Topic Paper #10

Are We Going to be Able to Meet World Food and Biofuel Demands in 2050? (Long Term Food and Biofuels Projections)

IOWA STATE UNIVERSITY

Are we going to be able to meet world food and biofuel demands in 2050?

Swatilekha Bhattacharjee
and
John Miranowski

Department of Economics
Iowa State University
Ames, IA

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1. Executive Summary

From available literature we have reviewed, our intuitive description and analysis we know what factors and how far these factors may affect the demand and supply for agricultural crops in 2050. One major prediction of every study has been that supply of agricultural crops can be increased beyond the predicted level with the advancement and widespread adoption of different agricultural technology in spite of increased demand of agricultural crops due to increased use of biofuels in 2050. According to most of the studies that we have reviewed, total agricultural crop production will exceed total agricultural crop demand in 2050. But the problem of malnutrition and risk of hunger may prevail in some regions of the world.

On the demand side of agricultural crops, all the factors - income, population and biofuel demand positively affect the demand for agricultural crops (section 2 – Review of literature and section 3 - Intuitive model underlying projections). Most of the studies we have reviewed have similar projections on the two important factors - income and population. All the major projection studies[1] project that population will be nearly 9.1 billion in 2050 and world incomes will also increase. Studies also suggest that the gain in income will be more in the developing countries, but per capita income growth in sub Saharan Africa will be less than other developing countries. Increases in incomes in the developed countries will have less impact on food consumption than the developing countries. But significant increases in incomes in developing countries along with rapid urbanization will have a substantial effect on the amount and patterns of food consumption in these countries. Urbanized population will consume more processed foods and livestock products than basic staples (Rosegrant et al., 2001). Also due to urbanization the demand for meat will increase and thus will increase the demand for feed crops.

All the studies we have reviewed suggest that biofuel use will increase significantly in 2050 due to environmental concerns and rising oil prices. Mandates and other biofuel incentives further increase the demand for biofuels. For instance, Chen et al (2010) projects that biofuel production will increase to 1.3 trillion liters in 2022 under 'Biofuel Mandate with Volumetric Tax Credit' as compared to only 28 billion liters under 'Business As Usual' (i.e. without any policy incentives). The increased biofuel demand will further increase the demand for agricultural crops. The IIASA (2009) studies show that food consumption in the developed countries will be much less responsive to biofuel demand than the developing countries. Cereal is a major agricultural crop that is used for both food and feed uses and also as biofuel feedstock. Fischer (2009) shows in his baseline scenario (with no biofuel demand but only increase in population and income) that world cereal production will exceed the world cereal consumption in 2050. Inclusion of

[1] Kruse (2006), who projects higher population levels under different scenarios, is the exception 2050.

biofuel demand in Fischer's (2009) baseline scenario will change cereal use in 2050 - cereals used for biofuels will increase while those used for direct food consumption will fall. Biofuel inclusion will also increase cereal prices. But Fischer (2009) concluded that even in case of inclusion of the biofuel scenario, the aggregate production of cereals and also any other agricultural food crops will exceed aggregate consumption. Following Kruse's (2006) projections, we find that consumption increases in all scenarios, yet production exceeds consumption in all of them (both including and excluding biofuel use). Global availability of agricultural crops in 2050 will be significantly driven by agricultural supply side factors - yield, arable land and agricultural technology (section 2 - Review of literature and section 3 - Intuitive model underlying projections).

Yield increases have a major positive impact on agricultural crop supply over time. Some studies cited that yields and yield growth will increase, while others assume that yields will increase but at a decreasing rate over time (section 2 - Review of literature and section 3 - Intuitive model underlying projections). But all studies suggest that yield growth will play a significant role in increasing world production. Bruinsma (2009) assumes that though yield will increase at a decreasing rate, in 2050 the major production increase will be the result of intensification rather than land expansion. In all the four scenarios discussed by Kruse (2006) significant increases in production generally comes more from yield improvement than land expansion. Fischer et al (2009) assume that yield growth will be 0.8% annually, whereas, Bruinsma (2009) assumes it to be 0.7% per year. Tweeten and Thompson (2008) project that yield will grow at 43 kg/ha, but Rosegrant et al (2008) projects a lower annual yield increase. Their yield growth projection is low as they had assumed the level of agricultural technology to be fixed. Both Tweeten and Thompson's (2008) and Rosegrant et al's (2008) projections show that due to lower yield growth, production will not be able to meet demand for agricultural crops because demand will grow faster than production. But they have also projected that if yield is improved through investments in R&D, agricultural crops production will increase. According to Fischer et al (2009) the combined public sector and private investments in agricultural R&D will be double in developed countries than in developing countries. They have concluded that the spillover from R&D in developed countries are also important for developing countries. They have also indicated that there are worrying signs of reduced public investments in R&D. However there is a significant increase in private sector investment which explains for agricultural technology improvement. Considering all the studies we believe that agricultural technology will improve and production will increase.

All studies show that land expansion will take place in developing countries rather than developed countries. Almost all land expansion in developing countries will take place in sub-Saharan Africa and Latin America with some in East Asia. Harvested area is going to increase more than cultivated area due to intensification. Both Bruinsma (2009) and Kruse (2006) assume a significant increase in the amount of cultivated land. Though the expansion of arable land may play a major role in increasing production, most studies report that yield growth has more significant impact on production projections. One of the reasons for the continuing malnutrition in some regions of the world, especially in sub Saharan Africa will be lack of substantial yield growth due to less biotechnology adoption.

Production is significantly and positively affected by advancement and adoption of agricultural technology. Kruse's (2006) analysis show that in spite of having low yield growth, production under TG Scenario exceeds that of AM Scenario because TG Scenario is characterized by adoption and application of advanced technology. All of the studies including that of Msangi and Rosegrant assume that adoption and application of yield improving technology will further increase production beyond their projected levels and will help keep food prices low. With the adoption of improved agricultural technology, increased use of biofuels will not pose a threat to the availability of food and feed crops. From equation (1) of our model (section 3 – 'Intuitive model underlying projections') we conclude that yield growth and agricultural technology compared to amount of cultivated land will have more impact and will be the major drivers of agricultural crop production.

Even though in most of the projections we have noticed that world agricultural crop production exceeds world agricultural consumption, we also have to accept that some of the studies have projected the prevalence of malnutrition and undernourishment in 2050. Bruinsma (2009) have argued that unless yields are further improved by investment in R&D, number of malnourished people will increase. In both Fischer et al's (2009) and Msangi &Rosegrant's (2009) projections we find that undernourishment and malnutrition will continue to prevail in Sub Saharan African region. With increasing population, the per capita GDP growth in Africa will be less (Msangi & Rosegrant (2009)). Even though land expansion will be substantial here, lack of yield improvements will result in less than sufficient production growth and thus, risk of hunger. Fischer (2009) also projected that people at risk of hunger will increase in Africa and increased biofuel use will further aggravate the problem. In his analysis under the biofuel targets with extensive 1st generation biofuel use, problem of undernourishment in developing countries is projected to increase. But he projected that with the accelerated use of 2nd generation biofuels, prevalence of undernourishment in these countries fall. All these studies project that Asia will have the largest decline in malnourishment.

From available literature we have reviewed, our intuitive description and analysis . we find that, total agricultural crops production exceeds total agricultural crops consumption, even with the increased use of biofuels in 2050..But more agricultural crops may be used for producing biofuels rather than for food and feed use. This may result in unsatisfied nutritional demand. This problem may be acute in some regions of the developing countries, especially in the sub Saharan African region due to lower per capita income growth, low yield improvements and accelerated biofuel use. Thus, the problem of malnutrition and risk of hunger may prevail in some regions of the world . If more agricultural technology is adopted, it will lead to yield improvements, increase crop production and reduce the number of people at risk of hunger.

2. Introduction

Continuous population growth and economic changes are causing a surge in global food crisis with accelerating food prices. This crisis is further aggravated by increasing demand of biofuel produced from food items such as sugarcane, corn, soybeans, crop residue. Use of biofuel is believed to be able to mitigate climate changes and ensure energy security. Hence biofuel production is being promoted by governments around the world through various new policies, resulting in an increasing demand of certain food items. Thus, world agriculture in the 21st century faces a unique challenge – to simultaneously meet the huge demand of food and biofuel requirement in the long run. This problem is the main focus of this paper.

While the existence of biofuel industry dates back more than 3 decades, biofuel policy has expanded rapidly in recent years due to growing concern regarding global climate changes and energy security, as well as rising energy prices. For example, the European Union has set a biofuel target of 10% of transportation fuel by 2020 (from 2% in 2008). Under this target, the EU will require around 59 million tons of cereals (19% of total domestic cereals use) by 2020 (European Commission 2007a, 2007b). The US Energy Independence and Security Act of 2007 set "a mandatory Renewable Fuel Standard (RFS) requiring fuel producers to use at least 36 billion gallons of biofuel in 2022" (of which a maximum 15 billion gallons is from ethanol and 1 billion from biodiesel) (Von Braun, 2007). This would require 1.6 billion tons of biomass harvested per year and would require harvesting 80% of all biomass in the U.S., including all agricultural crops, grasses, and forests (Von Braun, 2007). As a consequence of such policy expansions, biomass demand for bio-energy has been the largest source of additional demand for agricultural crops in recent years. Production of biofuels, particularly ethanol and biodiesel for use in the transport sector, has tripled since 2000 and is projected to double again within the next decade (HLEF[2], 2009). The International Institute of Applied Systems Analysis estimates that biofuels' share of road transport fuel will reach 8% by 2050 (compared to 1.5% in 2008), depending on policies and technology.

Along with the growth of biofuel industry over the last decade, there has been a sudden and substantial increase in world food prices mainly due to rising global food demand, below average harvests in some countries and low levels of world food stocks. This rapid increase in prices of key food commodities such as maize, wheat, rice, soybeans - among others - has caused an increase in prices of energy products, clearly showing a strong correlation between energy and agricultural markets (Schmidhuber, 2006).

