Modeling Climate Change, Food Security, and Population

Pilot-Testing the Model in Ethiopia

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Cover photograph, by Apollo Habtamu of International Livestock Research Institute, shows an Ethiopian dairy farmer in the Ghibe Valley.

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Executive Summary

Developing countries face ever increasing challenges in the area of food security. Among these challenges, climate change is arguably one of the most serious and wide-spread threats, since it affects all regions of the world, albeit not equally. There is growing evidence that climate change is decreasing the productivity of many crops around the world, thus increasing the risk of food shortages in developing countries where agricultural systems are low-tech and malnutrition is common. While population growth is often mentioned as a contributing factor to food insecurity in developing countries, changing the rate of population growth is rarely seen as a policy alternative, especially when addressing strategies to adapt to climate change.

We developed a computer simulation model to help clarify the dynamic relationships between climate change, food security, and population growth. The aim was to develop a model that would be simple enough to adapt to a country and that could be used at the policy level to introduce population issues into the dialogue on adaptation to climate change in the context of food security. The resulting model links a population projection, a sophisticated economic model that takes account of the effects of climate change on agriculture, and a food requirements model that uses Food and Agricultural Organization formulas.

The model was tested and piloted in Ethiopia. The Ethiopia pilot demonstrated the usefulness of this model in quantifying the contribution of family planning in adapting to potential climate change-induced food security challenges. The model shows that the food security gap in Ethiopia is expected to be greater with climate change than the food security gap without climate change. The model also shows the potential of family planning to address this gap; the food security gap under an assumption of low population growth and climate change is lower compared to the gap with climate change and high population growth. In fact, by the year 2050 the model estimates that slower population growth will compensate completely for the effects of climate change on food insecurity.

We conclude that the model can serve as a starting point for a dialogue about the importance of taking into account population factors when adapting to climate change with regard to food security. While technological interventions on the supply side will surely be vital in adapting to climate change and achieving food security, addressing the demand side via population can also contribute to efforts to enhance food security in the face of climate change.

Background

Developing countries face ever increasing challenges in the area of food security. It was recently estimated that the number of hungry people in the world exceeded one billion in 2009, most of these in developing countries.[1] Not having enough food for a household to eat can be the result of many factors related to both food supply/production and food demand/consumption. Such factors include lack of resources to purchase or grow food (i.e. poverty,) which can be exacerbated by food price increases; policies that encourage the production of high value-added food products such as meat, which compete for agricultural resources with more traditional foods such as grains; food distribution systems that do not get food to markets where food is most needed; agricultural policies that do not respond to local needs; land use policies that take agricultural land out of the food production system or that favor export crops; environmental degradation; declining agricultural yields that are induced by climatic changes; and population growth. In this paper, we focus on these last two factors: climate change, a significant factor on the supply side of the food security issue; and population growth, a significant factor affecting demand.

Among these challenges, climate change is arguably one of the most serious and wide-spread threats since it affects all regions of the world, albeit not equally. There is growing evidence that climate change is decreasing the productivity of many crops around the world, thus increasing the risk of food shortages in developing countries where agricultural systems are low-tech and malnutrition is common. For example, Lobell and colleagues recently found that, for each additional day of temperatures above 30^0 C maize yields decreased by 1%.[2] It has been estimated that maize yields in Africa may decrease by between 22% and 35% by 2030.[3] Similar predictions have been made for other crops. This decreased productivity is due in large part to two of the major effects of climate change: increased variability of rainfall and changes in local temperatures. Despite an on-going debate in some circles about the extent of global warming, there is an emerging consensus that average temperatures are on the rise. For example, the United Nations Environment Programme (UNEP) reports that average temperatures have increased about 1^0 C in the last 100 years[4] and the Intergovernmental Panel on Climate Change (IPCC) predicts this trend to continue in relation to increased greenhouse gas emissions.[5]

These changes are concerning in sub-Saharan Africa, where small scale subsistence farmers are especially vulnerable to food insecurity when crop yields decrease. Most adaptation measures designed to address decreasing yields are technological in nature, usually focusing on agricultural systems, and many are costly.

