology Essentials: Biofuel Production. IEA Energy Technology Essentials.

Janulis, P. 2004. Reduction of Energy Consumption in Biodiesel Fuel Life Cycle. Renewable Energy 29 (6): 861-871.

Kammen, D. M. 2006. Bioenergy in developing countries: experiences and prospects, in Bioenergy and Agriculture: Promises and Challenges. 2020 Focus 14. International Food Policy Research Institute: Washington, DC.

Karekezi, S., and W. Kithyoma. 2006. Bioenergy and the Poor, in Bioenergy and Agriculture: Promises and Challenges. 2020 Focus 14. International Food Policy Research Institute: Washington, DC.

Kojima, M., D. Mitchell, and W. Ward. 2007. Considering Trade Policies for Liquid Biofuels. Energy Sector Management Assistance Program (ESPM), World Bank.

Licht, F.O. 2005. World Ethanol and Biofuels Report. Vol 3. Tunbridge Wells, United Kingdom

Liska, A., H. Yang, D. Walters, V. Bremer, G. Erickson, T. Klopfenstein, R. Koelsch, D. Kenney, P. Tracy, and K.G. Cassman. 2008. "Life-cycle assessment of greenhouse gas emissions from biofuel systems: BESS model," presentation given at Stanford University, 12 March 2008.

Macedo, I. C., M. R. L. V. Leal, and J. E. A. R. da Silva. 2004. Assessment of Greenhouse Gas Emissions in the Production and Use of Fuel Ethanol in Brazil. Report to the Government of the State of São Paulo.

MEA, 2005. Millennium Ecosystem Assessment. Ecosystems and human well-being: Scenarios. Findings of the Scenarios Working Group. Island Press, Washington D.C.

Jull, C., Carmona-Redondo, P., Mosoti, V., Vapnek, J. "Recent Trends in the Law and Policy of Bioenergy Production, Promotion, and Use, FAO Legal Papers Online #68 (September 2007), available at www.fao.org/Legal

Nabuurs, G.J., O. Masera, K. Andrasko, P. Benitez-Ponce, R. Boer, M. Dutschke, E. Elsiddig, J. Ford-Robertson, P. Frumhoff, T. Karjalainen, O. Krankina, W.A. Kurz, M. Matsumoto, W. Oyhantcabal, N.H. Ravindranath, M.J. Sanz Sanchez, X. Zhang, 2007: Forestry. In Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [B. Metz, O.R. Davidson, P.R. Bosch, R. Dave, L.A. Meyer (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nguyen, T., S. H. Gheewala, and S. Garivait. 2007. Full Chain Energy Analysis of Fuel Ethanol from Cassava in Thailand. Environmental Science and Technology 41 (11): 4135-4142.

National Research Council (NRC). 2007. Water Implications of Biofuels Production in the United States, Committee on Water Implications of Biofuels Production in the United States, Water Science and Technology Board, Division on Earth and Life Studies, THE NATIONAL ACADEMIES PRESS: Washington, D.C.

Organisation for Economic Co-Operation and Development (OECD). 2006. Agricultural Market Impacts of Future Growth in the Production of Biofuels. OECD Papers 6 (1): 1-57.

Organisation for Economic Co-Operation and Development and the Food and Agricultural Organization (OECD/FAO). 2007. OECD-FAO Agricultural Outlook 2007-2016. Paris.

Pimentel, D., and T. Patzek. 2005. Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower. Natural Resources Research 14 (1): 65-76.

Plieniger, T. and O. Bens. 2008. How the emergence of biofuels challenges environmental conservation (comment). Environmental Conservation 34(4): 273-275.

Rajagopal, D. 2007. Rethinking Current Strategies for Biofuel Production in India. Presented at the International Conference on Linkages in Water and Energy in Developing Countries Organized by IWMI and FAO, ICRISAT, Hyderabad, India, January 29-30.

Rajagopal, D. and D. Zilberman. 2007. Review of Environmental, Economic and Policy Aspects of Biofuels, Policy Research Working Paper No. 4341, The World Bank: Washington, D.C.

Rosegrant, M. W., M. Paisner, S. Meijer, and J. Witcover. 2001. Global Food Projections to 2020: Emerging Trends and Alternative Futures. Washington D.C., International Food Policy Research Institute.

Rosegrant, M.W., S.A. Cline, W.B. Li, T.B. Sulser, and R. Valmonte-Santos. 2005. Looking Ahead: Long-Term Prospects for Africa's Agricultural Development and Food Security. 2020 Discussion Paper No. 42. Washington, DC.: International Food Policy Research Institute.

Schmidhuber, J. 2006. Impact of an increased biomass use on agricultural markets, prices and food security: a longer-term perspective. Paper prepared for the International Symposium of Notre Europe, Paris, November 27-29.