While food price and energy price are increasing at a high rate world population is also growing significantly. It is expected to grow by over a third, or 2.3 billion people, between 2009 and 2050 (HLEF, 2009). This growth along with a growing trend of urbanization results in increasing market demand for

[2] HLEF - High Level Expert Forum

food. Urbanization is expected to continue at an increasing pace with 70% of the world population projected to be in urban areas by 2050 (up from 49% in 2009), rural population is projected to peak within next decade and decline thereafter (HLEF, 2009). Based on the projections of HLEF, feeding a world population of 9.1 billion people in 2050 would require a 70% increase in world food production between 2005/07 and 2050. It is also important to produce food that ensures nutrition security. However, according to a study by FAO[3] (2009), actual agricultural production is not expected to increase enough to meet the food and nutritional demand in 2050. Main reasons include a shift in demand towards biofuels. This will lead to price rise. As a consequence the number of food insecure will increase and access to food will decrease resulting in a significantly malnourished population. IFPRI[4] (2008) estimates that the number of malnourished preschool children in sub-Sahara Africa and South Asia could increase by 5 million under a scenario of huge biofuel expansion up to 2050.

Thus, the growing world population and increasing biofuel consumption are increasing agricultural commodity demand for both food and biofuels. This has a potential to cause food and feed shortages. In this paper we have evaluated the economic literature on agricultural crop production and demand projected out to 2050. We have set an intuitive model to identify and analyze various factors driving the demand for and supply of agricultural crops. Based on an intuitive model and the literature projections, we have discussed whether the long run supply will be able to meet the growing agricultural crop demand in the presence of increased demand for biofuels.

3. Review of literature

The food versus fuel controversy has triggered numerous studies by various economists and scientists. Hayes et al. (2009) demonstrated how the biofuel sector expands as energy price increases. The prices of agricultural commodities increase in response to the increased derived demand for corn grain as a biofuel feedstock. Higher market prices for corn cause supply-side adjustments for substitute crops and livestock. The derived demand for corn as an ethanol feedstock is in part driven by biofuel incentives such as mandates and tax credits. They used the FAPRI[5] model, a broad partial equilibrium model of the world agricultural economy, as a baseline and then changed energy prices and energy policies in a series of scenarios. The link between the energy price and agricultural prices was observed to be a key driver of both biofuel price and the prices of agricultural commodities. They showed that under High Energy Price Scenario, with a crude oil price of $105/barrel, total ethanol production from corn increases by 50%

[3] FAO – Food and Agriculture Organization

[4] IFPRI – International Food Policy and Research Institute

[5] FAPRI - Food and Agricultural Policy Research Institute

relative to the baseline (Under baseline, total ethanol production is 32.9 billion gallons and the ethanol price at wholesale rate is at $1.55/gallon). The ethanol price increases by almost 18% and the prices of corn and soybean increase by almost 20% and 9% respectively relative to the baseline. Under the High Energy Price with Removal of Biofuel Tax Credits scenario, the ethanol price declines by 11% and the corn price falls by 16% relative to the baseline scenario. Corn used for exports and for feed increases. These results show the link between energy price, biofuel policies and agricultural commodity prices.

Msangi and Rosegrant (2009) explored various drivers of changes in the food system, i.e. socioeconomic, environmental based, policy based and tried to analyze various entry points for policies to meet the growing food demand. According to them, the policy based drivers like Research and Developments, supports and biofuel mandates have had a strong impact on the food system along with the other key drivers. In order to examine the impact of biofuel production growth on country level and domestic agricultural markets, Msangi and Rosegrant used the IMPACT[6] (International Model for Policy Analysis of Agricultural Commodities and Trade) model developed by the IFPRI to project global food supply, food demand and food security to year 2020 and beyond (Rosegrant et al., 2001).

Fischer (2009) quantified the extent to which climate change and biofuel production expansion may affect the availability and prices of food, agriculture and other resources. Comparing various biofuel scenarios like World Energy Outlook (WEO) and Third Assessment Report (TAR) with a baseline scenario FAO-REF-00 (it assumes a world without any agricultural crops used for biofuels), Fischer showed that cereal for food and feed use will gradually fall under various biofuel scenarios compared to the baseline scenario (FAO-REF-00 Scenario) in 2050, while cereal for biofuel production will gradually increase.

Alexandratos (2009) argued that due to high energy prices and concerns about climate change, energy from biomass as an alternative energy source will gain more importance. Biomass energy will compete for land and water resources with food production. Thus, high prices of agricultural crops due to the tight situation in the global food supply–demand balance resulting may prevail for a long time. If factors increasing supply (more land and irrigation, higher yields) do not develop with the increasing demand, then biofuel feedstock prices (in relation to the price of petroleum) may increase so much that it will become uneconomical to produce alternative energy from biomass without any government support

[6] 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

(Schmidhuber 2006; Tyner and Taheripour 2007; FAO 2008b). Alexandratos refuted the claim that strong economic growth in the emerging economies, particularly in China and India, as a major cause of the rise in food prices (e.g., IMF 2008a: 60). He showed that both the combined average annual increase of growth rates in consumption and absolute increase in consumption of China and India were lower in the years 2002–08 when price increased, than in the previous period 1995–2001.

Khanna et al. (2010) used the Biofuel and Environmental Policy Analysis Model (BEPAM) to examine the effects of Biomass Crop Assistance Program (BCAP), volumetric tax credits, Renewable Fuel Standard (RFS) on the production and consumption of biofuels, food and fuel prices and GHG emissions. They argued that the BCAP and volumetric tax credits together lead to 26% more biofuel production than the minimum needed by the RFS. The BCAP and the volumetric tax credit also result in a transition towards cellulosic biofuels away from corn ethanol. This will reduce the demand for corn ethanol, which will increase the corn availability in food/feed markets, lower crop prices and benefit agricultural consumers. But they argued that these policies are costly and would impose a social welfare cost of $122B during the 2007-2022 periods.

Chen et al. (2010) used BEPAM to estimate the effects of various biofuel policies on land allocation between food and energy crops, on food and energy prices and on the mix of biofuel production from corn and various cellulosic feedstocks which are economically viable over the 2007-2022 period and compare them to the cases under Business As Usual (BAU) Scenario. Under BAU, they found that total crop acreage decreases by 0.3% over the period 2007 – 2022 with corresponding increases in pasture land But biofuel mandate would expand cropland by 1%, increase corn price by 26% and reduce the price of gasoline by 8% in 2022 relative to BAU.

Sexton and Zilberman (2008) discussed the benefits, negative impacts and costs of biofuel use. They argued that on its positive side biofuel policy helps to ‘‘increase farm income, spur rural development, improve energy security and terms of trade, and mitigate climate change through reduction in GHG emissions’’. But on its negative side, biofuels can reduce food security and increase food prices, which puts additional burden on the poor, especially the non-farming ones. Biofuels may actually increase global warming, lead to biodiversity loss, reduce water availability, worsen water quality and increase GHG emissions (due to the loss of carbon sequestration on forest and grasslands that are converted to energy crop production). They also argued that appropriate policies, adoption of biotechnology, etc. can help to overcome the drawbacks of biofuels and maintain food security. According to them, policies should be such that they prescribe ways about how to improve the GHG emission reduction from biofuels, reduce adverse impacts of biofuel expansion on food markets, and develop a biofuel industry.

Sexton and Zilberman (2010) tried to look at the impact of biotechnology adoption by estimating the yield improvement of genetically engineered (GE) crops. These crops significantly increase farm yields when the demand for farm output is increasing and the traditional methods of yield growth have all been exhausted. The GE-seed effect on yields is greatest for crops with IR traits, i.e. maize and cotton. They found that GM cotton, rapeseed and soybean showed positive yield growths over the period 1990-2008 which were statistically significant. They showed that if biofuel demand were absent in 2008, world prices for the major crops would have been significantly lower. If the yield gains of global biotechnology production were not there, 2008 cereal prices would have been higher.

Bruinsma (2009) did not consider the effect of increasing demand for bio fuels but rather presented a consistent picture of the food and agricultural situation in 2030 and 2050. He argued that growth in agricultural production will continue to slow down from 148% increment over the period 1961/63-2005/07 to 70% over the period 2005/07-2050. Agricultural production would need to increase by 70% by 2050 to cope with a 40% increase in world population and increase the average food consumption to 3130 kcal per person per day by 2050 from around 2820 kcal in 2005. This is equivalent to an additional billion tonnes of cereals and 200 million tonnes of meat produced annually by 2050 compared to 2005/07 average production. Per capita meat consumption will increase from 37kg in 2008 to 52 kg in 2050 necessitating more crop production to meet feed demand

Fischer et al (2009) focused on the yield prospects of wheat, rice and maize (since these cereals dominate human diet) to see whether continued yield growth in these crops will be able to meet future global demand for food, feed and fuel. Using a long term linear trend, Fischer et al project a 0.8% per year growth in global cereal yield till 2050. They also recognized the importance of Total Factor Productivity (TFP) which will grow over time and will help to reduce the yield gaps. They further argued that yield gains can be achieved by technology only if it is complemented by changes in policies and institutions. Research and Development (R&D) will play a major role in improving the yield.

Kruse (2006) used the IHS Global Insight (IHS-GI) to make a global forecast of food demand in 2050. He considers 4 different plausible scenarios of the world by assuming alternative methods of sustaining the ecosystem services – Global Orchestration (GO), Order from Strength (OS), Adapting Mosaic (AM) and Techno Garden (TG). Under all scenarios, we see increase in food consumption. He showed that global cereal production will increase under all four scenarios compared to the baseline values in 1997. Kruse showed that overall crop demand will increase by 84% over the period 2000 to 2050. Biofuels will cause an increase of 86% in crop production. He further projected that if there is a linear trend, on average the crop yield will increase 60% from 2000-2050.

Summary of the OFID[7] Study prepared by the IIASA[8] (2009), 'Biofuels and Food Security – Implications of an Accelerated Biofuels Production', provided a comprehensive evaluation of the impacts and implications of biofuels developments on the society, environment and economy via its effects on transport fuel security, climate change mitigation, agricultural prices, food security, land use change and sustainable agricultural development. It used the FAO/IIASA Agro-ecological Zone model and the IIASA global food system model. Under different biofuel scenarios, it compared the crop prices increase to the baseline scenario where there is no demand for biofuel. The largest price increase across different biofuel scenarios is observed for coarse grains. The biofuels development scenarios indicate that the agricultural prices and the share of biofuels in total transport fuels are significantly linked. For example when the biofuels share is of 4%, the cereal price index increases by 20% and it increases by 40% when there is a 7% biofuels target.