1 Von Braun J. *Food and Financial Crises: Implications for Agriculture and the Poor, IFPRI Food Policy Report.* Washington, DC: IFPRI, 2008

2 Lobell DB, Field CB. Global scale climate-crop yield relationships and the impacts of recent warming. *Environ Res Letters.* 2007;2(1):014002.

3 Bailey R. *Growing a Better Future: Food Justice in a Resource-Constrained World*. Oxford, United Kingdom: Oxfam International; 2011:26, figure 11.

4 McMullen CP, Jabbour J (eds.). *Climate Change Science Compendium 2009.* New York: United Nations Environment Programme; 2009.

5 Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2007: Synthesis Report Summary for Policymakers.* Geneva, Switzerland: IPCC; 2008.

Many reports that link climate change and food security mention growing population as a factor but adaptation strategies rarely mention reducing population growth rates via voluntary family planning as an adaptation strategy.[6] This project aims to develop an evidence-based advocacy tool that puts family planning among the mix of adaption strategy options with regard to climate change.

On the demand side of food security, there are two main concerns. One is that as economies develop their food consumption habits change in favor of fewer grains for human consumption and more meat and dairy products. Figure 1 shows an example of how diet and income are related in China and Japan. As income increases, rice consumption decreases and meat consumption increases Meat and dairy require more land and resources per unit of food (as measured in kcal) because animals must be fed and maintained through intermediate agricultural outputs such as hay and grain. Population growth is also a major concern, especially in sub-Saharan Africa. Population growth rates in Africa have fallen over the past decade but remain the highest in the world. Even under the most optimistic assumptions, the population in sub-Saharan Africa will at least double by 2050.[7] In addition, populations will be increasingly urbanized, putting additional pressure on food production and distribution since an increased proportion of the population will be dependent on food production that emanates in rural areas.

The literature on adaptation to climate change and food security mentions many (and more) of the issues cited above, including population pressure, but most of the policy and program strategies that are suggested focus almost exclusively on the supply-side and rarely, if ever, suggest addressing population growth as a policy option. While addressing population growth cannot be seen as a strategy that on its

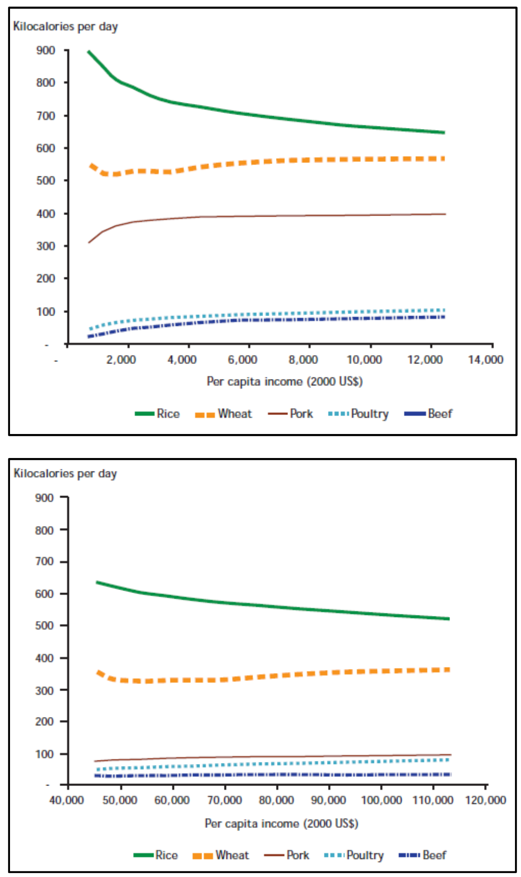


Figure 1. Relationship between diet and income in China (top) and Japan (bottom).

