Biofuel and Food Security: Insights from a System Dynamics Model.

The Case of Ghana

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Abstract

Empirical evidence from research points to biofuel as a possible substitute to conventional fossil fuel-gasoline and diesel. Some countries—USA and many in Europe—are working towards mandates and legislations that impose on the market a share of biofuel in the national energy mix in the medium to long term. In response to policy preferences and attractive incentives, global biofuel production tripled between year 2000 and 2007 and again was projected to double by 2011 (Molony & Smith, 2010).

Unlike other developed countries, countries in Africa have remained relatively less engaged in the biofuel revolution thus far, but the continent is increasingly viewed as the global powerhouse for biofuel feedstock production (Wetland International, 2008) due to its supposed abundant land resources, cheap labor and preferential access to protected markets. Records on land acquired for biofuel production in Africa is difficult to obtain or are not available. However, recent reports have revealed the scale of biofuel rush in the sub-region where foreign and local firms have acquired large tracts of agricultural land for biofuel production. African governments are increasingly paying attention to the opportunities of biofuel production to stimulate economic development, increase international trade, encourage foreign investment, increase rural development and reduce energy dependency—Tanzania, for instance spends US$1.3-I.6 billion per year, about 25 percent of total foreign earnings on oil imports (Sulle & Nelson, 2009).

This research aims to develop a dynamic simulations model that incorporate available data, evidence and expert's opinion on how biofuel and food production interacts, to project the impact of large-scale cultivation of biofuel feedstock on food security in Ghana. It is hoped that the model could be used as a boundary object to engage policy-makers in developing countries to better understand-quantitatively and qualitatively-the interactions, linkages and feedback relationships among biofuel production, food security and land use. In addition, the model could be used to test the likely impacts of proposed biofuel policies and alternative policies on food security.

The key finding from the simplified model of biofuel and food production interaction is that, as biofuel production takes off, some land will be used for the production of biofuel—albeit as a small fraction of potential agricultural land remaining. But biofuel production is likely to

increase income— to local farmers or investors who are directly engaged in biofuel production—and may revive rural economies of out grower farmers; however, it is expected to contribute to food price increase—the effect chiefly taking hold among the poor, but higher food prices will also cause investment in food production to rise, contributing to eventual high food production. This key finding has policy implications; which suggest that if policy makers place more emphasis on biofuel production without actively supporting food production, could lead to food security issues if gains from biofuel production are not effectively used to reduce cost of food production as food price rise.

1.0 Introduction

In the last decade, countries around the world-especially the U.S.A, Brazil, and many in Europe-have accelerated the production and commercialization of biofuel (An, Wilhelm, & Searcy, 2011). Biofuel growth has led to influx of investors- local and foreign investors - acquiring vast hectares of arable land-mostly in developing countries-for the production of biofuel. The scramble for land to biofuel production (feedstock cultivation) especially in developing countries where food production lags consumption has sparked concerns over the likely effect of biofuel on food security—food availability and access. Moreover, the recent increase in food prices has been attributed, in part, to biofuel production—use of food crops for biofuel that would otherwise be used for human consumption.

Figure 1 shows the price index–nominal monthly average - for agricultural and energy commodities. From the 1980s to the early 1990s, agriculture and energy prices remained relatively stable, however, that changed in the late 1990s, when nominal prices—especially energy—began rising. In roughly six years, energy prices increased four-fold, and continued rising. Agriculture commodities, on the other hand, took a while to change significantly, but around 2006, and since then, food prices have outpaced energy prices.

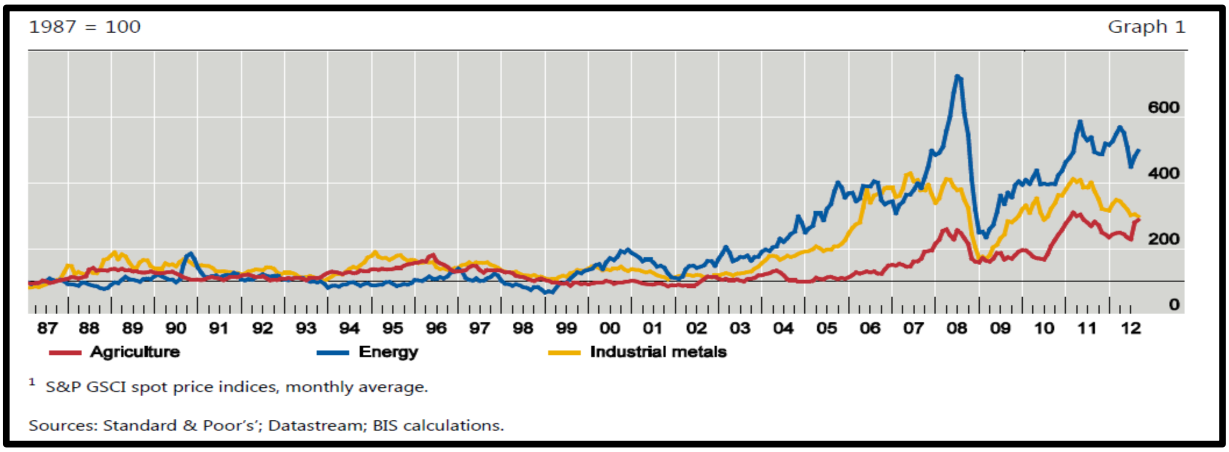

Figure 1: Price index--nominal monthly average--for agricultural and energy commoditioes

Because nominal prices can be deceptive, figure 2 portrays the real price of agricultural and energy commodities—nominal price deflated by US consumer price index. The real agricultural price looks less sharp; and by 2012, the real price of energy has roughly doubled since the mid-1980s, while real agricultural price rose about 50 percent.

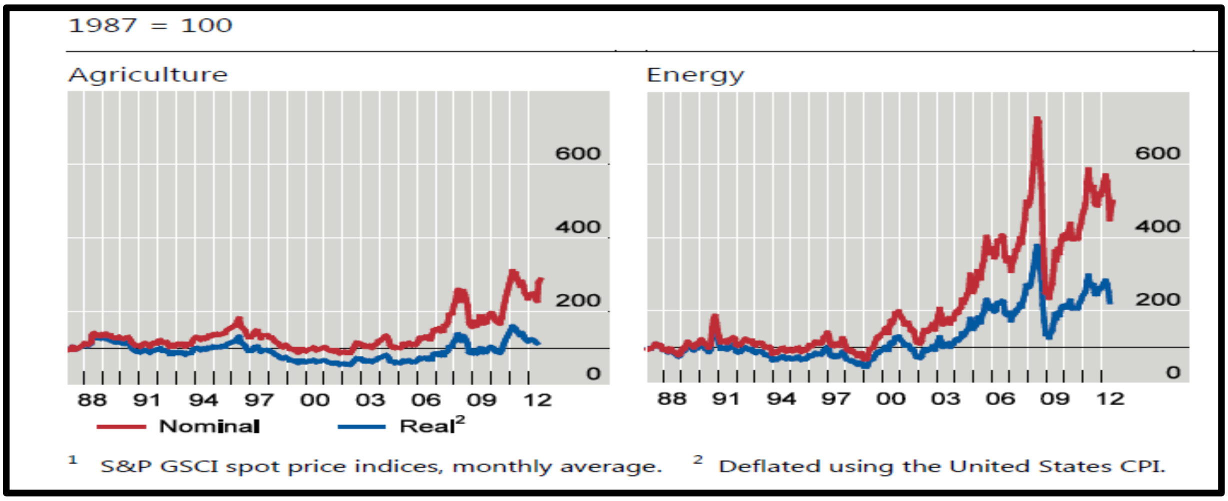

Figure 2: Real price of agricultural and energy commodities--nominal price deflated by US consumer price index

Source: standard & Poor's'; DataStream; BIS calculations.

Africa has become a major importer of food and agricultural products. Majority of Africa's low income countries, mostly Sub –Saharan African had been net importers. Between the years 1980-2007, Africa's total net food imports in real terms grew at 3.4 percent per year due in part to population growth of 2.6 per year. The domestic food production has remained relatively low and increased only by 2.7 per year, just barely above population growth. Since 1980, agricultural imports have grown consistently faster than agricultural export; in 2007 reached a record high (Comtrade, 2010; F. FAO). Raising food imports imply that growth in domestic supply lags the demand (W. FAO, 2012).

Growth in biofuel is stimulated by high fossil fuel prices due to a combination of increasing global demand-to a large extent from energy hungry emerging economies such as China and India-and depletion of easily accessible reserves of crude oil. The "food-versus-fuel" narrative is based on three interrelated arguments; the first is that there is less food available to eat because crops that would otherwise be used for human consumption are being diverted for processing into biofuel. The second is that demand for biofuel has increased the competition for land and water resources that would otherwise be used for cultivating edible crops-and that runs the risk of heightening conflicts over water use, particularly in Africa's drier areas (Cushion, Whiteman, & Dieterle, 2010; Molony & Smith, 2010). As a result of these two concerns is, thirdly, that more production of biofuel will force food prices up and make it more difficult for poor people to purchase food (Molony & Smith, 2010). To direct investment into commercial biofuel, policies and incentives to support research, development and deployment of biofuel have been or are being put in place to increase the production and use of biofuel.

Empirical evidence from research points to biofuel as a possible substitute to conventional fossil fuel-gasoline and diesel. Some countries-USA and many in Europe-are working towards mandates and legislations that impose on the market a share of biofuel in the national energy mix in the medium to long term. In response to policy preferences and attractive incentives, global biofuel production tripled between year 2000 and 2007 and again was projected to double by 2011 (Molony & Smith, 2010).

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This research aims to develop a dynamic simulations model that incorporate available data, evidence and expert's opinion on how biofuel and food production interacts, to project the impact of large-scale cultivation of biofuel feedstock on food security in Ghana. It is hoped that the model could be used as a boundary object to engage policy-makers in developing countries to better understand-quantitatively and qualitatively-the interactions, linkages and feedback relationships among biofuel production, food security and land use. In addition, the model could be used to test the likely impacts of proposed biofuel policies and alternative policies on food security.

System dynamics method is suitable for this research because biofuel and food production as a system is characterized with accumulations, feedbacks, nonlinearity, interconnections and linkages that requires a dynamic simulation model to integrate the system's components (land, demand for and supply of biofuel, demand for food, energy pricing, food pricing and import and export of food) to better understand the behavior overtime resulting from this interactions. System dynamics methodology will provide a rigorous approach for description, investigation and analysis of the interactions between biofuel production and food security.

Consequently, biofuel has become an important part of many energy policies the world over; first, to ensure energy security, and second, to reduce the environmental impact of fossil fuel. Ghana is one of the countries blessed with many oil bearing food crops-jatropha, soybean, sunflower, palm tree, maize, cane sugar and cassava-suitable for biofuel; the potential to produce biofuel is reflected in the strategic national energy policy (SNEP). According to the SNEP, by 2030, 20 percent of national gasoline consumption must be replaced with biodiesel and 30 percent of national kerosene consumption must be replaced with jatropha oil (Ghana, 2006). This strategy is vital to reigning in the cost of oil import, which has been increasing over years-US$1.3 billion in 2005 to US$2.4 billion in 2008. To achieve these targets would require significant restructuring of biofuel feedstock production at the national level. To understand the short and long-term impact of reorganizing and redesigning the agricultural sector in Ghana towards the achievement of the national biofuel targets, it is important to comprehend what it will take to achieve the goal, and the likely intended benefits and unintended impacts-positive and negative-of biofuel production, especially on food security. [1]

The rest of the thesis is arranged in the following way: Chapter two is Model overview which deals with an overview of the structure, the main feedback loops and the interconnections between the model sectors. The remaining chapters following chapter two, individual sectors will be presented in more detail and linked together methodically. The food sector and the biofuels sector will be presented in chapter three individually, the individual sectors will be linked together and model validation will be done. In chapter four, which deals with policy testing will define policy scenarios and run for each policy scenario. Chapter five is the result of the various simulations run. Chapter six is discussion of the result and finally, conclusion remarks and suggestions for further research are presented in chapter seven.

[1] Strategic National Energy Plan (2006-2020) published by the Energy Commission, 2006

2.0 Background of Study

2.1 Brief overview of the energy sector in Ghana

According to Ghana Energy Commission, 76 percent of energy consumption in Ghana is from wood—mainly charcoal and firewood, while 17 and 7 percent respectively, come from petroleum and electricity. Electricity is obtained from hydro (i.e., with two main dams i.e., Akosombo and Kpone, with installed capacities of 1020 MW and 160 MW, respectively. A third dam with installed capacity of 400 MW is under construction at Bui) and thermal plants (i.e., with installed capacity of 831 MW) giving a total capacity of 2011 MW. Ghana is part of West Africa Gas Pipeline project, along with Nigeria (the gas supplier), Togo, and Benin. With an installed capacity of over 700 MW along the coastal areas, the country hopes to take advantage of the cheaper natural gas from Nigeria to produce power at lower cost than using oil. Currently, the gas from Nigeria is used in powering the thermal plant in Aboadze for generating electricity.

At 66 percent nationwide coverage, this means that about a third of the population still do not receive electricity and those who do experience frequent power outage. Ninety percent of rural dwellers still get their light from kerosene lamps. Moreover, about 25 percent of electricity generated is lost through technical and commercial lapses (Ofosu-Ahenkorah, Essandoh-Yeddu, Amankwah, & Dzobo, 2010). Production of biofuel would affect the 17 percent of the total energy component, which comes from petroleum products (Afrane, 2012). According to the Bank of Ghana, in 2008 the country imported US$2349 million worth of crude oil and refined petroleum products (SERVICE, 2010).

2.2 Overview of Biofuel production and investment in Ghana

Ghana has in recent years joined the number of developing countries promoting biofuel investment; consequently, foreign and domestic investors are seeking to acquire large tracts of land for agricultural enterprises including the cultivation of biofuel crops for the production of feedstock. While information on land acquired for biofuel production is scarce or not published by the government, there are few well-documented examples. Prominent oil bearing crops identified for biofuel feedstock production include but not limited to jatropha, cassava, maize, sunflower, soybean, cane sugar and palm tree. According to Hughes et al 2011, Ghana's favorable investment climate has attracted over 20 companies from around the world seeking to acquire tracts of land to cultivate jatropha, sugarcane and palm oil. Four types of biofuel cultivation projects have arisen:

(a) Biofuel cultivation by smallholders for local consumption
(b) Biofuel cultivation by large industrial farms (100 hectares or larger) for local consumption
(c) Biofuel cultivation by out-growers linked to commercial plantation or smallholders linked to commercial biofuel processing plants for national and international consumption
(d) Biofuel cultivation by large industrial farms for national and international consumption

According to (Boamah, 2011), foreign biofuel companies operating in Ghana include Scan Fuel AS from Norway, operating a jatropha biodiesel production in the Asante Akim North Municipality and Solar Harvest AS through its African affiliates—biofuel Africa ltd in northern Ghana and Agroils of Italy in the Brong Ahafo region of Ghana. Boamah 2011 further calls attention to the fact that European Union has launched a two million project for a 500 hectare of jatropha farm at Walewale in the west Mamprusi district of Northern Ghana. Furthermore, biofuel investors seeking land in Ghana for biofuel investment include Israeli company Galten as well as an Indian company requesting for a land area of 50,000 hectares to cultivate jatropha for biofuel feedstock. Other locally owned companies are Biodiesel 1 Ghana ltd and Caltech—Banket Ltd operating a land area of 1,180 hectares for cassava production for ethanol in the Volta region of Ghana. However, the debate on the rapid emerging biofuel industry peaked in Ghana when a company acquired 400,000 hectares of land in 2008 for jatropha plantation.