For comparative purposes, a concise summary from the studies discussed above is provided in Table A in the Appendix. The table attempts to summarize the key assumptions underlying these studies and to highlight how the studies differ and the implications of these differences.

4. Intuitive model underlying projections

In this section, we provide an intuitive explanation for how supply and demand side factors will affect and bring a change in the agricultural crops production by 2050.

There are several factors that affect the overall agricultural crops production. On supply side, we focus on effects from yields, cultivated lands and agricultural technology. The development and market for agricultural technology is beyond the scope of this model and therefore, it is assumed to be exogenously given. Since climate change is difficult to quantify[9], we do not include climate change in our intuitive model.

Based on the review of literature in section 2- 'Review of literature' yield increase was a major factor contributing towards increased production in most studies. Studies with low or decreasing yield prediction also have lower growth in production. If yield increases, production will increase for a given level of cultivated land. Alternatively, an increase in yield could reach an agricultural production target with less land. At a given yield or state, total production also increases with an increase in the level of

[7] OFID - OPEC Fund for International Development

[8] IIASA - International Institute for Applied Systems Analysis

[9] There is no single instrument to measure climate change. Various instruments are used to measure climate change like temperature, precipitation, biomass, sea level, solar activity, chemical composition of air, etc. So, it's very difficult to quantify climate change.

cultivated land. With enough land and yield increases, energy crops could potentially be produced without sacrificing cropland for food and feed. Agricultural technology also plays a major role in increasing production. It increases agricultural production through increased pest and insect resistance, drought tolerance, improved nutritional quality of crops and a reduction in negative environmental impacts. Assuming a log-linear functional form, agricultural crop supply can be written as follows:

$$\ln Q^S = \alpha_0 + \alpha_1 \ln P + \alpha_2 \ln y + \alpha_3 \ln H + \alpha_4 \ln T + \varepsilon \qquad (1)$$

Where Q^S equals total agricultural crop supply, P denotes price of agricultural crops, y denotes yield, H denotes total cultivated land, T represents technology. The error term may capture certain omitted variables like impacts of climate change and supply side agricultural policies. We assume that the error term is not correlated with any other explanatory variables. Yield, cultivated land and technology are assumed to be exogenous. $\alpha_1, \alpha_2, \alpha_3$ and α_4 are assumed to be positive. Equation (1) assumes a log-linear functional form with parameters $\alpha_1, \alpha_2, \alpha_3$ and α_4 interpreted as the percentage change in agricultural crop supply from a percentage increase in the corresponding value (e.g. α_1 is the percentage change in agricultural crop supply from a one percent increase in agricultural crops). We assume a log-linear form to see the percentage change in supply due to a percentage change in the corresponding variable. We don't want to look at the absolute change but the percentage change in supply relative to the change in the driving factors. This will help us in projecting by how much the supply will respond to the changes in the driving factors.

On the demand side, there are both socio-economic drivers and biofuel policies We focus on income, population and biofuel policies all of which have a positive effect on the demand for agricultural crops. As income rises, aggregate food demands increases and the composition of goods demanded changes. At higher income levels, people tend to consume more meat and dairy products (which are rich in meat and protein content) than cereals which have higher carbohydrate content (Rosegrant et al, (2009)). Thus demand for livestock rises. This results in an increase in grains demand for livestock feeds.   From the review of literature we found that most studies have a positive relationship between income growth and per capita consumption, high income growth is associated with higher per capita consumption relative to scenarios with middle or low income growth. Thus higher income increases the demand for agricultural crops for both food and feed. If population increases, demand for food and agricultural crops will increase. Although demand will increase with increased population, actual consumption depends on both demand and supply factors and the resulting market equilibrium. Many studies (Msangi and Rosegrant (2009), Fischer (2009), Tweeten and Thompson (2008)) considered the population in 2050 to be approximately 9.1 billion. But projected consumption varies by study based on model assumptions for other factors such as income and yield.

Biofuel feedstock demand in recent years has significantly increased the demand for agricultural crops Maize for ethanol production in the United States jumped by 41% in 2001, compared with an average annual growth of 10% in the preceding five years (Alexandratos (2009)). Biofuel production not only affects the demand for agricultural production but also competes for other resources for agricultural production such as land and water. Crops production for biofuels competes with other food and feed crops and has contributed to higher food prices, with adverse effects on consumers. According to Fischer, one of the main contributing factors towards the increase in Food Price Index by 140% during the period 2002-2007 was increased demand for cereals and oilseed for biofuel production. . The demand for agricultural commodities for biofuels is based on biorefinery's derived demand for feedstocks. The derived demand will depend on biofuel policy measures such as biofuel mandates and tax credits. Therefore, biofuel policies will affect the agricultural crops demand through the derived demand for biofuel feedstocks. Assuming a log-linear form, agricultural demand can be written as follows:

$$\ln Q^D = \beta_0 + \beta_1 \ln P + \beta_2 \ln Y + \beta_3 \ln N + \beta_4 \ln G + \gamma \qquad (2)$$

Where Q^D equals total agricultural crop demand, P equals the price of agricultural crops, Y denotes measure of income, N represents global population, G denotes potential biofuel policies. The error term may capture certain omitted variables like geographical locations and local weather conditions. We assume that none of the explanatory variables are correlated to the error term. Income, population and biofuel policies are considered to be exogenous to the model. $\beta_2, \beta_3, and \beta_4$ are expected be positive and β_1 will be negative. Equation (2) assumes a log-linear functional form with parameters, $\beta_1, \beta_2, \beta_3$ and β_4 interpreted as the percentage change in agricultural crop demand from a percentage increase in the corresponding value (e.g. β_1 is the percentage change in agricultural crop demand from a one percent increase in price of agricultural crops). We assume a log-linear form to see the percentage change in demand due to a percentage change in the corresponding variable. We don't want to look at the absolute change but the percentage change in demand relative to the change in the driving factors. This will help us in projecting by how much the demand will respond to the changes in the driving factors.

In equilibrium the market will clear, such that $Q^S = Q^D = Q$ resulting in the following two equations simultaneous model:

$$\ln Q = \alpha_0 + \alpha_1 \ln P + \alpha_2 \ln y + \alpha_3 \ln H + \alpha_4 \ln T + \varepsilon \quad (3a)$$

$$\ln Q = \beta_0 + \beta_1 \ln P + \beta_2 \ln Y + \beta_3 \ln N + \beta_4 \ln G + \gamma \quad (3b)$$

In the two equation model, Q and P are endogenous variables and are determined simultaneously. Each equation has explanatory variables that are not there in there in the other equation. The number of included variables in each equation is at least as great as the number of omitted variables. So the problem of identification does not arise and both the equations get identified. Given data on projected yield, cultivated land and technology for 2050, we can project agricultural crop supply in 2050. Similarly, with data on population, income and biofuel demand, we predict world agricultural crop demand in 2050. If projected supply does not meet projected demand; there will be shortage of agricultural crops resulting in higher prices for agricultural crops and ultimately higher prices for food in the market equilibrium. Ultimately, market impacts will depend on the magnitude of changes in the key factors underlying market demand and supply.

4.1 Supply Factors

We will try to focus on the supply/production side factors discussed in our model separately and try to find out how they will affect food production and availability in 2050.

Yield

Different studies have made different projections regarding yield in 2050 which lead to different levels of production. The following table summarizes the yield assumptions of different important studies:

Table 1: Yield projections

Studies	Yield growth (per year)
1. **F, B & E** (baseline: year 2000)	0.8%
2. **JB** (baseline: year 2000)	0.7%
3. **M & R** (baseline: year 2000)	1.8%
4. **T & T** (baseline: year 2000)	43 kg/ha
5. **R** (baseline: year 2000)	37 kg/ha
6. **GF** (baseline: year 2000)	N/A
7. **JK** (baseline: year 1997)	
GO Scenario	1.02%
OS Scenario	0.48%
AM Scenario	…..
TG Scenario	…..

F,B & E – Fischer et al (2009); T& T – Tweeten and Thompson (2008); R – Rosegrant et al (2008); JB – Bruinsma (2009); M & R – Msangi &Rosegrant (2009); GF – Fischer (2009); JK – Kruse(2006).

According to the paper '*How to Feed the World in 2050?*'published by FAO in 2009, in developing countries, yields increase and cropping intensity will cause 80% of the required production increase and only 20% of the required production increase will come from expansion of arable land. But the fact is that globally the yields growth rate of the major cereal crops has been steadily declining and decreased from 3.2% per year in 1960 to 1.5% in 2000 (HLEF, 2009). Technology has to reverse this decline because if this trend in yields growth continues, then it will not be sufficient to meet food needs and will result in malnutrition.

Fischer et al (2009) have shown that globally, annual yield increases of rice and wheat are falling and in 2008 were just below 1%, their growth of yields in absolute terms (kg/ha/year) is also declining in the developing countries. For maize the annual yield increase in 2009 was 1.6%. Global demand modeling to 2050 shows that real price of cereals is significantly affected by yield growth rates. It implies that if current yield growth rates are not increased, there will be significant increase in prices. Fischer et al (2009) have shown in their paper that yield is expected to decrease in 2050. They examined Farm Yield (FY), Potential Yield (PY) and yield gaps in more than 20 important "breadbasket" regions around the world. In 2009, for both wheat and rice the average annual PY progress was about 0.5%. Maize had a higher average PY growth of around 1%. Yield gaps are high in Africa. Fischer et al (2009) predict that this gap will fall very slowly resulting in food crisis in this region. A few important facts are worth noticing here. Land expansion will be small, so future agricultural growth will be more dependent on intensification. But yields growth rate for cereals has been falling since the Green Revolution years. A major question is whether this decline means that we are reaching a technological stagnation for crop yield, or whether there exists scope for further yield improvements through research and development.