Source: International Food Policy Research Institute (IFPRI), *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, and Policy Options.* Washington: IFPRI; 2011.

6 Beddington J, Asaduzzaman M, Fernandez A, Clark M, Guillou M, Jahn M, et al. *Achieving Food Security in the Face of Climate Change: Summary for Policy Makers from the Commission on Sustainable Agriculture and Climate Change.* 2011. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security; 2011. Available at: www.ccafs.cgiar.org/commission.

7 See Moreland S, Smith E. *World Population Prospects and Unmet Need for Family Planning.* Washington: Futures Group; 2010.

own could sufficiently address food security challenges, we argue that it can be seen as one of many strategies that countries should consider.

In order to help clarify the dynamic relationships between climate change, food security, and population growth we developed a computer simulation model that focuses on some key elements of the issues briefly outlined above. Our aim was to provide a tool that would be simple enough to adapt to a country and that could be used at the policy level to introduce population issues into the dialogue on adaptation to climate change in the context of food security. For many years the RAPID Model, a dynamic computer simulation model developed by Futures Group, has been used successfully to advocate for family planning programs by showing the linkages between rapid population growth and selected socio-economic development indicators.[8]

In this report, we describe a RAPID-type advocacy model that we developed to demonstrate how increased use of family planning can lighten the burden of countries to adapt to climate change in the agricultural sector, thus leading to increased food security and improved nutritional status of the population. The model compares projected food requirements of the population with projected food consumption. Food requirements are influenced by population size and structure as is food consumption, which is also influenced by other factors such as prices, household incomes, and food supply (which is inter alia influenced by climate change). The model can be used to demonstrate how slowing population growth, and thereby changing the size and structure of the population, can increase food security in the face of climate change.

There are several models available that link climate change and food. Perhaps the most ambitious and complete of these is the IMPACT Modeling Suite developed by the International Food Policy Research Institute (IFPRI).[9] This model consists of three linked models: a partial equilibrium agricultural model, a hydrology model, and a Decision Support System for Agrotechnology Transfer (DSSAT) crop model that estimates crop yields under various management systems and climate change scenarios. The IMPACT Model does take account of population growth. However, because the model focuses mainly on cereals, we felt that it was not appropriate for studying food security at the country level, where we wanted to model a more complete diet. We also felt that the model was too big and complicated for use as an advocacy tool at the country level.

Another model is the dynamic GLOBE Model that is maintained at the Institute of Development Studies at Sussex University.[10] The GLOBE Model is a global computable general equilibrium model that has country-level data. It takes account of population growth and climate change parameters, and covers a wide range of agricultural commodities. As a global model, it takes account of inter-country trade flows in

8 Available at: http://futuresgroup.com/resources/software_models/rapid.

9 Nelson GC, Rosegrant MW, Palazzo A, Gray I, Ingersoll C, Robertson R, et al., *Food Security, Farming and Climate Change to 2050: Scenarios, Results, Policy Options.* Washington, DC: International Food Policy Research Institute; 2010.

10 Institute of Development Studies (IDS), University of Sussex, http://www.ids.ac.uk/.

different products including agriculture. The model was used to generate expected changes in food prices as a result of climate change for a recent Oxfam report on food security.[11] As described below we decided to link our model to the GLOBE model at the country level.

11 *Growing a Better Future: Food Justice in a Resource-Constrained World.* Oxford, United Kingdom: OXFAM; 2011.

Model

The model projects food energy requirements (in kilocalories) of the population using Food and Agricultural Organization (FAO) and World Health Organization (WHO) formulas and a population projection. The resulting energy requirements are then compared to projections of what the population will actually consume. Food consumption is calculated in an economic sub-model where food units expressed in monetary value are converted to their equivalent in kilocalories. The balance between food requirements and predicted food consumption is taken as the model's estimate of the extent of food insecurity.