The government of Ghana has yet to develop a policy governing commercial land acquisitions for biofuels. The ministry of agriculture charged with the Energy Commission with drafting such legislation and no legislation has been finalized yet. With no policy framework guiding commercial land acquisition, advocates against this development argues that rural farmers are vulnerable to losing their land as demand for biofuel increases.

2.3 Agricultural Resources in Ghana

Ghana has a total land area of 238,537 sq. km, with an estimated population of 24.6 million according to the 2010 population census. For agriculture, there are six agro-ecological zones—rain forest, deciduous forest, transitional zone, coastal savannah and Sudan savannah—classified based on climate, which reflect the national vegetation and the soil type (Kemausuor, Akowuah, & Ofori, 2013). Table 1 below describes the characteristics of the agro-ecological zones in Ghana:

Zone	**Area (1000ha)**	**Rainfall (mm/yr)**	**Dominants land use**	**Main food crops**
Rain forest	750	2200	Forest, plantations	Cassava, maize, oil palm
Deciduous forest	740	1500	Forest, plantations	Cocoa, cassava, maize, oil palm
Transitional forest	6630	1300	Food and cash crops	Maize, cassava, yam, groundnut
Guinea savannah	14790	1100	Food, cash crops, livestock	Maize, sorghum, millet
Sudan Savannah	190	1000	Food crops and livestock	Millet, cowpea, groundnut
Coastal savannah	580	800	Food crops	Cassava, maize

Table 1: Characteristics of agro-ecological zones in Ghana

Source: adopted from (Kemausuor et el, 2013)

As indicated above, annual rainfall ranges from about 800 mm along the coastal savannah to 2200 mm in the rain forest. About 155,000 sq. km. which is about 65 percent of the total land area in Ghana is classified as agricultural land (Worldstat.inf) Like many developing countries in the world where agriculture production has virtually been dominated by small-scale farmers, Ghana's agricultural sector is characterized by small-scale farmers employing manual cultivation techniques with little or no purchased inputs providing 90 percent of the total food supply (Garrison, 1990; Haralambous, 1993; Odulaja & Kiros, 1996). Agriculture is an important sector to the economy of Ghana, contributing 30 percent to the value added to GDP at 2010—representing a reduction from 40 percent as of 1995, and providing approximately 50 percent employment. Cocoa earnings including beans and cocoa products have typically constituted the greatest portion of Ghana's total export earnings. Ghana's share of world cocoa production has fluctuated between 25% and 40% since 1960. Starchy foods generally appear to have low export potential

Food production in Ghana has increased from approximately 42.8 million tons in 2000 to 70.3 million tons in 2011 (see figure 3 below). However, net food import (food export minus import) has increased systematically from 1.62 million tons in 2000 to 3.78 million tons in 2010, representing 0.01 percent of food production as at 2010.

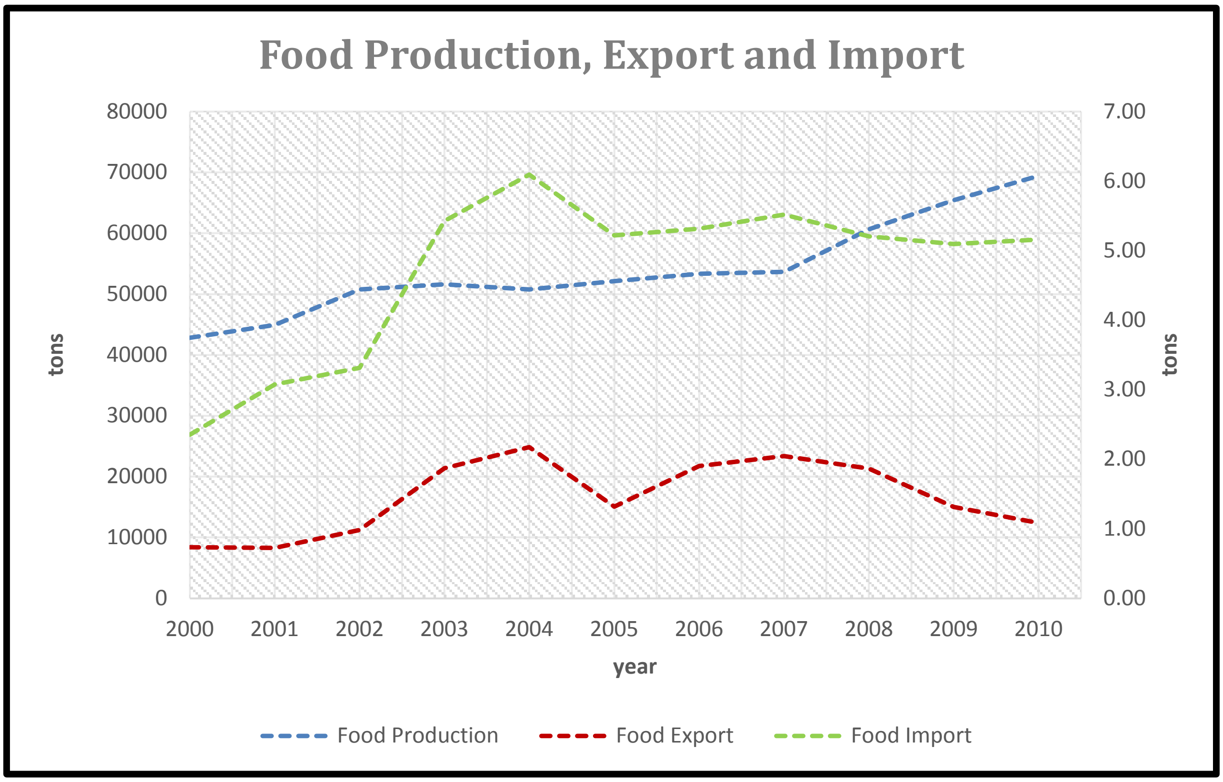

Figure 3: Food production, export and Import in Ghana from 2000 to 2010

Source: United Nations Food and Agricultural Organization (FAOSTAT)

Figures 4, 5 and 6 below show the production trend overtime of the major cereals, roots and tuber and cash crops grown in Ghana. These varieties of crops are cultivated in different kinds of land in different climatic zones which ranges from dry savanna to wet forest ((SRID), May, 2011).

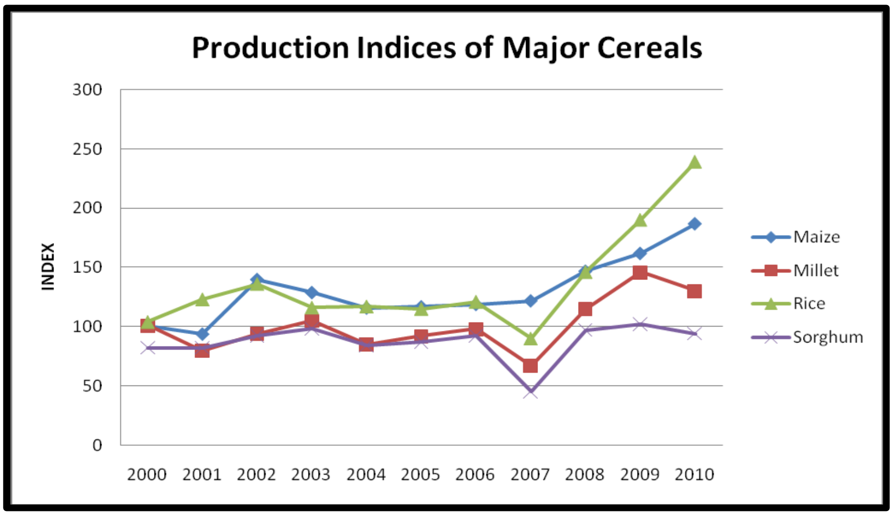

Figure 4: Production of major cereals

Source: Ministry of Food and Agriculture, Ghana

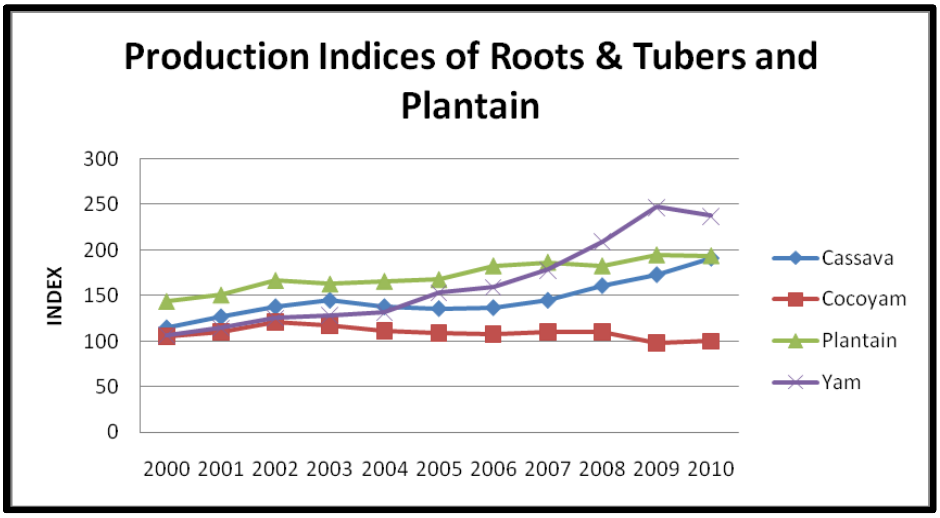

Figure 5: Production of roots and tubers and plantain

Source: Ministry of Food and Agriculture, Ghana

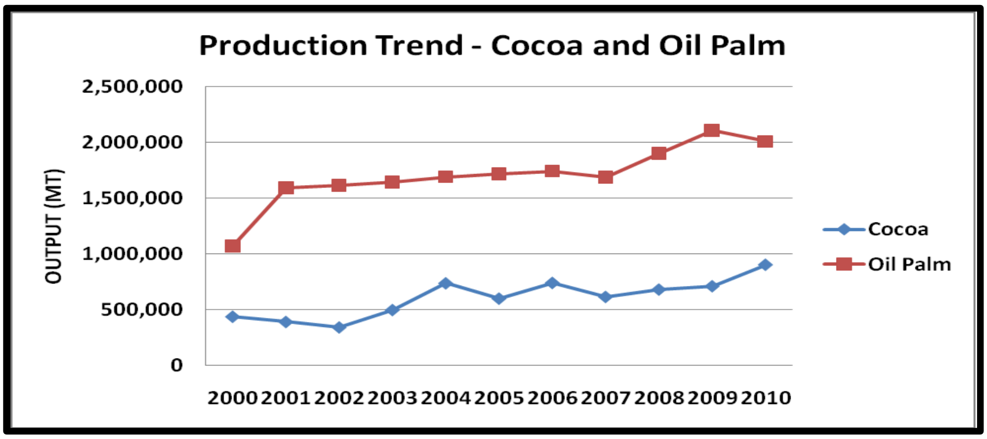

Figure 6: Production of cocoa and oil palm

Sources: Ministry of Food and Agriculture, Ghana

Situated in the tropical climate, Ghana has the advantage of growing the most desirable energy crops for biofuel production such as sugarcane, corn (maize), sweet sorghum, cassava, oil palm and jatropha, which already forms part of the types of crops grown in Ghana.

Agricultural land under cultivation in Ghana has increased from 42 percent in 2000 to 47.8 percent in 2011. Land tenure system in Ghana—the way in which rights to land is obtained and distributed among people—especially agricultural land is predominantly communal (i.e., where land ownership is the expression used to describe the system whereby land is collectively owned by an extended family, clan or community of ancestrally related people with the control of administration of the land vested in the leader of the group). Moreover, other avenues for acquiring land for agricultural purpose are (a) through leasing for a fee for 25 to 50 years, and (b) through sharecropping—where returns from the farm itself are shared between land owner and the tenant.

Ghana has three dominant farming systems according to the intensity of cultivation: bush fallow system, permanent system and combined system (Ngeleza, Owusua, Jimah, & Kolavalli, 2011) see figure 7 below. The bush fallow system involves intercropping trees in outfields used on a rotational basis that are located 1-6 kilometers from the compound house. Bush fallow is characterized by rotation of fields rather than of crops, easy acquisition of land for cultivation, use of fire for clearing vegetation, dependence on muscle power, and use of simple implements such as machetes and hand hoe for cultivation (Ngeleza et al., 2011). However, as population increases, bush fallow system of farming becomes unsustainable and cultivation of land shift to permanent cultivation. Permanent farming system stretch across different ecological zones in Ghana and involves tree cash cropping such as cocoa and food cropping such as cocoyam, plantain and cassava, albeit these system take forms of permanency (Ngeleza et al., 2011). The combined system of farming on the other hand, includes compound farming and distant farming. Compound farming includes cultivation of the land immediately surrounding the compound house and is observed in the densely populated area of northern part of Ghana. In addition, farmers cultivate larger fields far from home where they practice bush fallow system (Ngeleza et al., 2011).

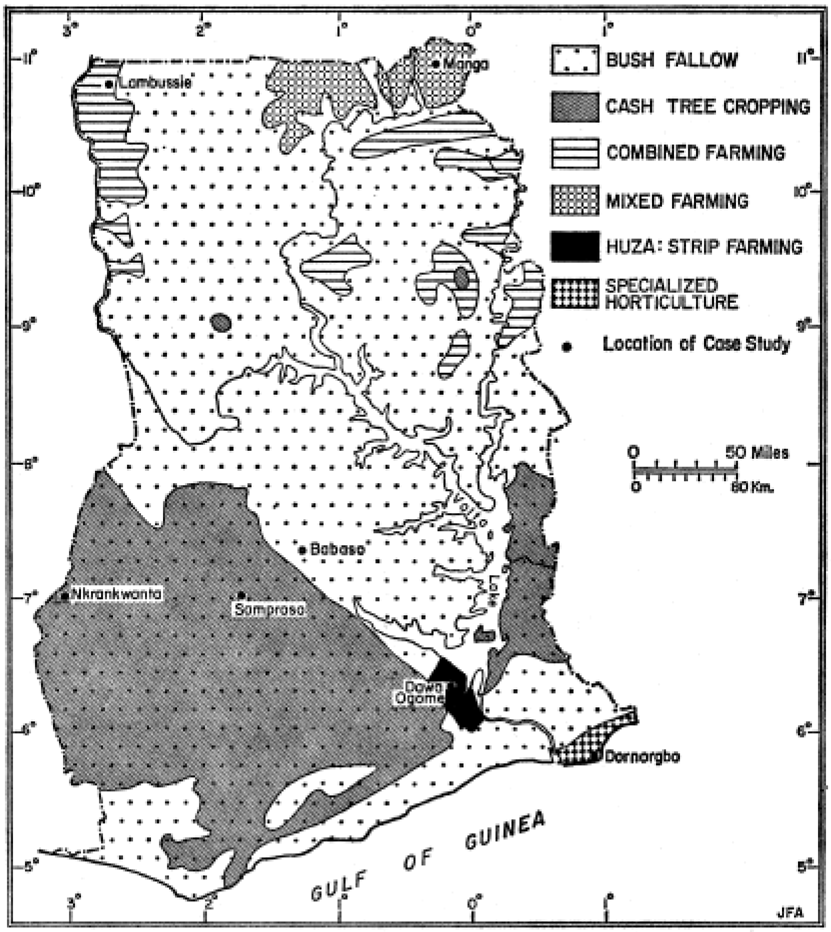

Figure 7: Farming systems in Ghana

Source: (Benneh, 1973)

According to (Breisinger, Diao, Thurlow, & Al-Hassan, 2008), crop (food) production which is a subsector of the agricultural sector in Ghana, forms between 75 to 80 percent of the entire agricultural sector growth between the years 1991 and 2006. Cocoa, which is one of the major cash crops, contributed 15 to 30 percent of the total agricultural growth in Ghana (Quiñones & Diao, 2011). Crops other than cocoa have been more modest and ranged between 1.5 and 4.5 percent during 1991 -2005 (Breisinger et al., 2008). Predominantly, increase or expansion of farm land together with modest improvement in crop yields have been the contributory factors for the development of staple crops production.