Over the last fifty years, global cereal yields have grown linearly at a constant rate of 43 kg/ha annually with a very low variation (Fischer et al (2009)). Fischer et al (2009) show that if this long term linear trend to 2050 is followed, growth in global cereal yield in 2050 will be 0.8% per year. They tested the coefficient, c, of the following equation, $y = a + bt + ct^2$ (where y is national average yield, t is year and c is the quadratic term of absolute yield trends) and found a declining absolute yield gains trend for rice and wheat. For wheat, no region showed an accelerating trend. For rice South and Southeast Asia showed a declining trend. But, for maize there was a linear trend globally, and an *accelerating* trend (positive and significant coefficient c) for the developing countries. In case of wheat and rice, FY progress was usually below 1%. For maize FY progress was 1.5% or more. They have estimated that average FY for wheat can increase by 50% by 2050. Cassman et al. (2003) argue that for maize the highest level of PY has already been reached in Nebraska, as reflected in a stable average yield of 18.8 t/ha. But on the other hand, Monsanto, a leading seed company, has set an FY goal of 17 t/ha for maize in the USA by 2030 compared to 8.5 t/ha in 2000. They will achieve this by using biotechnology. Fischer et al (2009) argue that if the PY-FY yield gap in Iowa is assumed at a minimum of 25%: that implies in 2050 PY will be at least 21 t/ha across the USA and higher in Iowa (in 2009, Iowa's yield 8% more than the national average). Thus, technology can play a major role in yield improvement and thus production.

Tweeten and Thompson (2008) provided a simple analysis of what might happen by 2050 with linear yield trend for cereals. Tweeten and Thompson (2008), projecting the linear annual yield growth of 43 kg/ha over the whole period, predicted that supply of cereal will increase by 71% over 2000. But demand will grow by 79% (1.17% exponential over whole period, world population of 9.1 billion in 2050), thus causing food deficit and increasing weighted real agricultural prices by 44% in 2050. (They assumed no change in area so that yield growth equals production growth). Rosegrant et al.'s (2008) projections show that the global average annual absolute rate of yield gain is 37 kg/ha which is 14% lower than the projection of Tweeten and Thompson (2008). Given lower yield growth, Rosegrant et al (2008) projected higher real price increases—91% for wheat, 60% for rice and 97% for maize from a 2000 base.

Bruinsma (2009) predicted that Potential Yield will increase (based on 2006 FAO study). He projected that nearly 80% of the required crop production growth in developing countries will come from intensification which can be disaggregated into yield increases (71%) and higher cropping intensities (8%). In the land-scarce region of South Asia, 95% of the required crop production will come from intensification and this share will increase to over 100% in East/North Africa because there will be a loss in the arable land area and yield will have to increase to offset that effect and maintain production level. Arable land expansion will continue to play a major role in crop production growth in many countries of sub-Saharan Africa and Latin America. The following table shows percentages of crop production increase that can be attributed to increase in cropping intensity and yield increases in different regions.

Table 2: Sources of increase in crop production (%)

Regions	Increases in cropping intensity		Yield increases	
	1961-2005	2005/07-2050	1961-2005	2005/07-2050
All Developing Countries	8	8	70	71
sub-Saharan Africa	31	6	38	69
Near East/North Africa	22	17	62	90
Latin America and Caribbean	7	18	53	52
South Asia	12	8	82	87
East Asia	-6	12	77	86
World	9	14	77	77

Source: 'The Resource Outlook 2050: By How Much do Land, Water and Crop Yields Need to Increase by 2050?', Bruinsma (2009)

According to Bruinsma (2009), increase in rice production will come from yield increase. Increase in maize production will be both from increase in harvested land and increase in yield. But the yield growth will fall. On average, over the projection period (2005/07 to 2050) the global annual cereal yield growth rate will be about 0.8% per annum as compared to1.7% per annum during the period 1961-2007. Average cereal yield will be 4.3 tons/ha in 2050 from 3.2 tons/ha in 2008. Bruinsma is of the opinion that if yield is not increased through governmental interventions and investment, food shortage may arise. The following table shows the production and yield for major crops in the world.

Table 3: Production & yield for major crops

	Production (million tons)			**Harvested area (million ha)**			**Yield (tons/ha)**		
	1961/63	**2005/07**	**2050**	**1961/63**	**2005/07**	**2050**	**1961/63**	**2005/07**	**2050**
Wheat	235	611	907	206	224	242	1.14	2.72	3.75
Rice (paddy)	227	641	784	117	158	150	1.93	4.05	5.23
Maize	210	733	1153	106	155	190	1.99	4.73	6.06
Soybeans	27	218	514	24	95	141	1.14	2.29	3.66
Barley	84	138	189	59	57	58	1.43	2.43	3.24
Rape seed	4	50	106	7	31	36	0.56	1.61	2.91
Sugarcane	417	1413	3386	9	21	30	48.34	67.02	112.34

Source: 'The Resource Outlook 2050: By How Much do Land, Water and Crop Yields Need to Increase by 2050?', Bruinsma (2009)

If we consider the 4 different plausible scenarios of the world focusing on different ways to maintain ecosystem services, as discussed by Kruse (2006) using the IHS Global Insight (IHS-GI) with the baseline scenario as that of 1997, we get different assumptions about yield and their respective production levels which are as follows:

- Under Global Orchestration[10] (GO) scenario with medium-high yield growth (1.02% per year), global cereal production increases at 73%.

- Under Order from Strength[11] (OS) scenario with global yield of 0.48% per year (medium-high yield growth in developing countries, low growth in developed countries), global cereal production increases at 55%.

- Under Adapting Mosaic[12] (AM) scenario with medium decreasing yield growth in developed countries and medium low, increasing growth in developing countries, global cereal production increases at 53%.

[10] Assumes a globally connected society with trade and economic liberalizations, global ecosystem management, environmental concerns, (leading to biofuel use) investments in infrastructure, education and R&D

[11] Assumes a fragmented world without international trade and emphasis on regional markets, less investments in R&D and public goods.

[12] Assumes a fragmented world with the local institutions and the local ecosystem management as the focus of political and economic activities.

- Under Techno Garden[13] (TG) scenario with low yield growth improvements, global cereal production increases at 57%.

The largest production increase occurs under GO Scenario which has the highest yield growth due to investments in R&D, technological advancement and public goods.

Cultivated/Arable and Harvested Land Use

Though different studies have made different assumptions on cultivated/arable and harvested land use in 2050, yet the overall impact of cultivated/arable and harvested land is positive on production across all studies. The following table summarizes the cultivated/arable and harvested land use assumptions of different important studies:

Table 4: Cultivated land projections

Studies	Cultivated land (million hectares)
1. F, B & E (baseline: year 2000)	N/A
2. JB (baseline: year 2000)	1673
3. M & R (baseline: year 2000)	N/A
4. T & T (baseline: year 2000)	N/A
5. R (baseline: year 2000)	N/A
6. GF (baseline: year 2000)	
FAO-REF-00	1727
FAO-REF-01	N/A
WEO-V1	1745
WEO-V2	1756
TAR-V1	1775
TAR-V3	1756
7. JK (baseline: year 1997)	1581.31

We now focus on each of these assumptions in details. Bruinsma (2009) showed that arable land would expand by 70 million ha (or less than 5%). The expansion of land in developing countries will be about

[13] Assumes a globally connected world with environmental concerns (leading to biofuel use), environmentally sound technology and management to sustain ecosystem services.

120 million ha (or 12%) which will be offset by a decline of 50 million ha (or 8%) in the developed countries. Almost all of the land expansion in developing countries will take place in sub-Saharan Africa and Latin America which have large land tracts with varying degrees of agricultural potential. In reality, expansion of land for agriculture will continue to take place. The following table shows that expansion of arable land plays a major role in agricultural growth in sub-Saharan Africa, Latin America and East Asia.

Table 5: Global arable land expansion

	arable land in use(million ha)						**Annual growth (% p.a.)**		
	1961 /63	**1989 /91**	**2005**	**2005 adj.**	**2030**	**2050**	**1961-2005**	**1990-2005**	**2005-2050**
sub-Saharan Africa	133	161	193	236	275	300	0.80	1.07	0.55
Latin America	105	150	164	203	234	255	1.01	0.64	0.52
Near East/ North Africa	86	96	99	86	84	82	0.34	-0.02	-0.11
South Asia	191	204	205	206	211	212	0.15	0.07	0.07
East Asia	178	225	259	235	236	237	0.99	1.12	0.02
excl. China	73	94	102	105	109	112	0.85	0.71	0.15
Developing countries	693	837	920	966	1040	1086	0.67	0.65	0.27
excl. China and India	426	536	594	666	740	789	0.75	0.66	0.39
Industrial countries	388	401	388	388	375	364	-0.02	-0.21	-0.15
Transition countries	291	277	247	247	234	223	-0.32	-0.90	-0.23
World	1375	1521	1562	1602	1648	1673	0.30	0.17	0.10

Source: 'The Resource Outlook 2050: By How Much do Land, Water and Crop Yields Need to Increase by 2050?', Bruinsma (2009)

The harvested area in the developing countries will increase by 160 million ha or 17%, due to increases in cropping intensities.

According to Kruse (2006), there will be a 16% overall expansion of land for cultivation (mainly because oilseeds, sugar and feed grains need more area and their production will increase over the projection period). Globally, crop area is projected to increase by 137 million ha to reach 823 million ha, i.e. an annual rate of 0.34%. We notice that due to low investments in technology and thus fewer improvements in crop yield, the OS scenario will have the largest agricultural land expansion. Under the GO scenario, due to adoption of biotechnology, there will be fewer expansions of croplands than in OS.

If we consider Fischer's (2009) analysis, we get various biofuel scenarios which have different assumptions about cultivated and harvested land. Under the FAO-REF-00 Scenario (starting in 2000 assumes a world without any agricultural crops used for biofuels), certain predictions were made regarding population, income, agricultural production, yield, etc. We can compare that to a few other biofuel scenarios like FAO-REF-01[14], WEO-V1[15], WEO-V2[16], TAR-V1[17] and TAR-V3[18].

Under FAO-REF-00 Scenario, it is projected that global cultivated land will increase by about 165 million ha during 2000 to 2050 to reach 1727 million ha and all of the net increases will occur in developing countries. Africa and South America together will account for 85% of the expansion of cultivated land.

Table 6: Aggregate Arable Land under FAO-REF-00 (Million ha)

FAO-REF-00	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Developed Countries	604	60	601	602	606	610
Developing Countries	915	960	1002	1035	1063	1081
Rest of the World	42	41	40	38	38	37
World	1561	1603	1643	1676	1707	1727

Source: 'World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?', Fischer (2009)

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14 Assumes historical biofuel development until 2008; biofuels feedstock demand is kept constant at 2008 levels.