As can be seen in figure 2, structurally the model consists of three distinct sub-models: (1) a population model that projects the population; (2) a food requirements model that projects food energy requirements necessary to maintain the health of the population; and (3) an economic model that projects food consumption. These are described in more detail below.

Population Sub-model

Population is a key variable in the model and is projected primarily using DemProj, a computer program for making population projections for countries or regions. DemProj operates within the suite of models maintained by the Futures Group and Futures Institute known as Spectrum.[12] The program requires information on the size of the population by age and sex in the base year, as well as baseline data and future assumptions about the total fertility rate (TFR),[13] the age distribution of fertility, life expectancy at birth by sex, the most appropriate model life table, and the magnitude and pattern of international migration. This information is used to project the size of the future population by age and sex for as many as 150 years into the future. DemProj uses a standard cohort-component population projection method on an annual basis; that is, it projects the population annually by single year age groups.

DemProj is preloaded with all national demographic data from the United Nations (UN) World Population Prospects.[14] The UN prepares three fertility and three mortality variants (high, medium, and low) for each country. While a user can design his or her own scenarios, it is useful to have the UN data as a starting point for making projections.

As noted, the main inputs required to run DemProj are:

- first year population by age and sex
- TFR
- age distribution of fertility (%)
- sex ratio (males to females) at birth
- life expectancy at birth (males and female)
- life table (model tables are preloaded)
- annual number of persons migrating internationally each year

The main outputs of DemProj for the purposes of this model are:

12 See http://futuresinstitute.org/pages/spectrum.aspx.

13 If the user wishes to link changes in fertility to family planning, another model called FAMPLAN can be used in conjunction with DemProj.

14 *World Population Prospects: The 2010 Revision*. New York: United Nations Department of Economic and Social Affairs; 2010.

- population by age and sex
- population by rural and urban residence (if requested)
- number of pregnancies
- age distribution of fertility
- number of deaths
- growth rate of the population

Family planning is one of the main determinants of fertility and as such can be included in the population model through the FAMPLAN sub-model of Spectrum. Since one use of the model is to demonstrate how family planning can be an option for adaptation to climate change this aspect of the model is useful. FAMPLAN can be used in two alternative modes: in one mode, the user makes assumptions about the future course of family planning use as measured by the contraceptive prevalence rate (CPR) and the model predicts the impact on fertility rates. In the second mode, the user provides a scenario of the future course of fertility and the model projects the levels of CPR that would be required to attain the assumed TFRs. So, for example, if the user chooses to use the UN TFR scenarios, FAMPLAN will calculate the corresponding levels of CPR.

The main inputs for FAMPLAN are:

- method attributes (commodities per CYP for short-term methods; duration of use for long-acting methods; average age for sterilization)
- effectiveness by method