Agricultural production (crop) is mainly on a small scale basis in Ghana. Approximately 90% of the lands cultivated by the farmers are less than 2 hectares in size. Notwithstanding that, there are medium and large scale farms and plantations, specifically for some crops- cocoa, oil palms, coconuts and some staple crops- maize, rice, pineapples, etc. Principal agricultural produce (crops) are categorized under three headings: Industrial crops, starchy & Cereal staples and Fruits and Vegetables. Traditional method of farming where by hoes and cutlass are the major farming tools is mostly used in Ghana. Only few farmers apply mechanized farming in cultivating crops. Intercropping (an agricultural practice in which two or more crops are grown together in the same piece of land) is the farming practice mostly adopted by the farmers cultivating sizeable land and the large scale commercial farmers practice mostly mono cropping (an agricultural practice in which the same crop is planted year after year).

3.0 Literature Review

3.1 Introduction:

The global increase of biofuel production and demand has raised concerns about the possible impact of this development on food security. Competition for arable land and rise or fluctuation of food prices are seen by advocates against biofuel production as the two foremost risks for food security of the poor in developing countries. However, multiple reasons account for food insecurity, therefore, understanding the various drivers of food insecurity is necessary to understanding possible impact of biofuel production on food security.

There are various definitions and concept of food security; however, one that is widely accepted is the World Food Summit, 1996, which defines food security to "include physical, political and socio-economic determinants to procure and consume food". According to this definition, "*food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meet their dietary needs and food preferences for an active and healthy life*". Inversely, food insecurity exists when people do not have adequate physical, social or economic access to food as defined above (FAO, 2009, 2010).

The list of causes of food insecurity is multifaceted: they range from political instability, war and civil strife, macroeconomic imbalances and trade dislocations to environmental degradation, poverty, population growth, gender inequality, inadequate education and poor health. These causes can be categorized into two main causes: insufficient national food availability and insufficient access to food by households and individuals. Total food availability is determined by food production. In any given year, at the national level, national food availability is determined by a country's own food production, its stock of food and its net import—import minus export—comprising food aid—as is the case in many developing countries. At the household or individual level, access to food irrespective of food availability, may be gained through; production of food, purchase of food from the market and receipt of in-kind transfers of food –whether from national or international institutions.

3.2 Theories of Famine (Food security)

This sections discusses the three main theories of famine (food security), namely demography (neo-maulthusianisim, economic or entitlement failure and politics—complex emergencies.

3.2.1 Demography—Neo-Malthusianism:

The neo-Malthusian theory of famine (food security) emerged from Thomas Malthus' essay on "the principle of population" (Malthus, 1798) which demonstrated, in its simplest from, that population could not continue growing indefinitely in a world of fixed natural resources. Eventually, famine (food security) would act as a natural check on population growth, equilibrating the demand for food with food supplies. The neo-Malthusian view of famine peaked in the 1060s and 1970s during the world food crises with the popular perception that the world was running out of food, though with hindsight, this proved to not be the case (Devereux & Berge, 2000). However, this perception is held by people with the believe that productivity gains from agricultural intensification during the 20th century (mechanization, chemical fertilizer, and high-yielding crop varieties) are tailing off, while the demand for food continues to increase. Consequently, the combination of rising demand for food and stagnating food production could eventually overwhelm the world population, pushing it into a new era of food scarcity.

But, opponent of this theory argues that, this world view fail to factor in projections that the global population will stabilize at around nine billion people, as fertility transition spreads throughout the world. Moreover, just as Malthus was taught to have failed to foresee the exponential increases in agricultural productivity that world accompany industrialization and urbanization in Britain, so current biotechnology research offers the prospect of a new agricultural revolution that will push the production possibility frontier well beyond the consumption needs of the projected 21st century global population (Ryan, 1999).

The argument of population exceeding natural resources has been invoked to explain onset of food crises in Africa and Asia. The carrying capacity debate united demographers and environmentalist in a neo-Malthusian perspective to argue that persistent of famine was due to overgrazing in Sahelian Africa and overpopulation in Asia. In a rebuttal, (Boserup, 1983) offered a counter-Malthusian argument for sub-Saharan Africa where, in her view, excessively low population densities increase vulnerability to famine (food security) by inhibiting investment in basic economic infrastructure and agricultural technologies. In any event, evidence available support the view that even the worst famines in history have conspicuously failed or even slow down population growth in the affected countries (Devereux & Berge, 2000). According to Osmani, in demographic terms, it will appear that famine does not matter much in the long run, because famine generally afflict sexually reproductive cohorts least and children and the elderly most, and most famine are followed by compensatory baby boom, with evidence pointing to population dynamics in China and Bangladesh, where a period of famine mortality and associated fertility decline was completely compensated for by return of population growth above and beyond the decline. However, as succinctly stated by (Watkins & Menken, 1985), the only way famine (food security) and other mortality crises related to food security could have been a major deterrent to long-run population growth is if they occurred with a frequency and severity far beyond that recorded for famine in history.

3.2.2 Economics—Entitlement Failure:

Two distinct strands of economic theories of famine (food security) can be identified in the literature (Devereux & Berge, 2000); they are market failure and demand failure. According to the market failure argument, famine is a product of imperfect market; where food market malfunction during food crises either because they are week or unintegrated, or because speculative and precautionary hoarding drives food prices up to unaffordable levels. Evidence for market failure according to (Seaman & Holt, 1980) was found in Ethiopia where food price rises were exported from famine epicenters, as drought-stricken Ethiopians migrated to neighboring and then distant market and drove prices up there, because of a failure of traders to import food to their isolated villages. Similarly, (Von Braun & Olofinbiyi, 2007) demonstrated econometrically that segmentation was prevalent in many food markets in Ethiopia during the famine years of the mid-1990s. Conversely, market failure due to excessive hoarding is a feature of certain South Asian famines, which was triggered by alarmist prediction of flood damage to crops that turned a minor shortfall in rise production into a major shortfall in market supplies, so that price escalated beyond the reach of the market dependent poor.

The second strand of theory emphasizes demand failure as possible cause for famine. The seminal contribution of Sen's "Poverty and Famine" in 1981, in which Sen applied his then development entitlement approach to the reinterpretation of four African and South Asian famine is undoubtedly the most important contribution to this theory. Sen's argument was to shift famine (food security) discourse away from its preoccupation with supply failure to effective demand failure or what he calls "entitlement collapse"—the inability of identifiable groups of people to command enough food for subsistence, irrespective of the stock of food available at local and international level. The entitlement approach has four major ways of acquiring food: production based entitlement (growing it), trade-based entitlement (buying it), own-labor entitlement (working for it) and transfer entitlement (being given it). According to the theory, individuals face starvation (food security) issues if their entitlement set does not provide them with adequate food. Entitlement failure can be a loss of access to productive based entitlement (such as during a crop and livestock destructive drought), a fall in trade or own labor entitlement due to unfavorable shift in prices (livestock prices fall, food price rise) or income (nominal or real wage fall, wages are lost due to unemployment). According to the entitlement theory, direct entitlement decline is analogues to a food availability decline at the aggregate level; while an exchange entitlement decline is purely a reflection of market forces. Thus, people can starve because they lack entitlement to access available food, even if markets are well stocked and prices are low. Sen's entitlement approach was applied to the analysis of boom famine—famine which might occur even while food availability is rising, because of adverse shifts in access to food for specific groups. Moreover, the entitlement theory was used to argue against what Sen labelled "Malthusian optimism" with the belief that adequate calories at the national level means that there is no risk of famine, which derives from the food balance sheet fallacy that food supplies are evenly distributed among the population.

Criticize of the entitlement theory argues that despite its elegance and simplicity, the one thing the entitlement approach did not offer was an explanation to famine (food security). They argued that the entitlement theory showed how people might face starvation during famines; it did not tell why. By doing that, it was argued that Sen perpetuate a technocratic view of famine that excludes politics and intent as causal factors and political action rather than public action as an appropriate even necessary solution. (Edkins, 1996) draws attention to Sen’s exclusion of non-entitlement transfer. Edkins argues, to the extent that the legal system of many countries upholds private ownership rights by force even if this denies subsistence to others.

3.2.3 Politics—Complex Emergencies:

For those who view famine as a political phenomenon, famine victims are defined not by economic but by political powerlessness—the near-total lack of rights or political muscle within the institutions of the state (Keen, 1994). Keen suggests that: the real roots of famine may lie less in a lack of purchasing power with in the market (although this will be one of the mechanisms of famine) than in a lack of lobbying power within national and international institutions. This argument is very different from the perspective taken by demographers and economists, both of whom neglect to assign culpability for famine to anyone other than the victims themselves and the banal mechanisms of market forces.

According to (De Waal, 1989) the well-known success of independent India in preventing famines has been due to the vigilance of its political institutions and electors in ensuring an adequate level of government accountability. Thus, a political contract imposes enforceable obligations on rulers to provide for certain basic needs and human rights of their citizens, specifically, in this contract, famine is a political scandal. The contract is enforced by throwing out a government that allows it to happen or otherwise punishing those in power. It is argued that, by extending this assertion, the persistence of famine in other countries might be explained in terms of an absence or failure of such a political contract. Thus, where respect for basic civil and political right is lacking, the state faces less compulsion to priorities the basic needs of its citizens—famine will go unpunished—and this largely explains why famine are more likely to occur under authoritarian regimes or during civil war, rather than in stable democracies with an active civil society.

This argument extends to the international community as well as national governments. If indeed famine is caused by failure of political accountability, then international governments and humanitarian organizations must share responsibility for famines that occur because of failure to respond adequately and promptly to developing food crises. According to (Wolde Mariam, 1986), natural phenomena have less to do with current famine than society itself and its various institutions. For Wolde Mariam, critical examination of recent famines suggest that even where drought or flood is given as the causal trigger, war or repressive government policies also played a significant role.

4.0 Methodology

Based on literature review on available evidence as well as discussion with individuals knowledgeable in biofuel production in Ghana, on how biofuel and food production interacts; and it's empirical and perceived impact on food production, food security, agricultural land and income; in a developing country context under the assumption of gradual substitution of conventional fossil fuel with biofuel, a system dynamics model was developed to capture and represent the interactions and the capacity of the Ghanaian agricultural sector to meet current and future food and biofuel demand.

I took as a point of departure the aim of this research; to develop a dynamic simulations model that incorporate available data, evidence and expert's opinion on how biofuel and food production interacts, to project the impact of large-scale cultivation of biofuel feedstock on food security in Ghana. Firstly, I aimed to develop a set of causal relationships that would explain the likely evolution of an agricultural sector that focuses on meeting the current and future demand for food and biofuel. Second, I am interested in doing "what if" analysis to gain insight in how the agricultural sector and its goal of meeting food and biofuel needs will developed under different sets of policies. Considering the above objectives, I believe this call for causal model which will not only describe but explain the observed behavior from the set of causal relationships; hence the use of system dynamics methodology due to its ability to represent a dynamic and long term perspective including delays and nonlinearities and link observable patterns of behavior of a system to micro level structures and decision making processes (J. W Forrester, 1971; Parayno & Saeed, 1993; Qudrat-Ullah, 2005; Yamaguchi, 1994).

4.1 Overview and Model Boundary

The model presented herein represents a simplified interaction between food and biofuel production. There are four major sectors of the model: population, food production, biofuel and land.

The population sector consists of the population, births and deaths. However, the food production sector employs agricultural capital and land for the production of food. Investment that goes into building agricultural capital is determined in the food production sector by expected profitability. Conversely, the biofuel sector, increases the demand for food crops, as biofuel capital is built and installed to use food crops (feedstock) for the production of biofuel. The allocation of food for biofuel is determined by relative profitability of biofuel and biofuel. Finally, the land sector categorizes agricultural land into three categories: land under food cultivation, land under biofuel production and potential agricultural land remaining. As demand for food and biofuel increase, *ceteris paribus,* land under food and biofuel cultivation will increase consequently decreasing the potential agricultural land remaining. The model configuration allows transfer of land between food and biofuel cultivation, determined by the relative profitability.

The model boundary (Table 1) divides the major variables into those endogenous to the model, those exogenous to the model and those major variables or concepts excluded from the model. The endogenous variables—although not exhaustive—include major population, food production, biofuel and land aggregates. In addition, the exogenous variables represent variables that are included in the model but are unlikely to be influence directly by the output of the model. The exogenous variables however, are variables or concepts that are outside the model boundary.