15 Uses International Energy Agency's (IEA) WEO 2008 Reference Scenario's projections on transport energy demand and regional biofuel use. Second-generation biofuel become commercially available after 2015.

16 Uses IEA's WEO 2008 reference scenario's projections for biofuel demand. Also assumes that 2nd generation biofuel use starts after 2030 and all biofuel production till then will be 1st generation biofuels.

17 Uses IEA's WEO 2008 reference scenario's projections for transport energy demand. Also assumes that mandates on biofuel use will be implemented by 2020, 2nd generation biofuel will become commercially available after 2015.

18 Uses IEA's WEO 2008 reference scenario's projections for transport energy demand. Also assumes that mandates for biofuel use will be implemented by 2020 and there will be rapid development of 2nd generation biofuel resulting in 33% of the total biofuel used in the developed countries in 2020.

Under the FAO-REF-00 Scenario, the total harvested land increases but at a decreasing rate. The cropping intensity will increase from 84% in 2000 to 92% in 2050. Most of the expansion of the harvested land is predicted to happen in Sub Saharan Africa.

Under FAO-REF-00, total cereal production increases from 2.1 billion tons in 2000 to 3.4 billion tons in 2050. The share of developing countries in total production will become 57% in 2050. According to Fischer (2009), under FAO-REF-00, number of people at risk of hunger will fall globally in 2050 except for Africa .In 2030, 40% of the total population at risk of hunger will be from Africa.

Table 7: Cereal Production under FAO-REF-00 (million tons)

FA0-REF-00	2000	2020	2030	2050
Developed Countries	1008	1149	1229	1363
Developing Countries	1060	1425	1590	1914
Rest of the World	75	94	103	125
World	2143	2668	2923	3402

Source: 'World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?', Fischer (2009)

Now if we compare this to various other biofuel scenarios, the predictions change.

Table 8: Change of Cultivated Land relative to FAO-REF-00 (million ha)

Scenario	World			Developed			Developing		
	2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
REF-00	8	8	5	3	3	1	5	5	4
WEO-V1	19	19	21	6	6	5	12	13	16
WEO-V2	20	23	29	6	8	7	13	15	21
TAR-V1	38	46	48	12	14	11	24	30	36
TAR-V3	29	30	29	9	9	6	19	20	22

Source: 'World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?', Gunther Fischer

From the above table, we find that under the WEO and TAR biofuel scenarios, the additional use of cultivated land in 2050 ranges from 21 million hectare (WEO-V1) to 29 million hectares (TAR-V3) with the amount increasing to 48 million hectares under TAR-V1 scenario. For developed countries the additional use of arable land increases in different biofuel scenarios during 2000-2050 in the range of 5 to 11 million hectares, but has a net decrease by 1 million hectares in the FAO-REF-00 scenario without biofuels. Under the FAO-REF-00 scenario, in developing countries arable land use will increase by 4 million hectares during 2000-2050. The largest land expansion globally occurs under TAR-V1. In Fischer's (2009) analysis, we see that largest production increase occurs under TAR-V1 followed by TAR-V3, WEO-V2, WEO-V1 and FAO-REF-01.

Table 9: Change of Harvested Area relative to FAO-REF-00 (million ha)

Scenario	**World**			**Developed**			**Developing**		
	2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
REF-00	13	15	8	6	7	2	7	8	6
WEO-V1	29	33	31	10	13	6	19	20	25
WEO-V2	30	39	43	10	15	8	20	24	34
TAR-V1	57	74	71	17	23	12	38	49	57
TAR-V3	45	50	42	14	17	7	30	32	35

Source: 'World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?', Fischer (2009)

The above table portrays the change in aggregate harvested area in different scenarios compared to the baseline scenario. Increases of harvested area account for both the expansion of cultivated land as well as the cropping intensification on existing cultivated land. In developed countries the harvested area decreases in 2050 for all the biofuel scenarios, whereas, in developing countries the harvested area increases under all the scenarios.

Looking at Chen et al (2010), we find that different biofuel policies scenario have different assumptions about cultivated land and production. They considered 3 scenarios.

Business As Usual (BAU) scenario is the one without any biofuel policy, except for the tariff on biofuel imports (which is kept unchanged in all scenarios). Under BAU, they find that total crop acreage decreases by 0.3% over the period 2007 – 2022 with corresponding increases in pasture land. Despite corn and soybean acreages reduction, their production would increase due to yield improvements. The production of wheat will increase because of the increases in both wheat acreage and yields. Under the

Biofuel Mandate (BM) scenario, i.e. under RFS, there will be a 16% increase in corn acreage in 2022 compared to the BAU to produce more corn for additional corn ethanol production. Of the 12.14 M ha of land required for biofuel production, 5 M ha will be achieved by reducing crops acreage under certain crops like soybeans, wheat, rice, cotton and pasture and the rest will be obtained by land use change. Corn production will increase by 18% in 2022 relative to the BAU. But 38% of corn production will be used for biofuel production. Rice, wheat, soybean and cotton production will fall in 2022 relative to the BAU as more land will be used for corn production. Biofuel Mandate and Volumetric Tax Credits leads to significant impacts on total biofuel production and the mix of feedstocks used for biofuels. It will reduce corn ethanol production. The reduction in production of corn ethanol (relative to the RFS) will reduce corn acreage by 8.4 M ha. The increase in biofuel production from miscanthus and switchgrass leads to more miscanthus and switch grass acreages compared to BM.

Technology

Biotechnology is used to increase supply or production of agricultural crops by improving yields, improving the nutritional quality of crops and reducing the impact on the environment. With biotechnology, the crop breeders can select a specific genetic trait from any plant and move it into another plant with greater ease and precision and can thus select the most beneficial traits. Biotechnology can help grow more food by making crops resistant to pests and disease and preventing the loss of crops. The environmental benefits of biotechnology throughout the world are also significant. For example, biotechnology can be used to grow plants that are resistant to herbicide and pesticides, reducing the amount of pesticides and weed controls used earlier. This can help reduce carbon emissions and soil erosion. Genetic engineering increases the efficiency of crop improvement. Thus, biotechnology could enhance global food production and availability in a sustainable way.

In 2008, 13.3 million farmers in 25 countries used 8% of global cropland for GE crops per year. In 2009, more than 80% of the sugar beet crop planted in the US was of transgenic varieties which were introduced in 2008. More than 90% of the 2008 cotton crops that were planted in South Africa, Australia and Argentina were of GE varieties as compared to 1-2% in the last decade (Sexton and Zilberman (2010)). All of the maize crops planted in Canada in 2008 were of GE varieties. Of these 25 countries, 15 were developed countries and 10 were developing countries. Sexton and Zilberman (2010) looked at ‘the spatial and temporal variation in the rates of agricultural biotechnology adoption across countries to estimate the yield effects of genetically engineered crops’. They used analysis of variance to decompose yield per acre to different components like time, location, technology and crops. They assumed that at each time and location with a given technology level, the yield per acre of each crop was fixed, but these yields vary across crops, technologies, and time. Their results suggest that the farms adopting GE seeds experienced significant yield improvements compared to farms using non-GE seeds. The estimated yield gains associated with GE seed were greater in developing countries than in developed countries for each GE crop.

Table 10: Yield Gain from GE Seed as % of Yield

Variables	Cotton	Maize	Rapeseed	Soybean
All Countries	65.042	45.607	25.484	12.475
Developed	22.886	15.193	24.057	7.040
Developing	109.510	56.403	-	30.189

Source: 'How Agricultural Biotechnology Boosts Food Supply and Accommodates Biofuels', Sexton and Zilberman (2010)

In 2008, global biofuel production used 86 million tons (10%) of global corn production and 8.6 million tons of global vegetable oil (which consisted of 7% of the global rapeseed harvest and 2% of the global soybean harvest) (Sexton and Zilberman (2010)). The increased demand for maize, soybean, wheat and rapeseed increased their prices by 67%, 40%, 36% and 57% respectively. Sexton and Zilberman (2010) showed that if the yield gains from adopting biotechnology in production were not there, 2008 prices would have increased further. Corn, soybean, wheat and rapeseed prices would have been 35%, 43%, 27%, and 33% higher respectively. They have further argued that without intensification from biotechnology adoption, an additional 20 million hectares of land–an area equal in size to the State of Utah–would have been needed to produce the 2008 harvest of staple crops. This indirect land use change by clearing forests to produce more crops would have caused more GHG emissions (from land conversion) and risk to biodiversity.

Msangi and Rosegrant (2009), using the IMPACT model, predicted that there will be a steady trend of cereals production growth till 2050. Cereal production will grow steadily worldwide, with North America and Europe in the main lead. Though per capita output will not grow much, due to yield enhancing technologies, North American, European and Central Asian regions will make significant increases in per capita output growth so that they will be able to produce surplus amount that will meet the food and feed needs of the rest of the world. The increased per acre yield of food, feed and fiber products resulting from adoption of yield enhancing technology, will both increase their production, lowering their market prices and increase land availability for non-agricultural uses like forestry, wildlife habitat and the 'plantation-style biofuel systems' to increase fuel supply. Msangi and Rosegrant (2009) showed that the Asian regions will be the most successful in reducing malnutrition in 2050. But child malnutrition remains almost same in sub Saharan Africa in 2050 as it were in 2000

We can now thus summarize various predictions of cereal production in different important studies in the following table:

Table 11: Cereal Production Projections

Studies	**Production of cereals (million tons)**
1. F, B & E (baseline: year 2000)	N/A
2. JB (baseline: year 2000)	3009
3. M & R (baseline: year 2000)	…..
4. T & T (baseline: year 2000)	3371.83
5. R (baseline: year 2000)	N/A
6. GF (baseline: year 2000)	
FAO-REF-00	3402
FAO-REF-01	3470
WEO-V1	3582
WEO-V2	3673
TAR-V1	3715
TAR-V3	3600
7. JK (baseline: year 1997)	
GO Scenario	3230
OS Scenario	2900
AM Scenario	2865
TG Scenario	2940

All of the studies have one prediction in common which says that production can be further increased (beyond their level of projection) by investment in research and technology and use of improved agricultural technology.