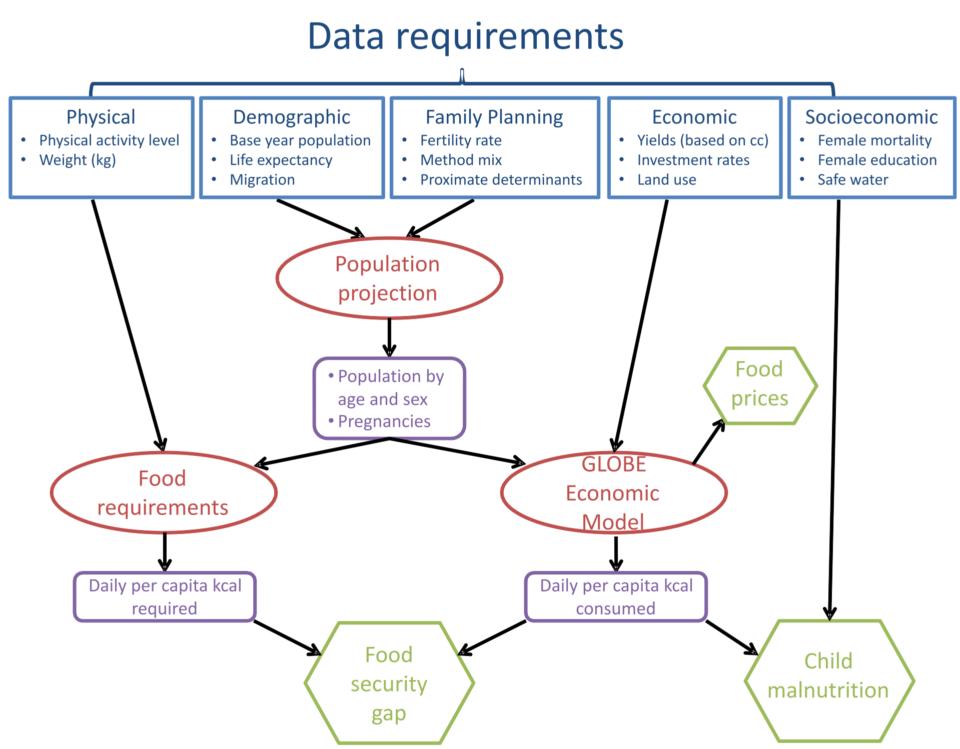


Figure 2. Model structure.

- method mix
- proximate determinants (percentage of women 15-49 in union, duration of postpartum insusceptibility, total abortion rate, percentage of women 15-49 who are sterile)

The main outputs for FAMPLAN are:

- CPR or TFR
- users, acceptors, CYP by method
- pregnancies, births, abortions

Economic (GLOBE) Sub-model

Projecting production and consumption of any economic commodity is a complex exercise. The present model uses the GLOBE model to forecast future food consumption. The GLOBE model was used in a recent major report published by Oxfam on food security challenges in developing countries.[15] The model is in the tradition of multi-country, trade-focused, computable general equilibrium (CGE) models developed to analyze the impact of global trade negotiations and regional trade agreements.[16] The dynamic version of GLOBE used here is based at the Institute of Development Studies (IDS) at the University of Sussex.[17] The model consists of a set of individual country or region models that provide complete coverage of the global economy and are linked through international trade in a multi-region model system. Although the GLOBE model is by definition a multi-country model, when applying it in the context of the present food security model we use only the results from the country of interest. For example when applying the climate change, food security and population model to Ethiopia one uses the GLOBE outputs for Ethiopia. GLOBE solves the *within* country models and *between* country trade relationships simultaneously. The country models simulate the operation of factor and commodity markets, solving for wages, land rent, profits, and commodity prices that achieve supply-demand balance in all markets. Each country engages in international trade, supplying exports and demanding imports. The model determines world prices that achieve supply-demand balance in all global commodity markets, simulating the operation of world markets.

Multi-country CGE models, like GLOBE, represent the whole economy, including the agricultural sector. Their strength is that they include the value chain from crops, processing and distribution, and finally to demand for food by households. That is, CGE models take into account the many uses of agricultural products other than human consumption (eg, animal feed, fuel, etc.); thus household consumption of food represents the end use a percentage of total agricultural outputs. They also incorporate links between agricultural and non-agricultural sectors, and the links between production, factor payments, and household income. Multi-country CGE models are well suited to analysis of policies or scenarios that will change the volume and structure of production, demand, and international trade,

15 *Growing a Better Future: Food Justice in a Resource-Constrained World.* Oxford, United Kingdom: OXFAM; 2011.

16 McDonald S, Thierfelder K, Robinson S. *Globe: A SAM Based Global CGE Model using GTAP Data*. [USNA Working Paper 14]. Annapolis, MD: US Naval Academy; 2007.

17 Willenbockel D. *Exploring Food Price Scenarios Towards 2030 with a Global Multi-Regional Model.* Oxford, United Kingdom: Oxfam; 2011.

and the allocation of factors of production throughout the economy.