Smeets, E., A. Faaij, I. Lewandowski. 2004. A quickscan of global bio-energy potentials to 2050 – an analysis of the regional availability of biomass resources for export in relation to underlying factors, Report prepared for NOVEM and Essent, Copernicus Institute – Utrecht University, NWS-E-2004-109, March. Pp. 67 + Appendices.

Smeets, E., M. Junginger, A. Faaij, A. Walter, P. Dolzan, and W. Turkenburg. 2008. The sustainability of Brazilian ethanol—An assessment of the possibilities of certified production. Biomass and Bioenergy. doi: 10.1016/j.biombioe.2008.005.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, T. Yu. "Use of U.S. Croplands for Biofuels Increase Greenhouse Gases Through Emissions from Land-Use Change," Science 319, 1238 (2008).

Sheehan, J, V. Camobreco, J. Duffield, M. Graboski, and H. Shapouri. 2000. An Overview of Biodiesel and Petroleum Diesel Life Cycles. Report No. NREL/TP-580-24772, National Renewable Energy Laboratory, Golden, Colorado.

Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales and C. De Haan. 2006. Livestock's Long Shadow: Environmental Issues and Options. Food and Agriculture Organization, Rome, Italy, 390 pages.

Tilman, D., J. Hill, and C. Lehman. 2006. Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass. Science 314 (5805): 1598-1600.

UN (United Nations). 1995. Copenhagen Declaration on Social development. World Summit for Social Development. United Nations, New York.

United Nations Environmental Programme (UNEP). 2007. Global Environmental Outlook Four (GEO4): Environment for Development. Progress Press Ltd: Malta.

United Nations Department of Social Affairs (UNDESA). 2007. Small-Scale Production and Use of Liquid Biofuels in Sub-Saharan Africa: Perspectives for Sustainable Development, Energy and Transport Branch Background Paper #2, Division for Sustainable Development: New York.

US Environmental Protection Agency (USEPA) 2006. Global Mitigation of Non-CO2 Greenhouse Gases. Office of Atmospheric Programs, Washington DC, USA

Utria, B. 2004. Ethanol and gelfuel: clean renewable cooking fuels for poverty alleviation in Africa. Energy for Sustainable Development. Vol VIII (3): 107.

van Dam, J., M. Junginger, A. Faaij, I. Jürgens, G. Best, and U. Fritsche. Overview of recent developments in sustainable biomass certification. Accepted for the IEA Bioenergy Task 40 special issue of Biomass and Bioenergy, forthcoming.

Villavicencio Rivera, M. 2008. Bioenergy and Food Security. Presentation given at the 2nd Bioenergy and Food Security (BEFS) Technical Consultation, 5-6 February, Food and Agriculture Organization, Rome.

Verhagen, J., A. J. James, C. van Wijk, R. Nanavatty, M. Parikh, and M. Bhatt. 2004. Linking water supply and poverty alleviation: the impact of women's productive use of water and time on household economy and gender relations in Banaskantha District, Gujarat, India. IRC International Water Center: Delft.

von Brandt, A. 2008. The BEFS approach. Presentation given at the 2nd Bioenergy and Food Security (BEFS) Technical Consultation, 5-6 February, Food and Agriculture Organization, Rome.

von Braun, J. 2007. When Food Makes Fuel: Promises and challenges of biofuels for developing countries and for food security for the poor. paper presented at the Crawford Fund Conference ‘Biofuels, Energy and Agriculture: powering towards world food security’, Canberra, Australia.

Wang, M., C. Saricks, and D. Santini. 1999. Effects of fuel ethanol use on fuel-cycle energy and greenhouse gas emissions. Center for Transportation Research, Energy Systems Division, Argonne National Laboratory: Argonne, IL.

Woods, J. 2006. Science and technology options for harnessing bioenergy’s potential, in Bioenergy and Agriculture: Promises and Challenges. 2020 Focus 14. International Food Policy Research Institute: Washington, DC.

Woods, J., P. Helm, A. Hofer, D. Rutz, R. Jansen. 2007. COMPETE – Competence Platform on Energy Crop and Agroforestry Sytems – Africa, 15th European Biomass Conference & Exhibition, 7-11 May 2007, Berlin, Germany.

Worldwatch Institute, “Biofuels for Transportation: Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century,” prepared for the German Ministry of Food, Agriculture and Consumer Protection (BMELV) in coordination with the German Agency for Technical Cooperation (GTZ) and the German Agency of Renewable Resources (FNR) (Washington, DC: 2006).

Zeller, M. and M. Grass. 2007. Pro-poor development in low income countries: Food, agriculture, trade, and environment, Paper prepared for the 106th seminar of the EAAE, 25-27 October, Montpellier, France.