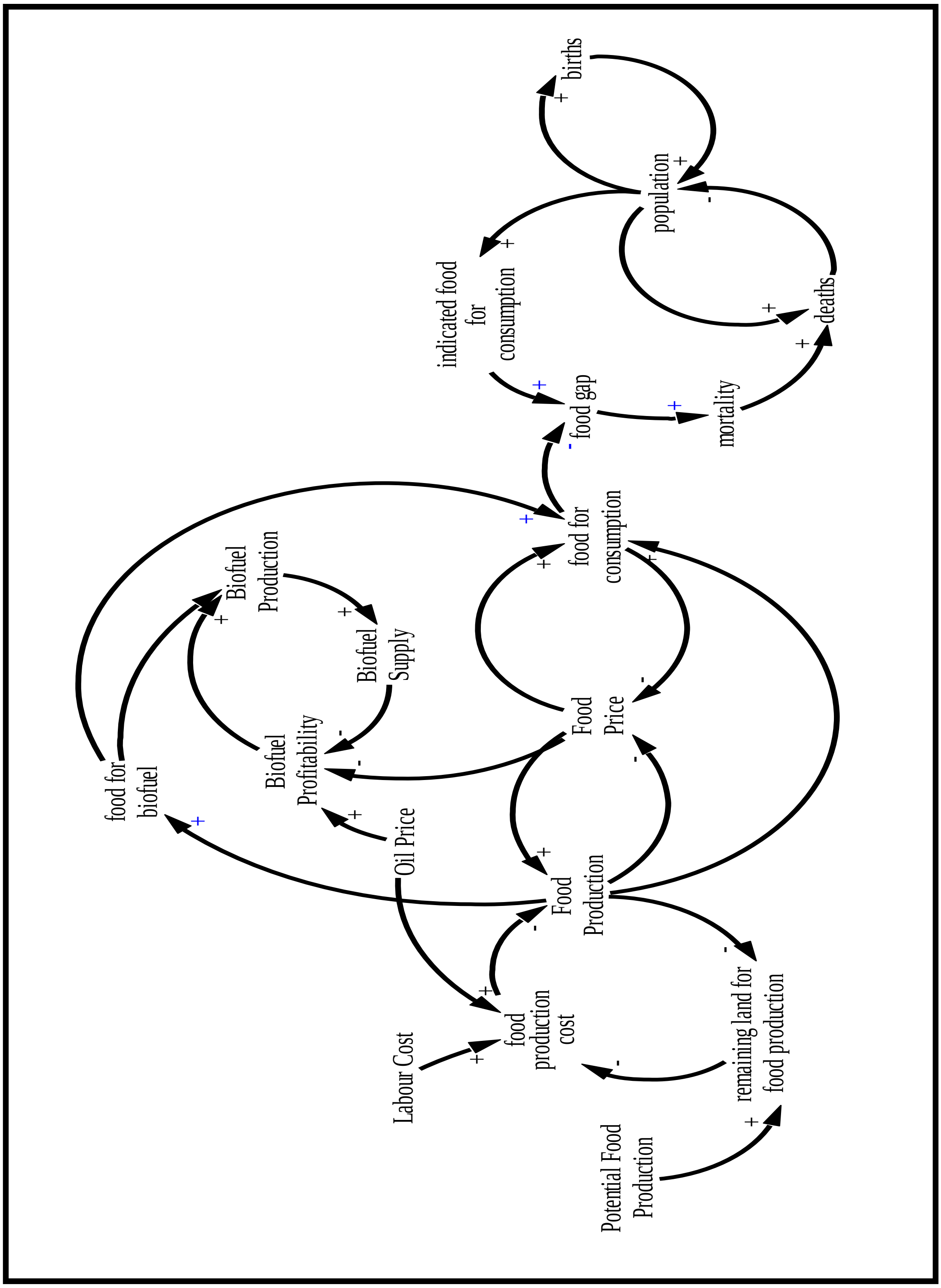

Figure 8: Causal loop structure of biofuel and food security

Endogenous	Exogenous	Excluded
Population	Crude Birth Rate	Economy
Deaths	Food Imports	Purchasing Power
Food Production	Food Exports	Biofuel production capital
Food Consumption	Oil Price	
Food for Biofuel	Capital Life	
Agricultural Capital		
Total Food Demand		
Land Productivity		
Land under Cultivation		
Potential Agricultural Land Remaining		
Biofuel Demand		

Table 2: Model boundary

4.2 Sources of Information for Modelling:

The complex nature of social systems makes it ever vital for social models to draw on vast amount of relevant data about the social system being modeled. According to (Jay W. Forrester, 1994), three main data sources that modelers should tap into in developing complex dynamic social models are: mental data base, written data base and numerical data base.

Mental data base:

Mental data base consist of relevant data about the social system being modeled that resides in the minds of people with significant experience of the system or people who have experienced the system and are able to share their experience. Mental data base is particularly rich in structural detail about operation and past behaviour (trends and patterns of key variables) that is useful in guiding model conceptualization and for building confidence in simulation (Morecroft, 2007). By talking to individuals with experience in biofuel production and how it interacts with food production, data collected during the informal conversations was used to guide the model conceptualization and more importantly, where numerical data was not available authors estimates were discussed with these individuals for validation.

Written data base:

This data base consists of published data from studies that could be used to improve our understanding of how the social system works. For the purpose of this study, a significant written data base from peer-reviewed journals and reports that describe food production in Ghana and the interactions between food and biofuel production were utilized to deepen my understanding and more important to validate model structure and equations.

Numerical data base:

Numerical data base includes secondary data sources used by modelers to initialize and parameterize models. In this study, I used numerical secondary data from the statistical division of Food and Agricultural Organization of the United Nations (FAOSTAT), Ghana Statistical Services, data from published studies and author's estimates.

4.3 Model Structure

This section presents the stock and flow structure of the population, food, biofuel and land sub-models herein referred to as the model. In system dynamics, dynamic behavior is thought to arise due to the principle of accumulation—which states that all dynamic behavior occurs when flows accumulates in stocks. A stock, however, can be described as a bathtub and a flow as a faucet and a pipe assembly that fills (inflow) or drains (outflow) the stock. In addition, in system dynamics modeling, both informational and non-informational entities can affect flows and consequently accumulates in stocks. The population, food and biofuel sub-models comprise of stocks, flows and causal links (represented by arrows that links information to flow variables). The stocks, flows and causal links consist of interconnecting set of differential and algebraic equations developed from a broad range of relevant empirical data (Homer & Hirsch, 2006) to capture my understanding of the interrelationships among population, food, biofuel and land production and its impact on food production, food security, agricultural land and income.

4.3.1 Population Sub-Model:

Figure 8 below shows the structure of the population model. Fundamental to the understanding of the likely future demand for food and energy in Ghana is the demographic characteristics of the population. The population sector models the population in its simplest form to keep track of the main components of population change: births and deaths (White, 2000). The relationship between births and deaths is assumed to determine population growth—due to unavailable data on migration. Using the crude birth rate—number of live birth occurring during the year (RATE, 1988), birth is computed as inflow to the population and death as an outflow, determined by mortality rate. To account for the effect of food security on mortality, we assumed a positive nonlinear relationship between "food consumption per person" and "life expectancy" at birth. In other words, as "food consumption per person" decreases, it is assumed that mortality rate associated with inadequate food will increase, causing "life expectancy" at birth to decrease beyond "normal life expectancy".

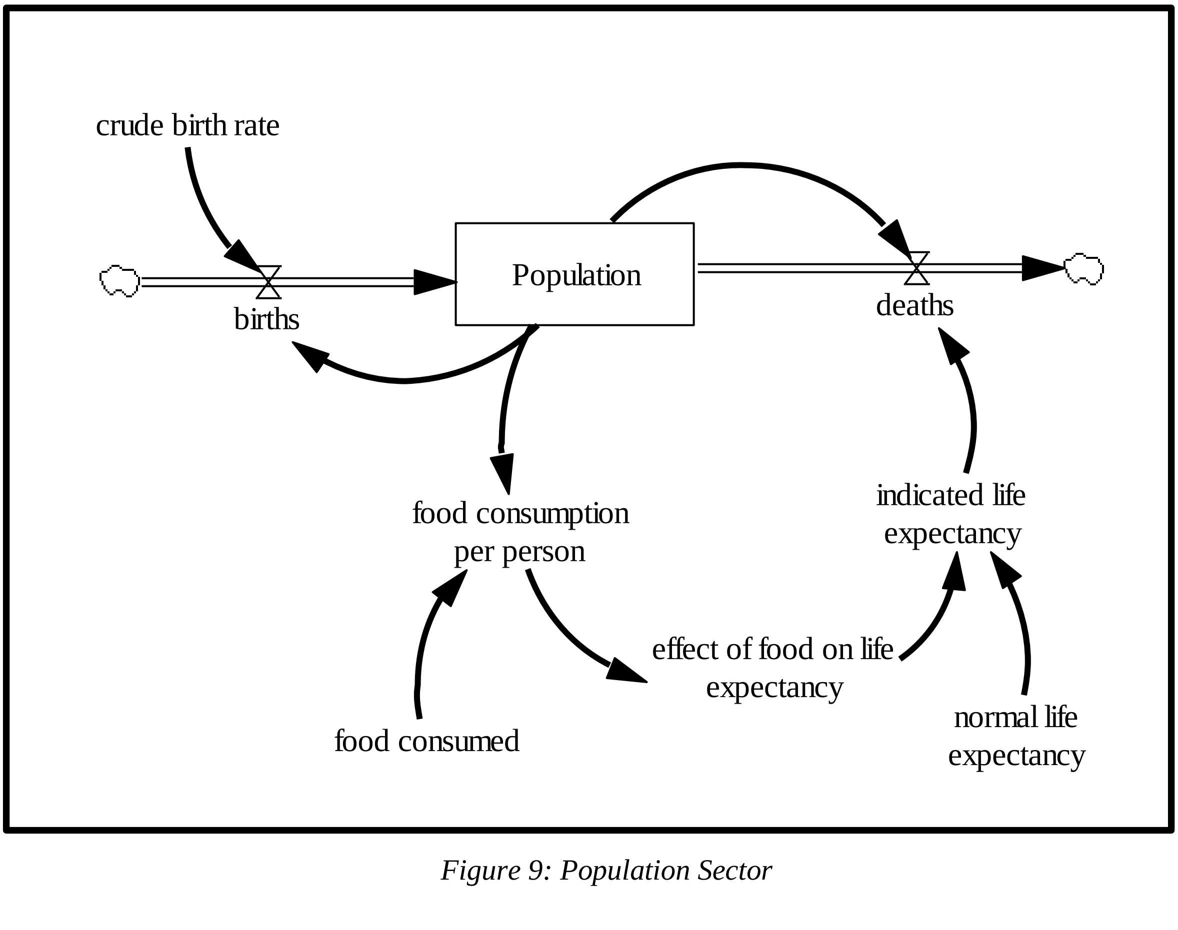

Figure 9: Population Sector

4.3.1.1 Population Sub-Model Equations

The population stock is represented mathematically in the model as:

$$P_{t+1}=P_t + (dt)BR_t - (dt)DR_t$$

Where P_{t+1} is the current population; P_t is initial population at time (t); BR_t is births at time (t); and DR_t is deaths at time (t).

Birth is calculated in the model as a function of crude birth rate *(CBR)* and current population (P_{t+1}). Births equation is represented as:

$$BR = CBR * (P_{t+1})$$

Death, on the other hand is determined by "indicated life expectancy" at birth. The equation for deaths is represented as:

$$DR = (P_{t+1}) / \text{indicated life expectancy}$$

Where "indicated life expectancy" is defined as "normal life expectancy" multiplied by the "effect of food on life expectancy". The relationship between "food consumption per person" and "life expectancy" at birth is depicted in figure 10 below. The equation for "indicated life expectancy" is:

Indicated life expectancy = Normal life expectancy * effect of food on life expectancy

For the purpose of this model, "food consumption per person" is assumed to be the only variable that affects life expectancy, albeit nonlinearly. Hence, as "food consumption per person" increases, generally, normal life expectancy is assumed to increase. However, "normal life expectancy is a model parameter defined under model inputs.

Food consumption per person is defined in the model as "food consumed" divided by population. Thus as population increases, all things equal, food consumption per person is expected to decrease, and vice versa. The equation for food consumption per person is:

Food consumption per person = food consumed / population

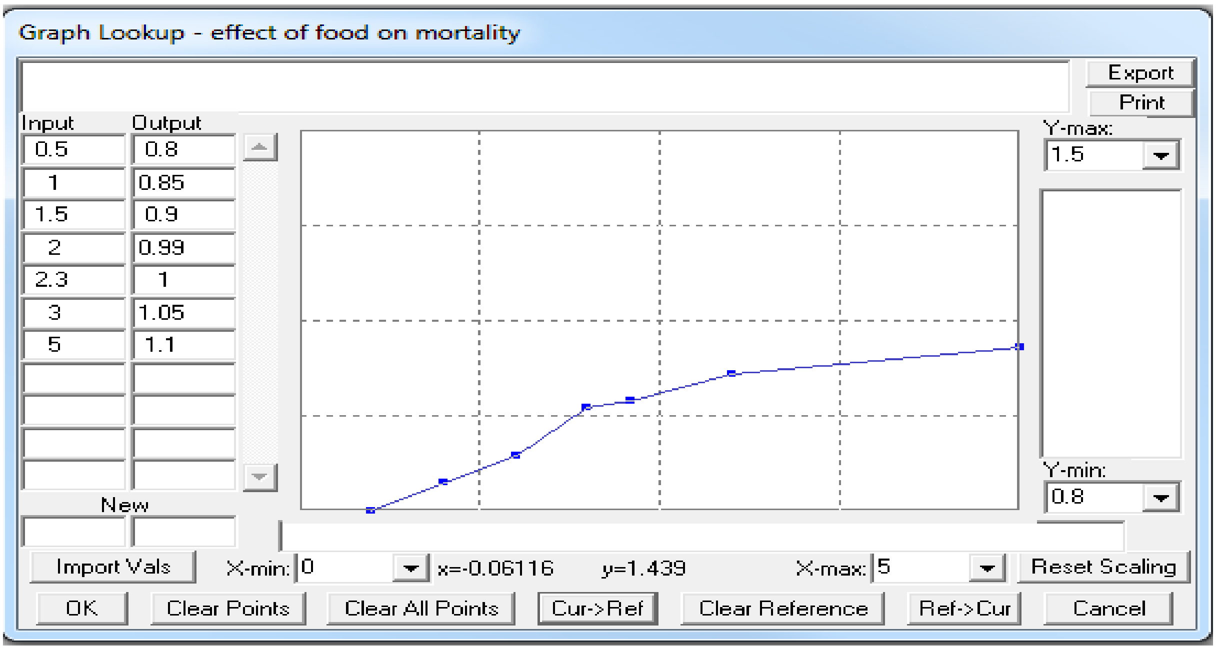

Figure 10: Effect of food on life expectancy

4.3.2 Food Production Sub-Model:

The food production sector projects the demand for and supply of food crops for human consumption. On the demand side, demand for food is determined by population and per capita food demand. The impact of food price on food demand was captured by the effect of food price on per capita food demand to demonstrate the negative relationship between food price and food demand. As population increases, demand for food is postulated to increase.

On the supply side, the structure of the food production sector shows food production as a process of deploying capital—physical and human—to cultivate land for food production. Food production capital is the accumulation of new capital—from investment—and capital depreciation. As food production capital change over time—represented in the model as "relative food production capital"—productivity of land is postulated to change; assuming a positive association.

In the model, food price is determined by food demand supply balance and oil price. Oil price and food demand supply balance are hypothesized to be positively related to food price; thus, as oil price and food demand supply balance rise, food price is expected to increase accordingly, consequently, increasing expected profit. As expected profit to food production increases, all things equal, agricultural investment, land productivity and food production are expected to increase over time, therefore, in turn raising food supply and decreasing food demand supply balance and food price.

Food consumption per capita—a blended measure of “food security”—is defined in the model as the available food—food production minus food export plus food imports—divided by the population. The structure of the food production model is depicted in figure 11 below.