The model is initially calibrated to the GTAP 7.1 database that combines detailed bilateral trade and protection data reflecting economic linkages among regions with individual country input-output data, which account for inter-sector linkages within regions, for the benchmark year 2004. For the present study, we use a 24-region, 21-sector/commodity group aggregation of the GTAP database, including 18 regions in sub-Saharan Africa.

Table 1 shows the African regional disaggregation of the model. The model distinguishes 16 food commodity groups (table 2) and five non-food sectors.

Population growth rates for the total population and those aged 15-64 are used by the GLOBE model as proxies for the growth in the labor force, one of the principal factors of production. Thus, population growth is one driver of aggregate production, although the marginal productivity per person declines with population growth, due to an increasing ratio of human to physical capital. Population also is used to calculate per capita indicators in the model such as per capita household food consumption.

Table 1. Regional Aggregation

North Africa
Nigeria
Senegal
Rest of West Africa
Central Africa
South Central Africa (Angola and DR Congo)
Ethiopia
Madagascar
Malawi
Mauritius
Mozambique
Tanzania
Uganda
Zambia
Zimbabwe
Rest of East Africa
Botswana
South Africa
Rest of South African Customs Union

Table 2. Sector and Commodity Group Aggregation

Paddy rice
Wheat
Maize and other cereals
Vegetables and fruits
Oil seeds
Sugar cane and beet
All other food crops
Raw milk
Non-processed fish
Meat and meat products
Processed rice
Vegetable oils
Dairy products
Sugar and sugar products
All other processed food products
Livestock

Exogenous Assumptions for the Drivers of Growth in the Economic Sub-model - The baseline assumptions about agricultural productivity growth by country and crop type are based on a synopsis of the corresponding projections in three studies.[18] These correspond to a world without climate change. For example, the analysis by Nelson and colleagues uses IFPRI's IMPACT model to estimate agricultural productivity growth with what they refer to as "perfect mitigation" of the effects of climate change on crop productivity.[19]

Growth rates of technical progress for industry and services up to 2015 are calibrated residually such that the growth rates of real gross domestic product (GDP) by region for 2004 to 2010 are approximately equal to observed average annual growth rates and match IMF *World Economic Outlook* (April 2011 update) medium-run growth projections for the period 2011-2015. From 2016 onwards, TFP growth rates are projected forward towards 2050 assuming a gradually declining trend.[20] Aggregate productive capital stock growth projections by region are based on average annual observed investment/GDP ratios for the period 2004 to 2010, IMF projections towards 2015, capital-output ratios from the GTAP database and an annual depreciation rate of 5 percent.

18 Jaggard KW, Qi A, Ober ES. Possible changes to arable crop yields by 2050. *Phil Trans Royal Soc B.* 2010. 365:2835-2852; Nelson et al. op. cit.; Alcamo J, van Vuuren D, Cramer W, et al. Chapter 9. Changes in ecosystem services and their drivers. In *Ecosystems and Human Well-being: Scenarios.* Washington, DC: World Resources Institute; 2005.

19 Nelson et al., op. cit.

20 International Monetary Fund (IMF). *World Economic Outlook.* Washington, DC: IMF; April 2011.

Changes in agricultural land use are based on a synopsis of projections in the Nelson study and two others.[21]

Impacts of Climate Change on Agricultural Productivity - The assumed climate change impacts on factor productivity in crop agriculture by region used in the simulations are based on a synthesis of recent studies.[22] The low-productivity scenario presented here depicts a world with rapid temperature change, high sensitivity of crops to warming, and a carbon dioxide (CO_2) fertilization effect at the lower end of published estimates.

The main inputs of the GLOBE model are:

- rates of technical progress
- investment rate
- changes in agricultural land use
- climate change assumptions
- agricultural yields

The main outputs, disaggregated by food category, are:

- domestic production
- import volume
- consumer price indices
- indices of household and per capita consumption

For the purposes of this model, we considered three different future worlds that would

21 Nelson et al., op. cit.; Smith P. et al. Competition for land. *Phil Trans Royal Soc B.* 2010. 365: 2941-2957; Alcamo et al., op. cit.