4.2 Demand Factors

We will now focus on the demand side factors discussed in our model and try to find out how they will affect the global availability of agricultural crops and thus food in 2050. Most of the studies have same assumptions over income and population growth in 2050 (except a few).

Socio-economic drivers

The drivers like rise in population growth, rise in total income, urbanization imply increased demand for food and energy. The combined effect of rising income and urbanization leads to a change in the nature of diets. The demand for livestock products has increased in the developing countries due to rise in incomes. 84% of the population increase from 1995 to 2025 in developing countries is expected to localize in urban areas (Msangi and Rosegrant et al). According to the growth projections of a number of studies, per capita GDP is expected to grow significantly in the developing countries and this income growth will be the most rapid in East Asia and the Pacific (World Bank, 2007a; UNEP, 2007. Urbanized populations consume less basic staples and carbohydrates but more processed foods and livestock products which are rich in protein (Rosegrant et al., 2001). Due to increasing incomes and rapid urbanization, it is predicted that by 2020 over 60% of meat and milk consumption will take place in the recent developing countries, and the production of beef, meat, poultry, pork, and milk will be twice than the 1993 levels (Delgado et al., 1999). Demand for meat and livestock products put additional pressure on land resources for pasture for animal grazing and coarse grains for feed, including maize.

Msangi and Rosegrant, using the IMPACT Model projected that over 2000-2050, total food demand for cereals will increase globally. Sub-Saharan Africa will have the largest growth in terms of food use. Eastern Europe, Central Asia, and Pacific regions will have the lowest demand growth. The North American and some European regions will be the highest consumers of cereals for feed usage. In East and South Asia, there will be a fall in per capita cereal consumption. Compared to other developing regions, East Asia will have the largest increase of meat demand (which is the largest driver for feed use of cereal demand) due to its rapid growth in per capita income.

Focusing on Fischer's (2009) analysis, the main projections under FAO-REF-00 Scenario, is that the aggregate demand growth for the major food commodities will fall due to a decline in population growth rate. The slowdown will be more significant for rice than wheat, and will be absent for coarse grains because more coarse grains will be used as animal feed to meet the rising demand for livestock products, mainly in developing countries. The growth rates of vegetable oils consumption for food will also increase. To meet the global average daily calorie requirement of 3050 kcal per person (or a 10% increase over its level in 2003/05) under the FAO-REF-00 Scenario, Fischer argues that global cereal production will have to increase by 900 million tons or a 40% increase over the period 2006/08 average and 2050. In the absence of biofuels, much of the increase in cereals demand will come from animal feed to meet the increasing consumption of livestock products. Globally, meat consumption per capita will increase from 41 kg in 2009 to 52 kg in 2050 (from 30 to 44 kg in the developing countries). Total cereal consumption under the baseline scenario is given in the following table:

Table 12: Cereal Consumption under FAO-REF-00 (million tons)

FA0-REF-00	2000	2020	2030	2050
Developed Countries	858	945	993	1072
Developing Countries	1183	1596	1808	2171
Rest of the World	103	120	128	146
World	2144	2661	2928	3388

Source: 'World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?' Fischer (2009)

Income

Most of the studies have the same assumption over income. The income growth enables the populations to meet their daily calorie requirements and include more proteins in their diets. This can be characterized by three phases. In the first phase, extremely low income countries almost spend their entire income growth on additional food consumption which includes rice, starchy roots such as potatoes or cassava, and pulses but very little protein in the diet. Many African are in this first phase of consumption. In the second phase, consumers are able to meet the total daily calories needs, but they want to consume more protein items which are expensive. Countries like India and China are in this phase of income growth. In the third phase, personal preferences and health concerns dominate the choice of food. Food expenditures occupy a small share in the consumers' budget and are less responsive to income changes. Europe, Japan, South Korea, the US, Canada, etc. are examples of such countries.

The world income and GDP is projected to rise with the major rise being in BRIC (Brazil, Russia, India, and China). This rise in income will have a huge impact on the demand for food and feed and the pattern of consumption. Based on the rates that are used in IFPRI's IMPACT model projections (von Braun, 2008), GDP per capita in China is expected to increase 5.2% per year from 1995 to 2025, while Republic of Korea, Thailand, and India will grow at approximately 4.5% per year. In general, growth rates in Asia will be the highest, ranging from 2.1 to5.2% per year, while Eastern European incomes will rise by 4.1% per year. But due to high population growth, per capita growth rate in Sub Saharan Africa will be only between 0.8% to 1.7% per year. Growth rate of the developed countries will fall.

Table 13: World GDP Per Capita

Country (in constant 2004 $ terms)	**GDP Per Capita at market exchange rates (2005)**	**GDP Per Capita at market exchange rates (2050)**
US	40,339	88,443
Canada	31,466	75,425
UK	36,675	75,855
Australia	32,364	74,000
Japan	36,686	70,646
France	33,978	74,685
Germany	33,457	68,261
Italy	29,455	66,165
Spain	23,982	66,552
Korea	15,154	66,489
Russia	4,383	41,876
Mexico	6,673	42,879
Brazil	3,415	26,924
Turkey	4,369	35,861
China	1,664	23,534
Indonesia	1,249	23,097
India	674	12,773

Source: 'The Long Term Growth Prospects of the Global Economy – Horizon 2050', Poncet (2006)

According to the FAO Expert Meeting in June 2009, there will be an average annual GDP growth rate of 2.9% during the period 2005 and 2050 in the form of 1.6% for developed countries and 5.2% for the developing countries. Developing countries' shares in global output will increase from 20 to 55%. As a result, the relative income gap (ratio of per capita GDP) between the developed and the developing countries will become small, but the absolute differences will increase further as there is large gap in absolute per capita incomes at present. The increasing incomes in the developing countries will lead to more food consumption. In the developed countries, though there will be significant income growth, it will have little impacts on food consumption other than following health trends.

Population

As population increases, demand for agricultural crops increases. Most of the studies assume that the population level in 2050 will be 9.1 billion. Only a few studies assume different population levels. The following table shows the population level assumption of different important studies:

Table 14: Population Projections

STUDIES	POPULATION (in billions)
1. F, B & E (baseline: year 2000)	N/A
2. JB (baseline: year 2000)	8.796
3. M & R (baseline: year 2000)	N/A
4. T & T (baseline: year 2000)	9.1
5. R (baseline: year 2000)	9.1
6. GF (baseline: year 2000)	9.1
7. JK (baseline: year 1997)	
GO Scenario	8.1
OS Scenario	8.8
AM Scenario	9.5
TG Scenario	9.6

The world's human population has increased almost four times in the past 100 years (UN population Division, 2007). By 2050 the world's population will reach 9.1 billion, 34% higher than in 2009 (United Nations Population Division, 2009). Nearly all of this population increase will occur in developing countries. Urbanization rate will increase, and about 70% of the world's population will be live in the urban areas (compared to 49% in 2009).

Table 15: World Population Distribution

Regions	Total Population (millions)					
	2000	**2010**	**2020**	**2030**	**2040**	**2050**
North America	306	337	367	392	413	430
Europe &Russia	752	762	766	761	748	729
Pacific OECD	150	153	152	148	142	135
Africa, sub-Saharan	655	842	1056	1281	1509	1723
Latin America	505	574	638	689	725	744
Middle East & N. Africa	303	370	442	511	575	629
East Asia						
South/Southeast Asia	1402	1500	1584	1633	1630	1596
Rest of World	1765	2056	2328	2553	2723	2839
Developed	210	233	249	262	272	280
Developing	1141	1177	1202	1211	1210	1198
Rest of World1	4696	5417	6132	6758	7257	7627
World	210	233	249	262	272	280
	6047	6827	7582	8231	8739	9105

Source: United Nations Population Division, 2009

In the long run, population and economic growth are the main drivers behind agricultural products demand increase and both of these factors are the most significant in developing countries. The most recent available UN population projections (United Nations, 2009) are shown above. Though the population growth rates will slow down considerably, but since the base number is very big, the absolute increase will be large, about 2.3 billion people (Fischer, 2009). In combination with income growth it will lead to a diversification of diet. Grains and other staple crops will be substituted by vegetables, fruits, meat, dairy, and fish. To meet the food demand of the bigger urban population with higher income, Fischer (2009) says that food production (net of food used for biofuels) will have to increase by 70%. The future food demand growth will be driven by the combined effect of population growth, income growth and urbanization in many of the developing countries which will be associated with shifts and diversification in diet structures. The future total demand for agricultural commodities may exceed the demand for food and feed more or less significantly, depending on the expansion of biofuels demand and on the technology used for the conversion of agricultural biomass into biofuels.

If we look at the 4 different scenarios discussed by Kruse (2006), we get different predictions. All scenarios show small increases in total food consumption per person. This increase will be the fastest in the GO scenario which has higher income growth and greater average per capita purchasing power. But direct consumption of cereals as food falls relatively under all the scenarios.

- Under the GO scenario, with a high income growth of 3% per year during the 2020-2050 period and a low population growth which will cause 8.1 billion people in 2050, globally, annual consumption will reach to 3184.5 million tons by 2050.
- Under the OS scenario, with a medium income growth of 2.5% per year during the 2020-2050 period and a medium population growth leading to 8.8 billion people in 2050, annual consumption will be 2865 million tons.
- Under the AM scenario, with a medium/low income growth of 1.9% per year during the 2020-2050 period and a somewhat high population growth leading to 9.5 billion people in 2050, annual consumption will be 2826.5 million tons.
- Under the TG scenario, with a medium income growth in developed countries and low income growth in developing countries during the 2020-2050 period and a high population growth leading to 9.6 billion people in 2050, annual consumption will be 2857.6 million tons.

The following table portrays the percentage increase in production and consumption over the period 2000-2050.

Table 16: Consumption & Production Increase (%)

Crop Types	Domestic Consumption Increase (2000-2050)	Production Increase Needed (2000-2050)
Corn	105%	111%
Sorghum	102%	107%
Barley	53%	54%
Wheat	56%	57%
Rice	49%	48%
SugarBeets,SugarCane	93%	93%
Soybeans		
Sunflowers	153%	155%
Rapeseed	115%	118%
Palm	125%	136%
Cotton	265%	265%
All Crops	121%	127%
	84%	86%

Source: 'Estimating Demand for Agricultural Commodities to 2050', Kruse (2006)

By the year 2050, world crop and meat consumption is projected to increase significantly. From the above table we notice that overall crop demand will increase by 84% over the period 2000 to 2050. Corn, soybeans and sugar occupy a major portion of world crop consumption through their food, feed, and industrial demands. To meet the growing demand overall crop production will have to increase by 86%.