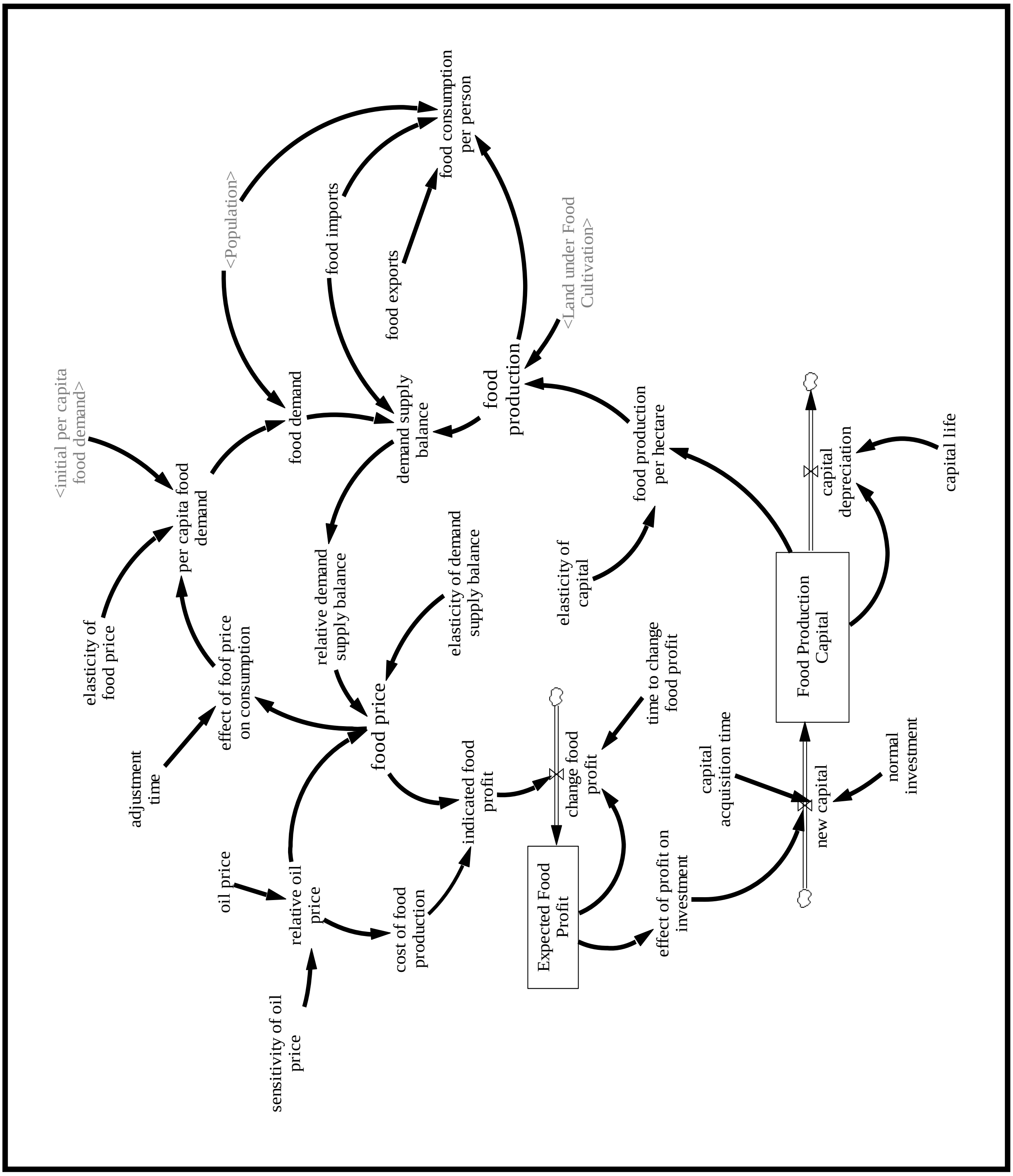

Figure 11: Food Production Sector

4.3.2.1 Food Production Sub-Model Equations

The food production capital—which is defined as physical and human capital, includes but not limited to agricultural machinery, irrigation and high productivity seeds—integrates investment (i.e. new capital) and capital depreciation. The difference equation for agricultural capital is:

$$\text{Food Production Capital}_{(t+1)} = \text{Food Production Capital}_{(t)} + (dt)\ \text{new capital} - (dt)\ \text{Capital Depreciation}$$

Where food production capital (t+1) is current food production capital and food production capital (t) is initial agricultural capital.

New Capital herein is a function of normal investment, effect of expected profit on investment and the time it takes to acquire and install capital. The algebraic equation for new capital is:

New Capital = (Initial investment * effect of expected food price)/ Capital Acquisition Time

Effect of expected profit on investment is modeled as a relative expected profit, wherein expected profit is divided by initial expected profit to estimate the relative change in investment due to change in expected profit.

Capital depreciation is assumed to be a common geometric depreciation with an average capital life of 15 years. The equation for capital depreciation is:

Capital depreciation = Agriculture capital/ capital life

Food production is modeled as a function of land under food cultivation and food production per hectare—which is a proxy for land productivity. Land under food cultivation is explained in the land sector; however, food production per hectare is determined in the model by initial food production per hectare multiplied by relative food production capital. The algebraic equation for food production as used in the model is:

Food production = Food production per hectare * Land under food cultivation

Where food production per hectare is modeled as:

Food Production per Hectare = Initial food production per hectare*

(Food Production Capital/Initial Food Production Capital)^Elasticity of Capital

Food consumption per person is the average per capita food consumption. The algebraic equation for food consumption per person is:

Food Consumption per person =

(Food Production + Food Imports — Food Exports)/Population

Food imports and exports are exogenous variables initialized with time series data of food imports and exports from years 2000 to 2010.

Food price is a function of oil price and the demand supply balance of food. Hence, due to heavy reliance of food production on fossil fuel for fertilizer, powering machinery, as well as, transporting food crops, a change in oil price is hypothesized to positively influence food price; whereas, elasticity of demand supply balance of food on food price was estimated to approximate the likely effect a change in demand supply balance on food price. The equation for food price is:

Food Price = Initial Food Price * Relative demand supply balance

^ Elasticity of demand supply balance * relative oil price

Relative oil price is the current oil price divided by the initial oil price—the oil price at the start of the simulation (i.e. oil price at year 2000); where relative demand supply balance of food is the current demand supply balance of food divided by the initial demand supply balance (at year 2000). Demand supply balance of food, however, is defined as food demand divided by the sum of food production and food import.

For simplicity, cost of food production is assumed to be influenced by changes in oil price. Therefore the equation for cost of food production is:

Cost of Food Production = Initial Cost of Food Production * Relative oil price

On the other hand, indicated food profit is the difference between food price and cost of food production; but, expected food profit accumulates changes in food profit adjusted over the time to change food profit. The differential equation for expected food price is:

Expected Food Profit (t) = Initial Food Profit (t) + (dt) Change food profit

Where change in food profit is:

Change in Food Profit =

(Expected Food Profit—Indicated Food Profit)/Time to change Food Profit

4.3.3 Biofuel Sub-Model

The biofuel sector models the demand for and supply of biofuel. The demand for biofuel is assumed to comprise desired local and foreign biofuel demand. Desired local biofuel demand is assumed at 30 percent of fossil oil consumption in Ghana; while that of foreign biofuel demand is postulated to equal local demand multiplied by the effect of oil price on foreign biofuel demand. The 30 percent is the government of Ghana's target biofuel content of fossil oil consumption by 2030 as stipulated in the energy policy of Ghana (Ghana, 2006). On the demand side, local demand for biofuel changes as oil consumption changes over time, due in part to rise in population and income. In the biofuel sector, a positive association is hypothesized for population and income to oil consumption; thus as population rise, oil consumption increases; likewise, as income increase, oil price is assumed to rise in turn, consequently, raising the local demand for biofuel, all other things being equal. For foreign biofuel demand, it is suggested that rising oil price, will increase the demand for alternative energy; accordingly, demand for biofuel in countries where biofuel production potential exist will increase, as a result, foreign biofuel demand will increase.

On the supply side, for brevity, it was assumed that capacity for biofuel production will always be built in time and be adequate to process feedstock into biofuel. Therefore, supply of biofuel is defined as feedstock for biofuel divided by yield per ton of feedstock without going in detail the dynamics of biofuel production capacity.

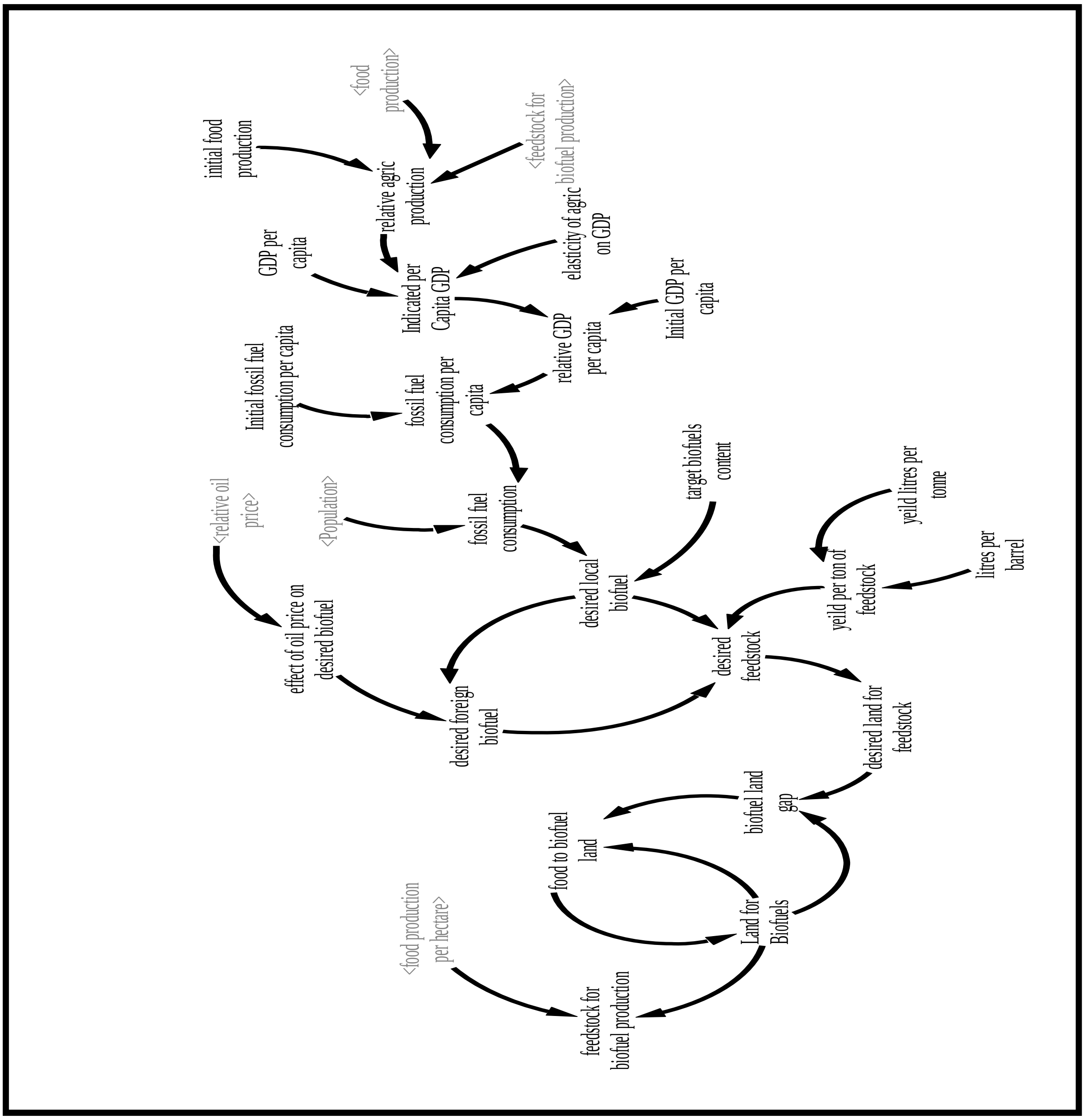

Figure 12: Biofuel Sector

4.3.3.1 Biofuel Sub-Model Equations

The algebraic equations used in modeling the biofuel sector are discussed below. Fundamental to the biofuel sector is the desired feedstock—which is in the end is converted to biofuel—is herein determined by the sum of desired local and foreign biofuel, divided by yield per ton of feedstock. The equation is:

Desired Feedstock =

(Desired local biofuel + desired foreign biofuel)/ yield per ton of feedstock

Desired local biofuel, however, is simply fossil fuel consumption multiplied by target biofuel content. Where fossil fuel consumption, is population multiplied by fossil fuel consumption per capita. The equations are:

Desired Local Biofuel = Fossil fuel consumption * Target biofuel

Desired Foreign Biofuel = Desired local biofuel * effect of oil price on desired biofuel

Fossil fuel consumption = Population * fossil fuel consumption per capita

The equation for fossil fuel consumption per capita is determined by initial fossil fuel consumption per capita multiplied by relative GDP per capita. As alluded earlier, it is hypothesized that as income rises, per capita fossil fuel consumption is assumed to increase due to expected consumption boost. Change in income—GDP per capita—is assumed to occur as agricultural production—food and feedstock—increases. The equations are as shown below:

Fossil fuel consumption per capita = Initial fossil fuel consumption per capita *

Relative GDP per capita

Relative GDP per capita = Indicated GDP per capita/Initial GDP per capita

Indicated GDP per capita = GDP per capita*

relative agriculture production ^ elasticity of agriculture on GDP

4.3.4 Land Sub-Model

Land is a vital resource for food production; hence to capture the land use changes which is the dynamics of interest for this research, agricultural land is herein divided into three categories—land under food cultivation, land under biofuel production and potential agricultural land remaining, with more emphasis on the two competing demand on land i.e. for food and biofuel production. The allocation of land—one of the factors of production—to food and biofuel production is determined herein by desired land for food and biofuel, potential agricultural land remaining and the time it takes to allocate land—"time to adjust land”. Desired land under food production is determined by food demand—as explicated in the food production sector—and the productivity of land (i.e. food production per hectare). Similarly, desired land for biofuel is defined herein as a function of desired biofuel and biofuel yield per hectare of land. The model structure of land—as shown in figure xx blow—accommodates the bi-directional transfer of land from food to biofuel production, and from biofuel to food production; which is as a result of relative incentive of biofuel production. Relative incentive of biofuel is a policy variable in the model, that explicitly captures the relative attractiveness of putting a piece of land into biofuel fuel production relative to food production; with a figure more than one suggesting higher profitability if a piece of land is put to biofuel fuel production, whereas a figure less than one suggest otherwise. Land use changes—especially the adoption of biofuel by farmers—is assumed to occur through word of mouth, as farmers interact with other farmers and educate them on the economic benefit of biofuel.

Land under food production is assumed to change by new food land from potential agricultural land remaining, transfer of land from biofuel production and transfer of land from food to biofuel production. Likewise, land under biofuel production is hypothesized to change in the model by new biofuel land from potential agricultural land remaining, transfer of land from food production to biofuel and transfer of land from biofuel production to food production.