22 Hertel TW, Burke MB, Lobell DB. The poverty implications of climate-induced crop yield changes by 2030. *Global Enviro Change.* 2010;20:577-585. This synthesis draws on 10 studies listed at the end of this paper.

results in three different scenarios of future food consumption:

- no climate change and high population growth;
- climate change and high population growth; and
- climate change and low population growth.

The first scenario, which considers a world without climate change, assumes there are no effects on the agricultural system due to weather change or CO_2 fertilization.

The second and third scenarios both assume the aforementioned climate change impacts on factor productivity in crop agriculture. The first two scenarios assume high population growth, based on high fertility rates. These scenarios are generally based on the UN's high fertility variant. The third scenario is generally based on the UN's low fertility variant.[23] In specific cases, such as the Ethiopia case study presented in this paper, other population growth scenarios already in use in country may be used.

The contrast between the first and the second scenarios serves to set up the issue of how climate change impacts agricultural productivity, and therefore food security, when population growth is held constant. Using the methodology described in the following section, it allows us to isolate the effects of climate change alone in reducing per capita food consumption. In turn, the contrast between the world depicted in the second and third scenarios allows us to isolate the effects of population growth on the food system, food consumption, and ultimately food security.

Future Food Consumption - Future food consumption is calculated based on growth rates of household food consumption as projected in the GLOBE model. These growth rates are applied to a baseline diet, which is expressed in terms of average daily caloric consumption by food category. Baseline diets can be taken from the FAO, national sources, or household surveys.

As mentioned, GLOBE forecasts indices of per capita food consumption. Changes in these indices are used to calculate growth rates of per capita consumption of each food category. It is important to bear in mind the varying importance of the different food commodities in households' total food expenditure. The model takes account of the use of agricultural products for human consumption (food), animal consumption, and fuel, as well as the use of agricultural output in processed food. For example, the *direct* household consumption of paddy rice in Africa is generally negligible except in West Africa. Paddy rice serves as *intermediate* input in the production of processed rice. Similarly, to a large extent other agricultural outputs - such as wheat, maize, other crops and livestock - enter household consumption indirectly via their use as inputs in processed food products (which include inter alia flour and bread, etc.). The model explicitly captures the input-output structure of food production and the associated linkage between the prices of agricultural raw outputs and processed food.

As incomes rise over time the importance of subsistence production for direct home

23 *World Population Prospects: The 2010 Revision, op. cit.*

consumption will tend to fall, and households will switch in tendency from direct purchases of raw agricultural output to processed food. Thus, the fact that the long-run simulation may suggest in many cases significant drops in the direct per-capita consumption of particular food groups, e.g. grains, in later years of a projection does not necessarily indicate a food scarcity problem per se, given that the per capita consumption of processed foods (including grain flour, bread, preserved vegetables and fruits etc.) will rise. Similarly, we often observe an increase in more desirable, resource-intense foods into the future, also driven by economic growth and increasing wealth. For example, increased consumption of meat often accompanies economic development, replacing inferior, more cheaply-produced staple foods (usually grains or tubers).

Because different data sources may use different food categories, it may be necessary to map the food categories defined by GLOBE (listed in table 1) onto the food categories of the baseline diet. For example, GLOBE groups fruits and vegetables into one category. If the baseline diet data differentiate between fruits and vegetables, the growth rate of the fruits and vegetables category from GLOBE would be applied to both the fruit category and the vegetable category in the dietary projection.