Biofuel

Demand for biofuels is affected by different policy measures, gasoline prices and environmental condition. Government mandates and policies, rising crude oil prices and more and more concentration of GHG in the atmosphere leads to the increased use of alternative fuels and thus biofuel demand rises. The following table shows the different assumptions of biofuel demand in different important studies across different scenarios:

Table 17: Biofuel Demand Projections

Studies	**Biofuel demand**
OECD-FAO Predictions	192 billion liters in 2018
GF	
WEO Scenario	224 Mtoe
TAR Scenario	424 Mtoe
Chen, Huang & Khanna	
Business As Usual	28 billion lts in 2022
Biofuel Mandate	1221 billion lts in 2022
Biofuel Mandate with Volumetric Tax Credit	1316 billion lts in 2022

Higher future crude oil prices and biofuel policies in different countries will increase the biofuel use. This will lead to increased demand for agricultural feedstock (sugar, maize, oilseeds) for biofuels in future which will again increase food prices. Biofuels, mainly ethanol and biodiesel, are produced from a number of agricultural crops which are also used for food and feed. In the recent years, biofuels production has increased in a large number of countries. Countries such as the United States, Member States of the European Union, China, India, Indonesia, South Africa and Thailand have all adopted biofuel policies and set targets for the development of biofuels. Though the use of biofuels to enhance fuel energy security, to reduce GHG emissions and to bring forth agricultural rural development is appealing, in reality the consequences of biofuels developments are controversial due to its negative impacts resulting in land use change, loss in biodiversity and increased food prices.

Msangi and Rosegrant (2009) showed that if biofuel production growth were maintained at 1990-2000 period level, instead of the actual growth rates over 2000-2007, the average grain prices grew at a rate 30% lower than the actual growth rate of world prices. In another experiment, they held the biofuel feedstock demand constant at the observed 2007 levels (rather than using the trend suggested by policy and plans for future expansion of biofuels) and found that grain, oils and cassava prices were 4%lower and maize prices were 14% lower than baseline in 2015. Per-capita levels of calorie availability were also 3% higher than baseline levels in 2015, in many developing regions, while in regions like Sub-Saharan Africa per capita levels of calorie availability were 6% higher than baseline levels in 2015.

Under the WEO Scenario of Fischer (2009), total biofuel consumption in developing countries (starting from 5.5 million tons in 2000) increases to 46 million tons in 2030. For 2050 projected biofuel consumption in developed countries is 124 million tons. The share of biofuel consumption in total transport fuel use in the developed and developing countries will be 5.5% and 3% respectively in 2030. In the TAR scenario, final consumption of biofuels reaches 295 million tons in 2030 and 424 million tons in 2050.

In 2008 about 80-85 million tons of cereals (mainly maize) were used for ethanol production in the USA and about 10 million tons of vegetable oil were used for biodiesel production in the EU (Fischer (2009)). In the reference scenario FAO-REF-01**,** Fischer keeps these amounts constant for the rest of the simulation period to 2050. The amounts increase in both the WEO and TAR scenario variants.

The increasing use of first generation biofuels has wide spread impacts. The following table shows how world price indices change under different biofuel scenarios.

Table 18: Change of Price Index relative to FAO-REF-01 (%)

Scenario	**Cereals**			**Crops**			**Agriculture**		
	2020	**2030**	**2050**	**2020**	**2030**	**2050**	**2020**	**2030**	**2050**
WEO-V1	11	5	10	10	7	10	8	5	7
WEO-V2	14	13	21	12	11	15	9	8	11
TAR-V1	38	38	27	35	34	27	27	26	20
TAR-V3	19	17	12	22	18	13	17	12	9

Source: 'World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?' Fischer (2009)

The rising agricultural prices in the biofuel scenarios provide incentives on the supply side, for intensifying production and for augmenting and reallocating land, capital and labor. Simultaneously, consumers react to price increases and adjust their consumption patterns.

Table 19: Change in Cereal Production, Consumption & Biofuel Use (million tons)

Scenario	2020			2030			2050		
	Biofuel Use	**Production**	**Food/Feed**	**Biofuel Use**	**Production**	**Food/Feed**	**Biofuel Use**	**Production**	**Food/Feed**
REF-01	83	64	-19	83	66	-17	83	68	-15
WEO-V1	181	134	-46	206	167	-45	246	180	-62
WEO-V2	192	140	-48	258	194	-68	376	271	-102
TAR-V1	327	229	-96	437	308	-133	446	313	-127
TAR-V3	238	174	-59	272	201	-69	262	198	-62

Source: 'World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?' Fischer (2009)

According to Fischer (2009), under FAO-RF-01, in developing countries number of undernourished people will gradually fall from 850 million in 2020 to 70 million in 2030. Under the biofuel target scenarios with less or no 2nd generation biofuel use, these numbers will increase to 982 million and 836 millions in 2020 and 2030 respectively. But under biofuel target scenarios with accelerated 2nd generation biofuel use number of undernourished people will fall to 935 million in 2020 and 774 million in 2030.

As there are increasing concerns over the effects of 1st generation biofuels use expansion, 2nd generation biofuels, produced from woody or herbaceous non-food plant materials, are gaining importance and they will soon become commercially available. They are considered better than 1st generation biofuels because they have more GHG saving potential and they can be produced on 'non-food' land. Under WEO-V1, TAR-V1 and TAR-V3 Scenarios, following are the projections:

Table 20: 2nd Generation Biofuel Production

Scenario	**Region**	**2015**	**2020**	**2030**	**2050**
WEO-V1 and TAR-V1	United States	Starts	7.5	25	50
	Other OECD	None	Starts	12.5	33
	Russia	None	Starts	5	20
	Brazil/China/India	None	Starts	5	20
	Other Developing	None	None	None	None
TAR-V3	United States	10	35	55	70
	EU-27	10	31	47	67
	Other OECD	10	31	47	67
	Russia	Starts	10	33	50
	Brazil/China/India	Starts	10	33	50
	Other Developing	0	Starts	10	33

Source: 'World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?' Fischer (2009)

While the concerns on the expansion of 1st generation biofuels increase, 2nd generation lignocelluloses technologies result in substantial GHG emission reduction and allow using land resources that are not extensively used for food production. It may impact the world food system in a significant way.

We can now thus summarize various predictions of cereal consumption in different important studies in the following table:

Table 21: Cereal Consumption Projections

Studies	Consumption of cereals (million tons)
1. **F, B & E** (baseline: year 2000)	N/A
2. **JB** (baseline: year 2000)	…..
3. **M & R** (baseline: year 2000)	…..
4. **T & T** (baseline: year 2000)	3837.76
5. **R** (baseline: year 2000)	3344.64
6. **GF** (baseline: year 2000)	
FAO-REF-00	3388
FAO-REF-01	3454
WEO-V1	3572
WEO-V2	3662
TAR-V1	3707
TAR-V3	3588
7. **JK** (baseline: year 1997)	
GO Scenario	3184.5
OS Scenario	2865
AM Scenario	2826.5
TG Scenario	2857.6

5.

6. Conclusion

In this paper we have evaluated whether the increasing demand of food and biofuel will cause shortage of food in 2050. After reviewing related literature (Section 2 – 'Review of literature') and with the help of our intuitive model (Section 3 – 'Intuitive model underlying projections') following are our conclusions.

- Supply side factors like yield growth, and technological advancement will be the main factors affecting aggregate agricultural crop production and food availability in 2050.
- World aggregate supply of agricultural crops will be more than world aggregate agricultural crop consumption in 2050.

- Regional malnutrition and risk of hunger may prevail in the developing countries especially in Sub Saharan Africa due to low yield improvements, lower per capita income growth and increased biofuel use.
- Investment in R&D for agricultural development and adoption of agricultural biotechnology will help to increase production beyond the predicted levels and reduce undernourishment.

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7. Abbreviations

Abbreviation	Full form
AEZ	Agro Ecological Zone
AM	Adapting Mosaic
BAU	Business As Usual
BCAP	Biomass Crop Assistance Program
BEPAM	Biofuel and Environmental Policy Analysis Model
BM	Biofuel Mandate
FAO	Food and Agriculture Organization
FAPRI	Food and Agricultural Policy Research Institute
GHG	Green House Gas
GO	Global Orchestration
HLEF	High Level Expert Forum
IFPRI	International Food Policy Research Institute
IIASA	International Institute for Applied Systems Analysis
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
OFID	OPEC Fund for International Development
OS	Order from Strength
RFS	Renewable Fuel Standard
TAR	Third Assessment Report
TG	Techno Garden
WEO	World Energy Outlook