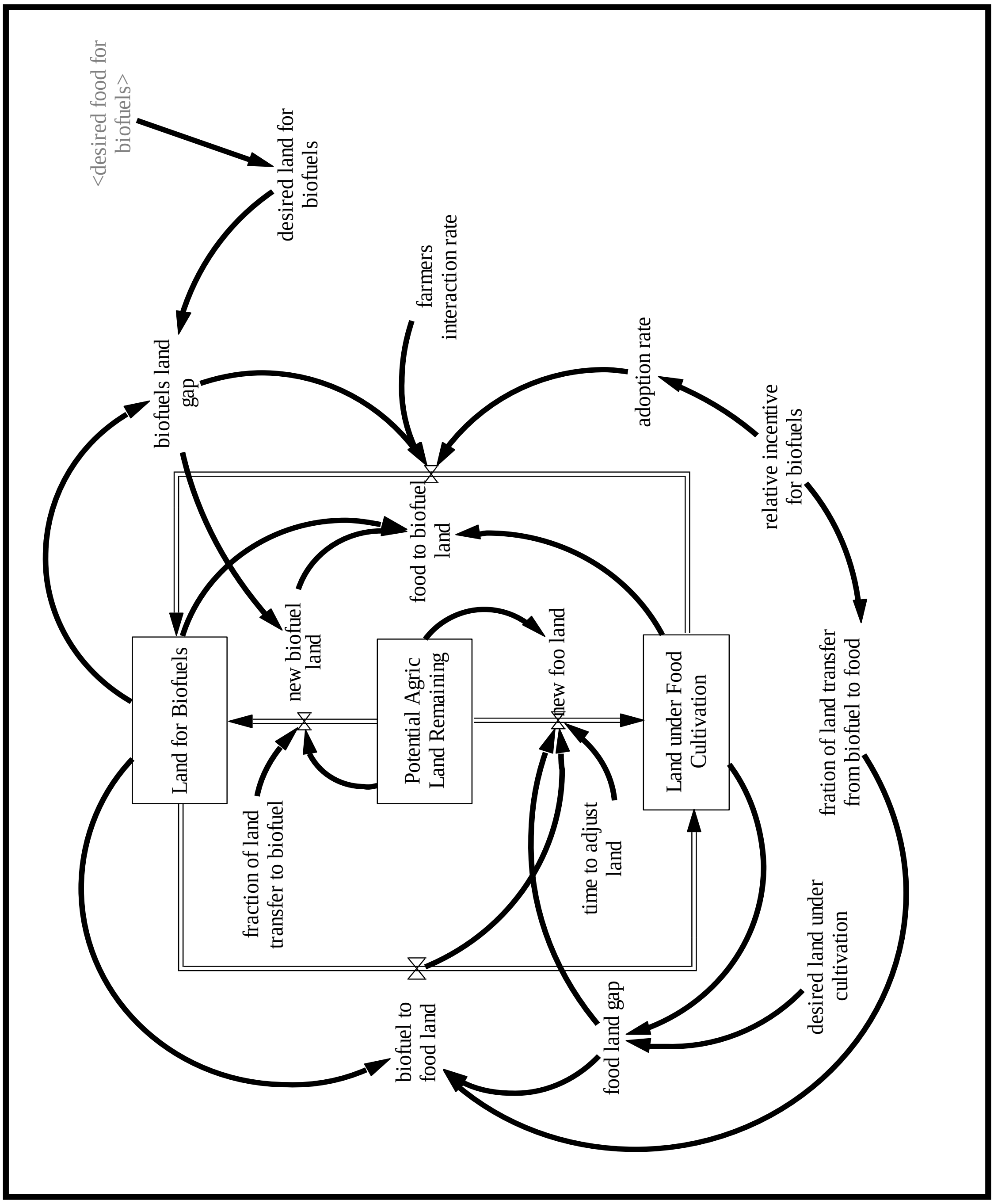

Figure 13: The Land Sector

4.3.4.1 Land Use Sub-Model Equations

The land under food cultivation changes by new land from potential agricultural land remaining and transfer of land from biofuel and decreases by transfer of land from food to biofuel. The differential equation used to represent land under food cultivation in the model is:

Land under Food Cultivation = Initial Land under Food Cultivation (t)

+ (dt) new food land + (dt) biofuel to food land— (dt) food to biofuel land

Where new food land is the minimum between potential agricultural land remaining and the difference between food land gap—which is desired land for food cultivation minus land under cultivation—and land from biofuel to food production, adjusted over the time to allocate land. The equation is as below:

New Food Land =

MIN (Potential Agriculture Land Remaining, food land gap-biofuel to food land)/time to adjust land

However, land from biofuel to food production is the minimum between land under biofuel production and food land gap multiplied by the fraction of land transfer from biofuel to food. The fraction of land from biofuel to food is assumed to be constant. The equation for land from biofuel to food production is:

Biofuel to Food Land =

MIN (Land for Biofuel, food land gap*fraction of land transfer from biofuel to food)

On the other hand, land from food to biofuel production is the minimum of the difference between biofuel land gap and new biofuel land from potential agricultural land remaining and the minimum between biofuel land gap and land under food cultivation multiplied by adoption rate, farmers interaction rate and land under biofuel divided by total land under food and biofuel cultivation. The equation for land from food to biofuel production is:

Land from Food to Biofuel Production =

MIN (biofuel land gap-new biofuel land, MIN (biofuel land gap,

(Land under Food Cultivation*adoption rate*farmers interaction rate)

*(Land for Biofuel / (Land for Biofuel + Land under Food Cultivation))))

Potential agricultural land remaining decreases as land is taken from to either food or biofuel production. The equation as used in the model herein is:

Potential Agricultural Land Remaining = Initial Potential Agricultural Land Remaining (t)

— (dt) new biofuel land — (dt) new food land

Food land gap is the difference between desired land under food cultivation and land under food cultivation; where desired land under food cultivation is the sum of the difference between food exports and imports and food demand divided by land productivity—food production per hectare. The equations for food land gap and desired land under food production are:

Food Land Gap = desired land under food cultivation—Land under Food Cultivation

Desired Land under Food Cultivation =

(Food demand + food exports – food imports) / land productivity

Likewise, biofuel land gap is the difference between desired land for biofuel production and land under biofuel production; while desired land for biofuel production is the desired feedstock divided by feedstock per hectare of land. The equations are:

Biofuel Land Gap = Desired land for Biofuel — Land for Biofuel

Desired Land for Biofuel = Desired Feedstock / Feedstock per hectare of land

5.0 Model Parameters and Validation

There are a variety of recommended tests in system dynamics to help build confidence in system dynamics models (J. D. Sterman, 2000), however, any study that attempt to report all the tests very quickly becomes confusing; hence, for brevity, two critical tests was selected to demonstrate to users of this model that the model is fit for the purpose and of adequate quality for which it was developed. Figure 14 below shows the validation tests conducted for this study.

Tests of Behaviour
Visual fit: In terms of magnitude, shape, periodicity and phasing
Statistical fit: In terms of goodness of fit

Tests of Structure
Boundary adequacy: Are important concept endogenous?
Structure verification: Is the model structure consistent with descriptive knowledge?
Dimensional consistency: Are all equations dimensionally correct without fudge factors?
Extreme conditions: Does each rate equations make sense even when its inputs take extreme values?
Parameter verification: Are parameters consistent with descriptive and numerical knowledge?

Figure 14: Behaviour and Structure Test

Source: Adopted from John Morecroft 2007: Strategic modelling and business dynamics. A feedback systems approach

For behaviour test, figures 15, 16 and 17 show simulated bahaviour compared to available time series data of selected variables: population, food production and land under food cultivation. The results clearly indicate that the simulated model compares favorably well with the time series data suggesting that on the face value, the model performs credibly for the visual fit test. In addition, the statistical fit reported (0.99, 0. 70 and 0.85) R^2 suggesting that the simulated behavior of the selected variables tracks data reasonably well.

For the structure test, as indicated earlier, model validation is an integral part of any system dynamics model (Barlas, 1996; J.W. Forrester & Senge, 1980; John D Sterman, 1984; J. D. Sterman, 2000), hence the structure of the model is firmly grounded in current available evidence on the interactions between food and biofuel production and its impact on food security, agricultural land and income; and more importantly, the major concept of the model is endogenously formulated to allow for policy test to generate insights for policy making.

In addition, it is important to ensure that the parameter values used in initializing and parameterizing the model are drawn from the appropriate data sources (see table 3), and that the formulated differential and algebraic equations used are dimensionally accurate and without fudge factors. Furthermore, to ensure that the model structure produces the right behavior for the right reason, the model was initialized in a steady state (i.e. a hypothetical situation where food demand and supply are equal); and then different exploratory simulation (step and ramp test) was run to ensure the model produces the right behaviour for the right reason.

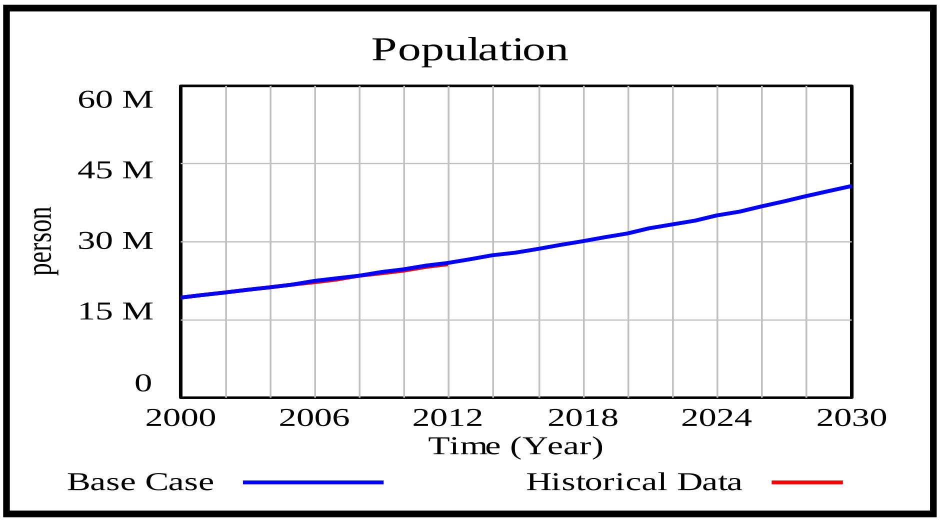

Figure 15: Simulated population compared to data

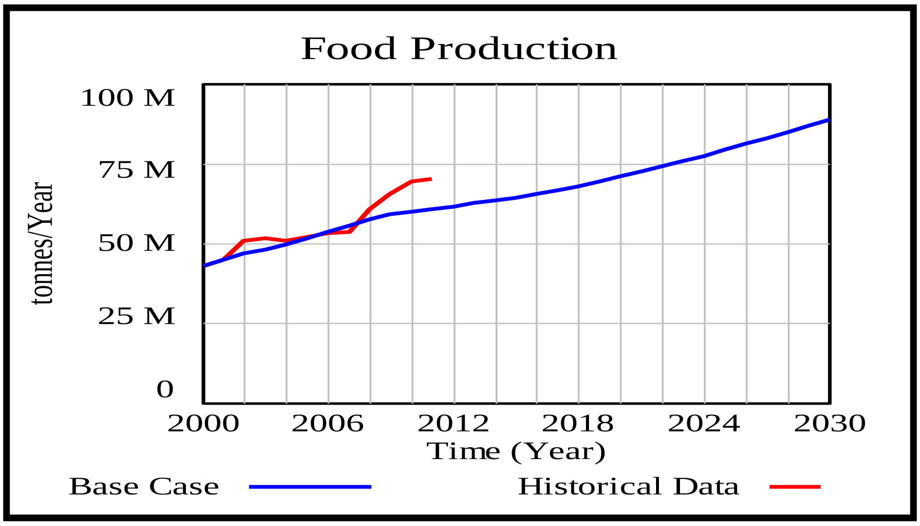

Figure 16: Simulated food production compared to data

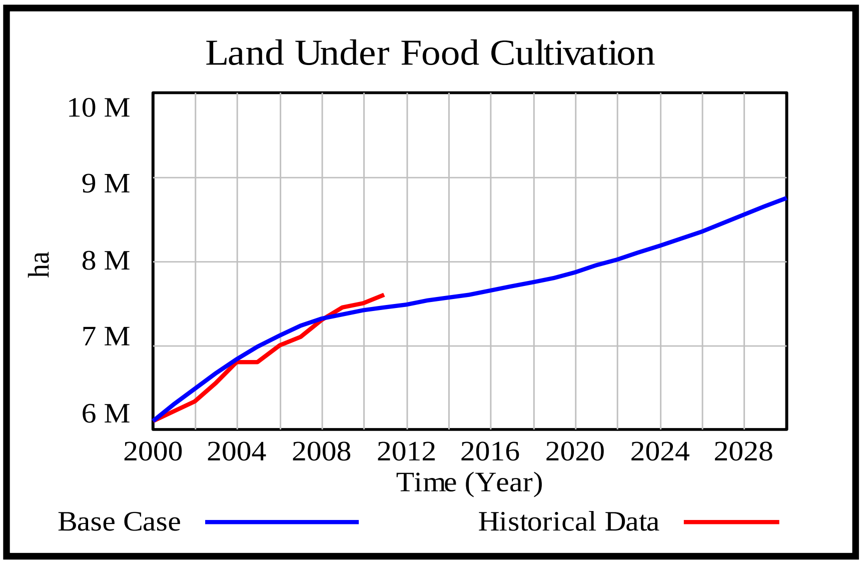

Figure 17: Simulated land under food cultivate compared to data

Parameter	Values	Unit	Source
Population			
Crude birth rate	0.032	Dimensionless	Ghana Statistical Service
Normal mortality rate	0.0082	Dimensionless	
Initial Population	1.92E+07	Person	
Land			
Fraction of land transfer to biofuel	0.5	Dimensionless	Author estimate
Time to adjust land	10	Year	Author estimate
Farmers interaction rate	100	Dimensionless	Author estimate
Relative incentive for biofuels	1.15	Dimensionless	Author estimate
Initial land for biofuels	0	Hectares	Author estimate
Initial potential agric land remaining	1.44E+07	Hectares	FAO (FAOSTATE)
Initial land under food production	6.10E+06	Hectares	FAO (FAOSTATE)
Food Production			
Initial per capita food demand	3	Ton/(Year*Person)	Author estimate
Elasticity of food price	-0.2	Dimensionless	Author estimate
Initial food price	67	Dollars/Ton	FAO (FAOSTATE)
Initial cost of food production	60	Dollars/Ton	Author estimate
Capital acquisition time	2	Year	Author estimate
Normal investment	1.75E+06	Dollar/Year	Author estimate
Capital life	15	Year	Author estimate
Initial food production capital	1.00E+07	Dollar	Author estimate
Elasticity of capital	0.65	Dimensionless	Author estimate
Elasticity of demand supply balance	0.25	Dimensionless	Authors estimate
Biofuel Demand			
GDP per capita	2925	Dollar/Year	Ghana Statistical Service
Elasticity of agric on GDP	0.23	Dimensionless	Author estimate
Initial oil consumption per capita	0.71	Barrel/Year/Persn	Ghana statistical service
Yield liters per ton	520	Liters/Ton	
Liters per barrel	119.24	Liters/barrel	

Table 3: Model Parameters

6.0 Policy Experimentation

One of the utility of system dynamics model is the ability to conduct policy experimentation to contribute to public policy making. According to (Ghaffarzadegan, Lyneis, & Richardson, 2011) the central characteristics that make system dynamics models especially suited for learning about designing effective policies are:

(a) The feedback approach and emphasis on endogenous explanation of behavior

(b) The aggregate approach

(c) The simulation approach and
(d) The fact that the models are small enough such that the structure is clear and the link between structure can be easily discovered through experimentation

On the basis of the above attribute of the model developed herein, in addition to the base-case scenario in which oil price and biofuel production were assumed to remain unchanged from 2012, the constant price of oil is disturbed by gradually increasing oil price from 84 to 200 US dollars—see figure 8, a scenario likely reflective of peak oil estimate. Under the increasing oil price assumption, the effect of three scenarios on food consumption per person—a blended measure of food security, food production, food price and land under biofuel production are studied. The three scenarios implemented in the model herein are:

(a) Scenario 1: Increasing biofuel production for local consumption from zero to 30 percent of local fossil fuel consumption by 2040 as indicated in the government of Ghana's Strategic National Energy Policy.
(b) Scenario 2: Increasing biofuel production for both local and assumed foreign demand as biofuel becomes the preferred substitute to conventional fossil fuel—gasoline and diesel
(c) Scenario 3: Assuming income gained (accrued income to government) from biofuel production will be used to subsidize food price, hence, the impact of high food price on food demand—especially among the low income populace—is avoided.

These hypothetical policies were selected to cover some of the possible or anticipated impacts of biofuel production on food security. Scenario 1 is implausible or at best very difficult to achieve since Ghana is an open economy and farmers and investors make investment decisions based on market forces—local and foreign; however, this scenario was selected to serve as a reference point for comparing scenario 2. Scenario 2 reflects what is expected when biofuel production takes off in Ghana; which emphasizes the likelihood that a significant percentage of biofuel produced will be exported to foreign market, supported by foreign investment. Finally, scenario 3 describes what might happen if revenue generated from biofuel production is used to subsidize expected increase in food price. This policy offers insight to policy makers on achieving sustainable food security in the midst of biofuel production.

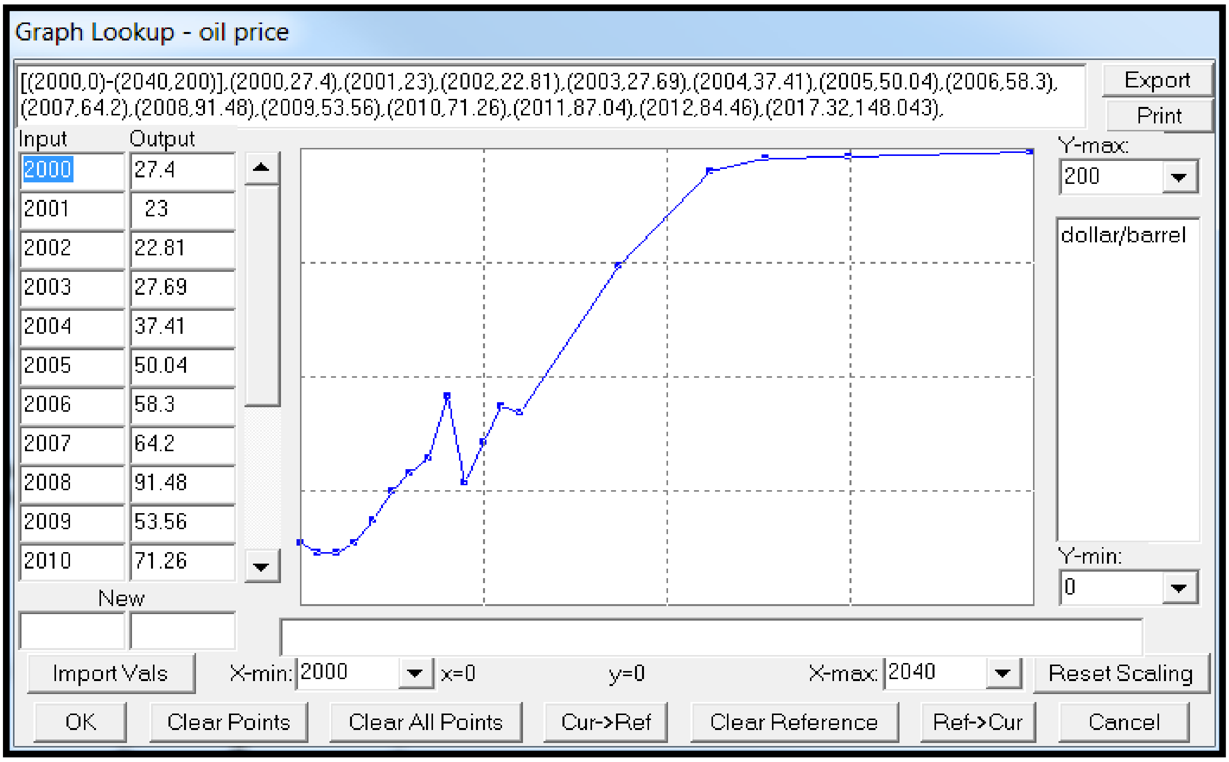

Figure 18: Assumed Future Oil Price

7.0 Results and Discussion

From 2012 to 2030, the total population of Ghana is projected to increase from over 25 million to 40 million, if current crude birth rate remains constant. Consequently, food production is projected to increase, from 68.8 million tons in 2012, to 108.5 million tons by 2030, as demand for food increase due to rising population. As food production increases, land under food cultivation is projected to increase from 7.8 million hectares as of 2012 to 10.1 million hectares by 2030. Food consumption per person—which is blended measure of food security—is projected to decrease slightly from 2.8 tons of food per person in 2012 to 2.7 tons by 2030, due to delayed response to food demand as food supply lags demand.

The results as shown in figure 10 A-F depict the impact of different simulated scenarios on food consumption per capita, food production, land under food cultivation, land for biofuel, per capita GDP, and food price.

In the "base case scenario", from 2012 to 2030, food production, land under food cultivation, per capita GDP and food price will increase by 44, 17, 8.8 and 1.7 percent, respectively (table 1). On the contrary, food consumption per capita is projected to decrease by 10 percent;

whereas land for biofuel production is projected to remain insignificant—almost zero hectares of land. Alternatively, in "scenario 1", land under food cultivation will increase by a small percentage (1%), while food production, per capita GDP and food price will increase by 36, 8, and 130 percent, respectively. But, not unlike the base case scenario, food consumption per capita will decrease by 16 percent and land for biofuel production is projected to increase from almost zero in year 2012 to about 175,000 hectares of land by 2030. However, in "scenario 2" food consumption and land under food cultivation is projected to decrease by 22 and 19 percent, respectively. On the other hand, food production, per capita GDP and food price will increase by 25, 19 and 134 percent, respectively; whereas land for biofuel is projected to increase from almost zero in 2012 to almost 4.3 million hectares of land by 2030. Lastly, in "scenario 3" food consumption per capita, food production, land under food cultivation, per capita GDP and food price will increase by 10, 80, 3, 26 and 136 percent, respectively; whereas land for biofuel is projected to increase to 4 million hectares by 2030.

Additionally, the outcomes of "scenario 2 and 3" at year 2030 were compared with that of the "base case scenario". Scenario 1 was eliminated from this comparison because as indicated earlier, this scenario is very unlikely to be implemented because Ghana has a market economy mostly free from trade barriers. At year 2030, "scenario 3" is projected to increase food consumption per capita and food production by 21 and 24 percent, respectively. In this scenario, land under food cultivation is projected to decline by 11 percent, while raising income (per capita GDP) by 15 percent. Likewise, "scenario 2" as simulated in the model is projected to decrease food consumption per capita, food production and land under food cultivation by 17, 13 and 30 percent, respectively; while at the same time increasing income (per capita GDP) by 10 percent.

	Outcome Variables				
	Food consumption per capita	Food Production	Land Under Food Cultivation	Per Capita GDP	Food Price
Base Case	-10%	44%	17%	8.8%	1.7%
Scenario 1	-16%	36%	1%	8%	130%
Scenario 2	-22%	25%	-19%	19%	134%
Scenario 3	10%	80%	3%	26%	136%