7. Appendix – TABLE A: Studies Table

Studies	Yield	Cultivated/arable and harvested land use	Production	Income	Population	Demand
1. How to Feed the World? - FAO	In Developing Countries, 80% of needed production increase will be from increase in yield and cropping intensity, i.e. from intensification.	In Developing Countries, 20% of needed production increase will be from expansion of arable land, i.e. from extensification	Food production (net of food for biofuels) increase by 70%. Annual cereal production will rise to3.1 billion (bl) tons from 2.1 bl tons today Annual meat production will rise to 470 million tons.	Average annual GDP growth of 2.9% (1.6% for high income countries and 5.2% for developing countries).	Almost 9.1 billion (Absolute increase is 2.3 bl). Most of the increase in the Developing Countries. 70% of the population will be urban.	Share of grains and staple crops falls. Share of vegetables, meat, and fish, dairy rises. Global demand for food, feed and fiber will rise by 70%.
2.Can Technology Deliver on The Yield Change to 2050?- Fischer, Byerlee &Edmeades (focused on yield prospects of rice, wheat, maize)	Projecting a linear trend to 2050 (over the last 50yrs global cereal yields grew linearly at a constant rate of 43kg/ha annually), will have 0.8% per year growth.					
Tweeten and Thompson (2008)	Linear annual yield growth of 43kg/ha.		Increase in cereal supply of 71% over 2000, or a total increase of 1.4 bl tons.(1.4% exponential growth initially becomes 1.07% over the whole period)		9.1 billion in 2050	Increase of 79% (1.17% exponential over the whole period)
Rosegrant et al. (2008)	Linear annual yield growth of 37kg/ha (global average)				9.1 billion in 2050	Increase in cereal demand of 1.048 bl tons (56%) in 2050 from a 2000 base.
3. The Resource Outlook 2050: By how much do land, Water, and Crop Yields Need to Increase by 2050? - Jelle Bruinsma (did not consider the effect of demand for Biofuel, based on 2006 FAO study).	Nearly 80% of the projected growth in crop production in developing countries will come from intensification in the form of yield increases (71%) and higher cropping intensities (8%).World yield increases by 77% over the period 2005/07-2050. Growth rate of yield falls. Cereal yield growth will fall to 0.7% p.a. (average cereal yield rise to 4.3 tons/ha from 3.2tons/ha in 2008)	Projected average annual increase in Developing Countries' arable area of 2.75 million (ml) ha (120 ml ha over 44 years). Harvested Area rise by 160 ml ha due to increase in cropping intensity. For wheat, rice, maize an soybeans, the harvested area will change from 224 ml ha, 158 ml ha, 155 ml ha, 95 ml ha respectively in 2005/07 to 242 ml ha, 150 ml ha, 190 ml ha, 141 ml ha respectively in 2050	Production for wheat, rice, maize and soybeans will increase from 611 ml tons,641 ml tons,733 ml tons,218 ml tons respectively in 2005/07 to 907 ml tons,784 ml tons,1153 ml tons,514 ml tons respectively in 2050		9.1 billion in 2050	Average daily calorie availability could rise to 3130 kcal per person, an 11% increase over its level in 2003.

Studies	Yield	Cultivated/arable and harvested land use	Production	Income	Population	Demand
4.'World Agriculture in a Dynamically-Changing Environment: IFPRI's Long term Outlook For Food and Agriculture Under Additional Demand and Constraints'- Msangi and Rosegrant (used IMPACT model developed by IFPRI)	Developing countries will have a 9 to 21% decline in overall agricultural productivity due to global warming, while industrialized countries will face a 6% decline	Additional 120 ml ha of land will be converted to agricultural land over the next 30 years.	For North America and Europe, total cereal production will be above 1000 ml of metric tons. For Eat and South Asia it will be below 1000 ml of metric tons. Cereal production is projected to grow steadily across all regions, with North America and Europe leading the regions in cereal production volume.	Overall, world GDP will increase. Growth rates in Asia will be the highest, ranging from 2.1 to 5.2 % per year, while Eastern European incomes will raise by 4.1% per year.	Global population will increase from approximately 6 bl in 1995 to 8 bl in 2025, with over 98% of this increase in developing countries, according to the UN medium Variant projections (UN, 2004). 84% of the population increase from 1995 to 2025 in developing countries is expected to localize in urban areas.	Per capita cereal demand in North America and Europe will be below 150kg/capita/yr. Over 2000-2050, the total demand for cereals will rise by 38%. For South Asia, it will between 150-200 kg/capita/year (71% increase in total cereals demand over 2000-2050). Total food demand for cereals is projected to increase in all regions with North America and Europe, and East Asia leading all other regions in total volume.
5.'Estimating Demand for Agricultural Commodities to 2050'- John Kruse (used IHS-GI modeling system)		16% overall area expansion for cultivation (mainly because oilseeds, sugar and feed grains need more area).Taking into account both food and feed demand, soybeans acreage will rise by 69% and that of corn will rise by 23%.				Crop demand from all uses increase to 84% from 2000-2050. Biofuels will need 86%increase in crop production.
Global Orchestration(GO)scenario	Medium-high yield growth (1.02% per year)		Global cereal production increase at 73% (from 1,872 million tons to 3,230 million tons)	High income growth 2020-2050: 3.0%/yr.	Low population growth 2050: 8.1 bl people	3184.5 ml tons
Order from Strength (OS) scenario	Medium-high yield growth in developing countries, low growth in developed countries (organic farming).Globally, 0.48% per yr.		Global cereal production increase at 55%	Medium income growth (increasing) 2020-2050: 2.5%/yr.	Medium population growth 2050: 8.8 bl people	2865 ml tons
Adapting Mosaic (AM) scenario	Medium, falling yield growth in developed countries, medium low, increasing in developing countries.		Global cereal production increase at 53%	Medium/low growth, improving over time 2020-2050: 1.9%/yr.	Somewhat high population growth 2050: 9.5 bl people	2826.5 ml tons
Techno Garden (TG) scenario	Low yield growth improvements		Global cereal production increase at 57%	Medium income growth in developed countries, low growth in	High population growth 2050: 9.6 bl	

Studies	Yield	Cultivated/arable and harvested land use	Production	Income	Population	Demand
				developing countries 2020-2050: 1.0%/yr.	people	2857.6 ml tons
6.'World Food and Agriculture to 2030/50: How do climate change and bioenergy alter the long-term outlook for food, agriculture and resource availability?'- Gunther Fischer*(used FAO/IIASA,AEZ Model, WFA Model)				World GDP will increase from 27136 bl US $ in 2000 to 98014 bl US $ in 2050 at constant 1990 prices. For Developed Countries it will increase from $19583 bl to $42770 bl. For Developing Countries it will increase from $5135 bl to $49331 bl.	9.1 billion in 2050.	
FAO-REF-00 (starting in 1990 assumes a world without any agricultural crops used for biofuel)		Area of arable land will increase by 70ml ha or by 5%. The total harvested area increases from 1306 ml ha in 2000 to 1583 ml ha in 2050.	Global cereal production will increase by 40% or by some 900 ml tons between 2006/08-2050. Global cereal production will rise to 3.4 bl tons in 2050.			Global cereal consumption will rise to 3.34 bl tons in 2050. Share of developing countries in global cereal consumption rises from 55%-64%.
FAO-REF-01			In 2050, there will be an additional use of 83 ml tons of cereals for biofuels. Additional cereal production (other than for biofuel will be) 68 ml tons.			Demand for cereals for food/feed will fall by 15ml tons. Total cereal demand will be 3454 ml tons.
WEO-V1		In respect to the baseline scenario, globally cultivated land increases by 21%, total harvested land increases by 31%. Most of the increase will be in developing countries.	In 2050, there will be an additional use of 246 ml tons of cereals for biofuels. Additional cereal production (other than for biofuel will be) 180 ml tons.			Demand for cereals for food/feed will fall by 62 ml tons. Total demand for cereals will be 3572 ml tons
WEO-V2		In respect to the baseline scenario, globally cultivated land increases by 29%, total harvested land increases by 43%. Most of the increase will be in developing countries.	In 2050, there will be an additional use of 376 ml tons of cereals for biofuels. Additional cereal production (other than for biofuel will be) 271 ml tons.			Demand for cereals for food/feed will fall by 102 ml tons. Total demand for cereals is 3662 ml tons
		In respect to the baseline scenario, globally cultivated land increases by 48%,	In 2050, there will be an additional use of 446 ml			Demand for cereals for food/feed will fall by 127ml

Studies	Yield	Cultivated/arable and harvested land use	Production	Income	Population	Demand
TAR-V1		total harvested land increases by 71%. Most of the increase will be in developing countries.	tons of cereals for biofuels. Additional cereal production (other than for biofuel will be) 313 ml tons.			tons. Total demand for cereals is 3707 ml tons
TAR-V3		In respect to the baseline scenario, globally cultivated land changes by 29%, total harvested land changes by 42%. Most of the increase will be in developing countries.	In 2050, there will be an additional use of 262 ml tons of cereals for biofuels. Additional cereal production (other than for biofuel will be) 198 ml tons.			Demand for cereals for food/feed will fall by 62ml tons. Total demand for cereals is 3588 ml tons
7. 'Biofuels & Food Security-Implications of an Accelerated Biofuels Production - Summary of the OFID study *prepared by the IIASA'* (used the AEZ Methodology, IIASA World Food System Model)		Additional use of cultivated land is about 35 ml hectares in 2020: 13 ml ha for developed countries and 22 ml ha for developing countries. Regarding developed countries, the increase of 13 ml hectares should be compared to a net decrease of 1 million hectares in a scenario without biofuels.	3.7 bl tons in 2050 (starting from 2.1 bl tons in 2000). Developing Countries' share in total production increases to about 60%			Relative to the baseline reference scenario in 2020 (1350 ml tons for consumption), cereals use for food consumption for developed & developing countries fall by 2 & 6 ml tons resp. The numbers for feed use change are 12 & 9 ml tons resp. But total consumption rises.
8. 'Meeting the Mandate for Biofuel: Implications for Land Use, Food & Fuel Prices'- Chen, Huang & Khanna (used BEPAM)						
Business-As-Usual(BAU)		Total crop acreage decreases by 0.3% from 121.5 in 2007 to 121.1 M ha in 2022 with corresponding increases in idle/pasture land. Corn and soybean acreages would decrease by 0.8 M ha (2.8%) and 0.1 M ha (0.4%) while wheat acreage would increase by 1.2 M ha (5.3%) over the 2007-2022 period.	Production of corn, soybeans and wheat increase by 16%, 10%, 25% respectively over the period 2007-2022			
Biofuels Mandate		The RFS leads to a 6% increase in total cropland (6.86 M ha. There is a 16% increase (about 4.7 M ha) in land under corn in 2022 compared to the BAU.	Corn production rise by 18% relative to BAU. Wheat & Soybean production fall by 8%. Rice, cotton production fall by 8% & 2% respectively.			

Studies	Yield	Cultivated/arable and harvested land use	Production	Income	Population	Demand
Biofuel Mandate with Volumetric Tax Credit		The acreage under corn falls by 8.4 M ha. 10.6 M ha of idle/cropland pasture is converted to produce energy crops. Total cropland increases by 1.1 M ha relative to that under the RFS alone, due to an expansion in acreage under energy crops. Acreage under corn and corn production in 2022 declines by 13% relative to the BAU scenario.	Corn & wheat production fall to 282.2 M MT (321.5 M MT under BAU) & 67.9 M MT (68.5 M MT under BAU) respectively. Soybean production rises to 92.6 M MT (89.5 M MT under BAU).			