Table 4: Results from Scenario Analysis

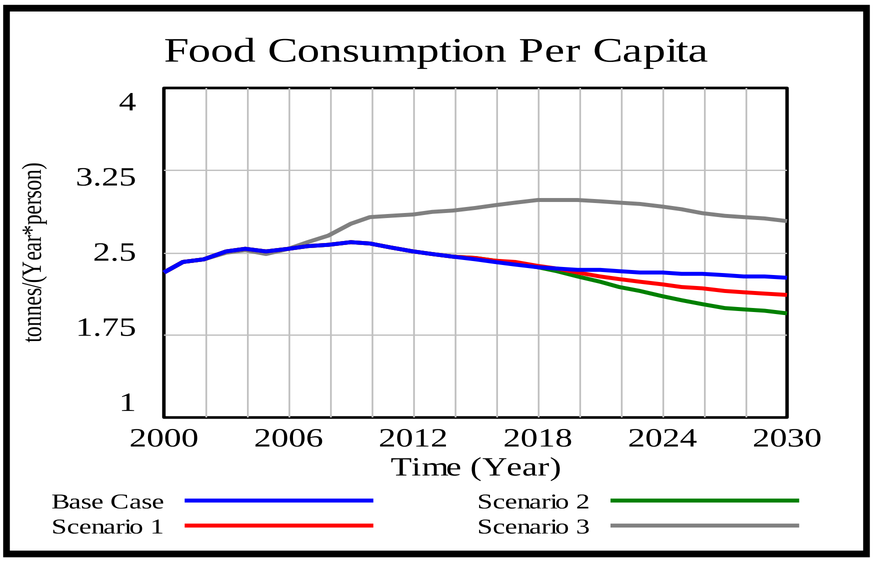

Figure 19: Impact of scenarios on food consumption per capita

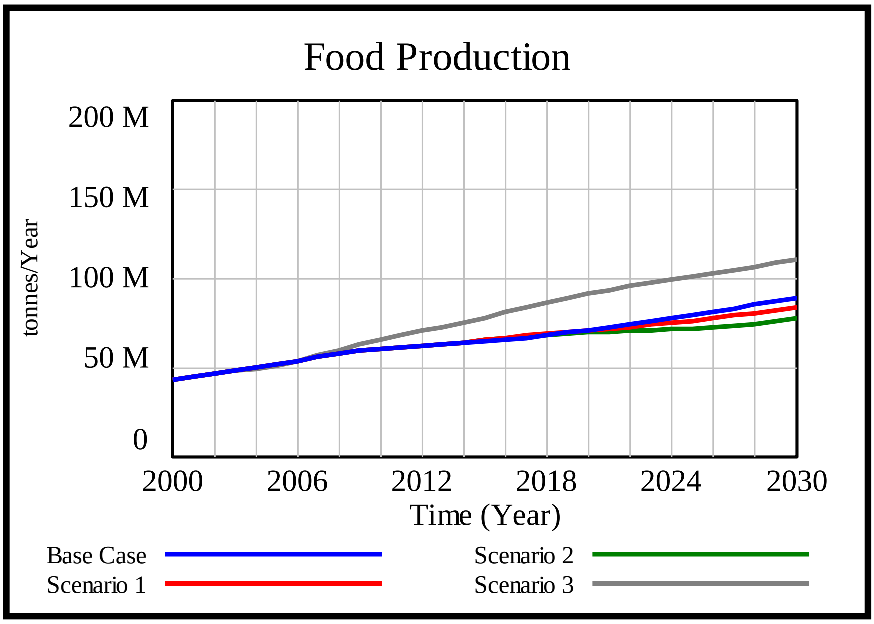

Figure 20: Impact of scenario analysis on food production

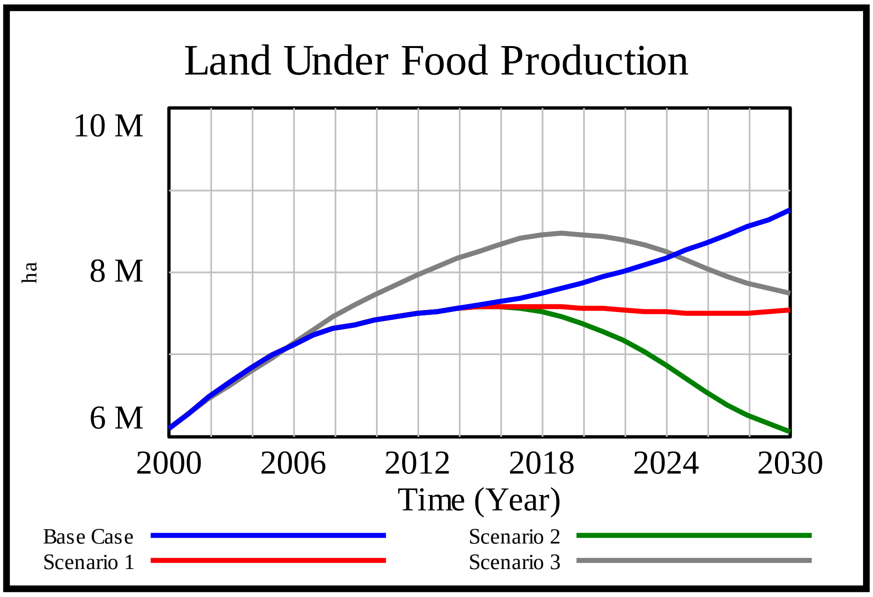

Figure 21: Impact of scenario analysis on land under food production

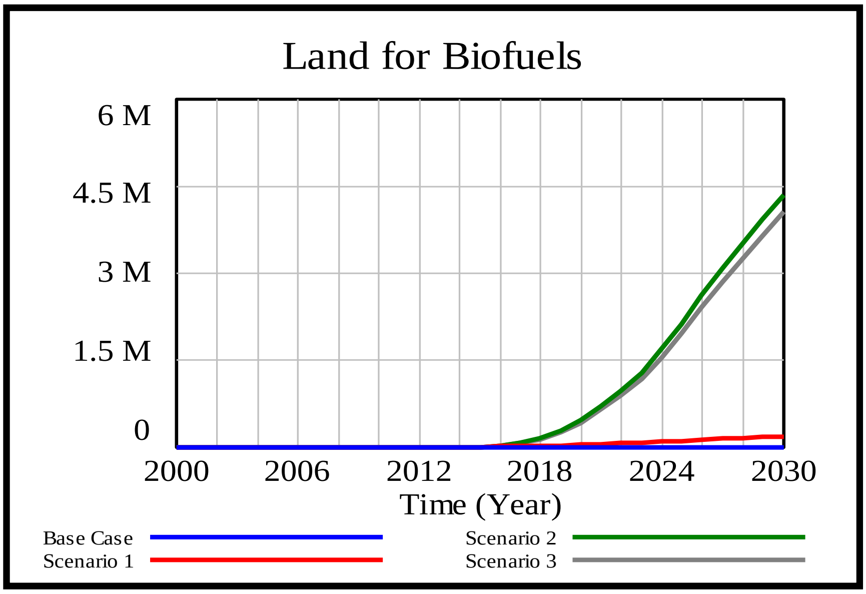

Figure 22: Impact of scenario analysis on land for biofuels

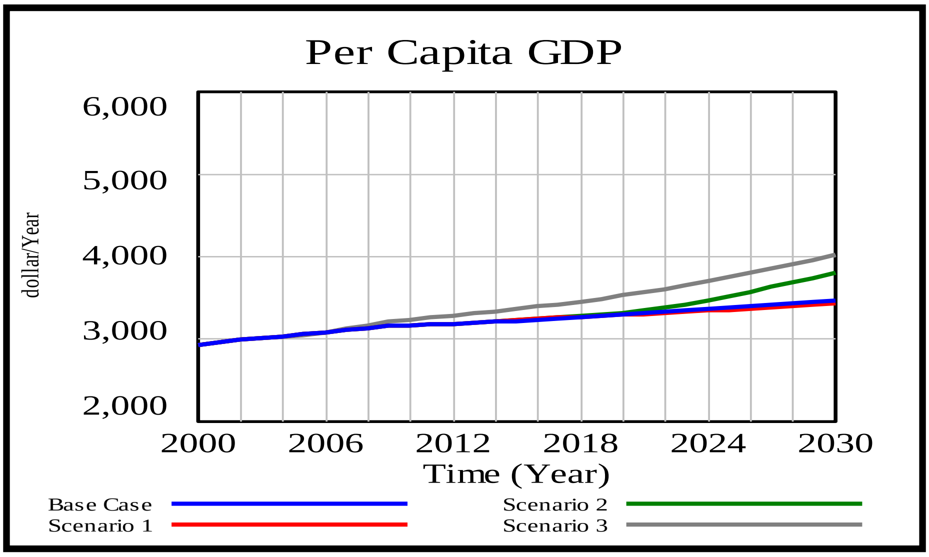

Figure 23: Impact of scenario analysis on per capita GDP

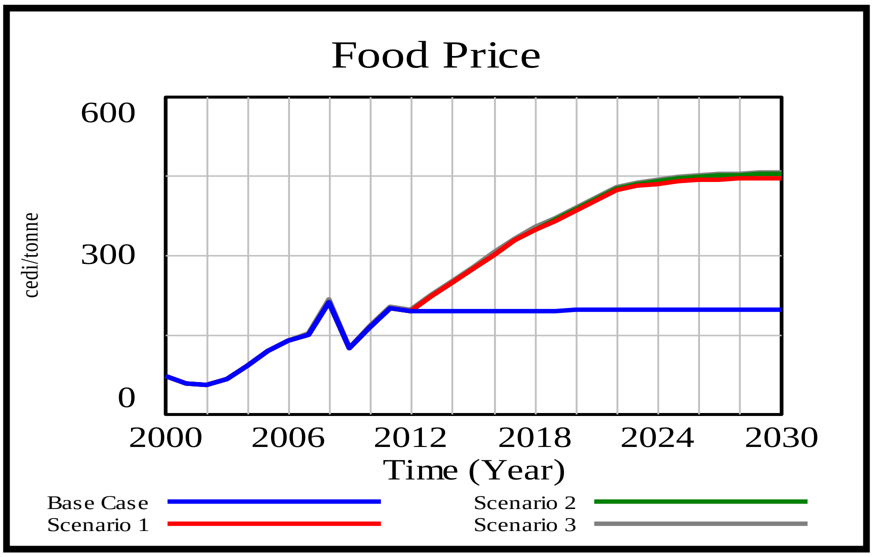

Figure 24: Impact of scenario analysis on food price

In this study we use a system dynamics model to study how the production of biofuel and food interacts in a relatively small developing country context and the likely impact on food security, agricultural land and income—especially farmers' income—as biofuels becomes important substitute for conventional fossil fuels. The results from the simulation model show that as biofuel production takes off—due in part to climate change concerns and the assumption of future high oil price—food production is projected to decrease disproportionally to food demand—as more land under food production is diverted to biofuel production due to higher expected profit from biofuel production relative to food production; consequently, food consumption per capita—a measure of food security—is projected to decrease due in part to high food price and increasing population. As food price increase, demand for food declines—especially among the poor due to reduced purchasing power. But, as food price increase, investment in food production increases as expected food profit increase, offsetting some of the effect of food price. However, insight from the model further suggest that if income derived from biofuel production is used to subsidize food price, as indicated in “scenario 3”, it is projected that food production and food consumption per capita will increase, as relatively more land and investment become available for food production.

The results can be explained by the allocation of land by farmers to food and biofuel production as informed by the perceived profitability of food and biofuel production. For instance, as oil price increase, profitability of biofuel production is likely to increase, which over time makes biofuel a viable alternative to conventional fossil fuel. As expected profit from biofuel exceeds that of food production—as assumed herein—either by word of mouth among local farmers or local and foreign investors, more land is transferred or acquired for biofuel production. This will reduce food production and in turn raise food price as demand for food exceeds the supply, coupled with increased cost of food production due to high oil price as assumed herein. However, increasing food price is likely to increase investment in food production which in turn increases food production. As food and biofuel production increase, it is likely to increase gross domestic product all things equal; as a result, income for farmers or investors is expected to increase—with a share accruing to the government through taxation.

The key finding from the simplified model of biofuel and food production interaction is that, as biofuel production takes off, some land will be used for the production of biofuel—albeit as a small fraction of potential agricultural land remaining. But biofuel production is likely to increase income— to local farmers or investors who are directly engaged in biofuel production—and may revive rural economies of out grower farmers; however, it is expected to contribute to food price increase—the effect chiefly taking hold among the poor, but higher food prices will also cause investment in food production to rise, contributing to eventual high food production. This key finding has policy implications; which suggest that if policy makers place more emphasis on biofuel production without actively supporting food production, could lead to food security issues if gains from biofuel production are not effectively used to reduce cost of food production as food price rise.

8.0 Conclusion

Africa is a continent where some of the pressing challenges of biofuel production –i.e., food security—are expected to be concentrated; however, it is where also hope lies: the continent is increasingly viewed as the global powerhouse for biofuel feedstock production (Wetland International, 2008) due to its supposed abundant land resources, cheap labor and preferential access to protected markets. As nations in Africa explore the opportunities of biofuel production—in some cases the urgency to become a leader in biofuel production has led to biofuel rush where foreign and local firms have acquired large agricultural land for biofuel production—to among others stimulate economic development, increase international trade, encourage foreign investment, increase rural development and reduce energy dependency, it is important to understand quickly both the opportunities and risks in economic, social and environmental aspects of biofuel production.

The finding from this study suggests that, by increasing biofuel production under the prevailing assumption as indicated herein, some agricultural land will be used for feedstock production for biofuel—albeit as a small fraction of potential agricultural land remaining. Moreover, it is expected that feedstock production for biofuel is likely to increase income for farmers—if local farmers are directly engaged in feedstock production—and this may revive rural economies of out grower farmers through job creation. On the contrary, it is expected that a rise in biofuel production will contribute to food price increase—as biofuel production becomes relatively profitable leading to the transfer of land from food to feedstock production for biofuel. But a higher food price is expected to cause investment in food production to rise, contributing to eventually high food production.

The finding from this study implies that if managed properly, the expansion of biofuel production would generate economic benefit such as increase GDP, create jobs and reduce energy dependency, especially for net energy import countries. Likewise, it is important to recognize the likely impact of biofuel production on food security and put in place necessary policies to mitigate this negative effect.

System dynamics modeling allowed for the succinct delineation of policy levers available for policymakers and helped demonstrate the interdependence of biofuel production and food security and potential outcomes of the selected policy tested in the model. While the model is useful in examining the dynamics of biofuel and food security, there are a lot of uncertainties in the model input which was not compressively dealt with in this study.

In sum, policymakers are faced with a difficult decision: encourage the production of biofuel, implying (a) a likely biofuel rush where foreign and local firms acquires large agricultural land for biofuel production, (b) design a smart policy that allows farmers to go into biofuel and food production concurrently, or discourage the production of biofuel due to its economic, social and environmental unintended consequences. Future work focusing on estimating the opportunity cost of biofuel production would be useful in helping policymakers weigh the economic, social and environmental impact of different policy options.

9.0 Reference

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Appendix A: Model Equations

Population= births-deaths
Initial Population = 1.9165e+007
UNITS: person

FLOWS:

*Births= Population*crude birth rate*

UNITS: person/Year

Deaths = Population(normal mortality rate*effect of food on mortality)*

UNITS: person/Year

Food consumption per person = (food production+food imports(Time)-food export)/Population
*UNITS: tonnes/(Year*person)*

Effect of food on mortality = food consumption per person/initial per capita food consumption

UNITS: Unitless

Crude birth rate= crude birth rate

UNITS: Dmnl/Year

Normal mortality rate = 0.0082

UNITS: Year

Food Production Capital = new capital-capital depreciation

Initial Food Production Capital = 1e+007

UNITS: cedi

FLOWS:

*New capital = (normal investment*effect of profit on investment)/capital acquisition time*

UNITS: cedi/year

Capital depreciation = Food Production Capital/capital life

UNITS: cedi/Year

Relative food production capital = MIN(MAXPRO,Food Production Capital/initial food production capital)^elasticity of capital
UNITS: Unitless

Initial food production capital = Food Production Capital

UNITS: cedi

Elasticity of capital = 0.65

UNITS: Unitless

MAXPRO = 3

UNITS: Unitless

Capital life = 15

UNITS: Year

Normal investment = 1.75e+006

UNITS: cedi/Year

Capital acquisition time = 2

UNITS: year

*Food production per hectare = initial food production per hectare*relative food production capital*

*UNITS: tonnes/(Year*ha)*

*Food production = food production per hectare*Land under Cultivation*

UNITS: tonnes/Year

*Food demand = (per capita food demand*Population)*

UNITS: tonnes/Year

Demand supply balance = food demand/(food production+food imports(Time))
UNITS: Unitless

*Per capita food demand = initial per capita food demand*effect of food price on consumption^elasticity of food price*
*UNITS: tonnes/(Year*person)*

Relative demand supply balance = SMOOTHI(demand supply balance/initial demand supply balance, 0.5, 1.25)
UNITS: Unitless

*Food price = initial index real food price*relative demand supply balance^elasticity of demand supply balance*relative oil price*
UNITS: cedi/tonne

Effect of food price on consumption = SMOOTHI(food price/initial index food price, adjustment time, food price/initial index food price)
UNITS: Unitless

Adjustment time = 3
UNITS: Year

Initial index food price = food price
UNITS: cedi/tonne

Elasticity of food price = 0
UNITS: Unitless
Initial per capita food demand = 3
*UNITS: tonnes/(Year*person)*
Expected Food Profit = change food profit
UNITS: cedi/tonne

FLOWS:

Change food profit = (indicated food profit-Expected Food Profit)/time to change food profit
*UNITS: cedi/(Year*tonne)*

Effect of profit on investment = (Expected Food Profit/initial expected food profit)
UNITS: Unitless

Indicated food profit = food price-cost of food production
UNITS: cedi/tonne

*Cost of food production = initial cost of food production*relative oil price*
UNITS: cedi/tonne

Initial cost of food production = 60
UNITS: cedi/tonne

Initial expected food profit = Expected Food Profit
UNITS: cedi/tonne

Time to change food profit = 1
UNITS: Year

*Relative oil price = (oil price(Time)/initial oil price)*sensitivity of oil price*
UNITS: Unitless

Oil price =
[(2000,0)(2040,200)],(2000,27.4),(2001,23),(2002,22.81),(2003,27.69),(2004,37.41),(2005,50.04),(2006,58.3),(2007,64.2),(2008,91.48),(2009,53.56),(2010,71.26),(2011,87.04),(2012,84.46),(2017.32,148.043),(2022.31,189.324),(2025.41,195.018),(2029.84,196.441),(2039.81,197.865)
UNITS: dollar/barrel

Initial oil price = oil price(Time)
UNITS: dollar/barrel

Sensitivity of oil price = 1

UNITS: Unitless

Land for Biofuels = new biofuel land+transfer from food land-biofuel to food land

Initial land for biofuels = IF THEN ELSE (biofuels switch=1 :AND: :NOT: Time<2014, 30000, 0)

UNITS: hectare

Potential Agric Land Remaining = -new biofuel land-new food land

UNITS: hectare

Land under Cultivation = biofuel to food land+new food land-transfer from food land

Initial Land under Cultivation = 6.1e+006

UNITS: hectare

FLOWS:

*New biofuel land = MIN(Potential Agric Land Remaining,(biofuels land gap*fraction of land transfer to biofuel))*

UNITS: heactare/year

New food land = MIN(Potential Agric Land Remaining,land gap-biofuel to food land)/time to adjust land

UNITS: hectare/year

Time to adjust land = 10

UNITS: Year

*Transfer from food land = MIN(biofuels land gap-new biofuel land, MIN(biofuels land gap,(Land under Cultivation*adoption rate*farmers interaction rate)*(Land for Biofuels/(Land for Biofuels+Land under Cultivation))))*

UNITS: hectare/year

Farmers interaction rate = 1000

UNITS: Unitless

*Biofuel to food land = MIN(Land for Biofuels, land gap*fration of land transfer from biofuel to food)*
UNITS: hectare/year

Biofuels land gap = IF THEN ELSE (Time<=2015,0, desired land for biofuels-Land for Biofuels)
UNITS: Hectare

*Biofuel production = food production per hectare*Land for Biofuels*
UNITS: bbl/Year

Desired land for biofuels = desired food for biofuels/food production per hectare
UNITS: hectare

Desired land under cultivation = (food demand+food exports table(Time)-food imports(Time))/delayed productivity
UNITS: hectare

Land gap = desired land under cultivation-Land under Cultivation
UNITS: hectare

Fraction of land transfer from biofuel to food = IF THEN ELSE(relative incentive for biofuels<1, 0.1, 0)
UNITS: Unitless

Relative incentive for biofuels = 1.15
UNITS: Unitless

Delayed productivity = SMOOTHI (food production per hectare, 4, food production per hectare)
UNITS: Unitless
Adoption rate = relative incentive for biofuels-1
UNITS: Unitless

*desired food for biofuels = ((desired biofuels/yeild barrel per tonne)+indicated food used for biofuels to export)*biofuels switch*
UNITS: tonnes/Year

Share of potential agric land for biofuels = Land for Biofuels/(Potential Agric Land Remaining+Land under Cultivation)
UNITS: Unitless

Effect of oil price on biofuels export = SMOOTHI(relative oil price, 10, relative oil price)
UNITS: Unitless

Target biofuels as a fraction of oil consumption by 2030 = Graph(Time) [(2000,0)(2040,0.4)],(2000,0),(2014,0),(2016.38,0.00854093),(2017.98,0.0256228),(2022.02, 0.103915),(2026.35,0.2121),(2030.02,0.270463),(2034.07,0.296085),(2040,0.3)
UNITS: Unitless

Initial oil consumption per capita= 0.71
UNITS: bbl/Year/person

Relative GDP per capita = Indicated per capita GDP/Initial GDP per capita
UNITS: Unitless

Initial GDP per capita = Indicated per capita GDP
UNITS: dollar/Year

Yeild litres per tonne = 520
UNITS: litres/tonnes

Litres per barrel = 119.24
UNITS: litres/bbl

Relative food production = (biofuel production+food production)/initial food production
UNITS: Unitless

Initial food production = food production+biofuel production
UNITS: tonnes/Year

Elasticity of agric on GDP = 0.23
UNITS: Unitless

ORIGINAL GDP PER CAPITA = Graph (Time)
[(2000,0)(2010,10000)],(2000,1443),(2001,1504),(2002,1559),(2003,1632),(2004,1928),(2005,2030),(2006,2168),(2007,2316),(2008,2503),(2009,2565),(2010,2725)
UNITS: Unitless.

*Indicated per capita GDP= GDP per capita*relative food production^elasticity of agric on GDP*
UNITS: dollar/Year

*Fossil fuel consumption per capita= Initial oil consumption per capita*relative GDP per capita*
*UNITS= bbl/(Year*person)*

*Desired local biofuels= Fossil fuel consumption*target biofuels as a fraction of oil consumption by 2030(Time)*
UNITS= bbl/Year

*Desired feedstock= ((desired local biofuels/yeild per tonne of feedstock)+desired foregn biofuel)*biofuels switch*
UNITS: tonnes/Year

yeild per tonne of feedstock= yeild litres per tonne/litres per barrel
UNITS: bbl/tonnes