Applying the GLOBE growth rates to the baseline diet results in an annual diet in which composition varies slightly from year to year. This diet is expressed in terms of the kcal intake of various foodstuffs for an average individual in the population, and sums up to total daily kcal consumption. It is recognized that some individuals in the population will consume more than this average, while others will consume less; it is also recognized that the diets of individuals may vary significantly from the average diet. Because the results of the model are meant to be interpreted on an aggregate level for an entire population, these variations are not inconsistent with the outputs of the model. Indeed, issues of variation and inequality may serve as important contextual factors to present alongside results from the model.

As described in the previous section, we have established three different scenarios for the possible future trajectory of the food system: no climate change and high population growth; climate change and high population growth; or climate change and low population growth.

Each of these three scenarios produces different results for future per capita consumption of various types of food. The three different sets of growth rates for per capita consumption of foodstuffs are each applied to the same baseline diet. The result is three patterns of food consumption into the future, each with an estimate of the average daily per capita kcal consumption. A comparison between the first and second scenarios tells us how average food consumption is impacted by climate change. A comparison between the second and third scenarios tells us how average food consumption is impacted by population growth.

As these projections of future food consumption are economically driven, the next step in thinking about food security is to compare what we think people will be eating with what they *need* to eat, from a physiological perspective.

Food Requirements Sub-model

Physiological food requirements are estimated based on the methodology outlined in a report of a joint FAO/WHO/United Nations University expert consultation.[24] This methodology uses age, sex, pregnancy and breastfeeding status, activity level, and body size to determine how much energy, as measured by kcal, is required by each individual. Thus, total energy requirements for a population are dependent not only on a population's size, but also its structure.

Adult energy requirements are estimated from measures of energy expenditure plus the additional energy needs for growth, pregnancy, and lactation. Adult energy requirements are calculated based on a basal metabolism and physical activity level (PAL). Basal metabolism is estimated based on age, sex, and body weight. Body weights by age and sex were extracted from the accompanying Population Energy Requirements software. PAL was also extracted from the same software, which uses estimates of the urban-rural distribution of the population to approximate average national PAL, with the assumption that rural populations have a higher level of physical activity than do urban populations.

Additional energy is required by pregnant women for maternal gestational weight gain, which is associated with protein and fat accretion in maternal, fetal, and placental tissues, and by the increase in energy expenditure associated with basal metabolism and physical activity. These additional energy requirements increase as a pregnancy advances, but are estimated to sum to a total *additional* caloric intake of 77,000 kcal over the course of the pregnancy. This represents an additional 297 kcal per day averaged over the course of a 37-week pregnancy, or 211 kcal per day averaged over the course of a year.

Breastfeeding women also have increased food energy needs; these additional needs are the sum of the energy content of the milk produced and the energy required for milk production. These additional needs are estimated to be 505 kcal per day during the first six months. For the sake of simplicity, this model assumes that all women practice exclusive breastfeeding for the first six months of life, and cease all breastfeeding after six months.

Both children's (1-17 years) and infants' (0-11 months) energy requirements are the sum of total energy expenditure (TEE) and energy needs for growth. Energy needs for growth have two components: the energy used to synthesize growing tissues; and the energy deposited in those tissues, basically as fat and protein, because carbohydrate content is negligible. The proportion of total energy requirements that go toward growth gradually decreases over the first twenty years of life:

> Energy demands for growth constitute about 35 percent of the total energy requirement during the first three months of life (40 percent in the first month), this proportion is halved in the

24 United Nations University, World Health Organization, Food and Agriculture Organization of the United Nations (FAO). *Human Energy Requirements: Report of a Joint, FAO/WHO/UNU Expert Consultation, Rome, 17–24 October 2001*. Rome, Italy: FAO; 2004.

next three months (i.e. to about 17.5 percent), and further reduced to one-third of that during the ensuing six months (i.e. to less than 6 percent) and to only 3 percent at 12 months. Energy for growth falls to less than 2 percent of daily requirements in the second year, remains between 1 and 2 percent until mid-adolescence, and gradually disappears by 20 years of age.[25]

For children, TEE is estimated for each single year of age, separately for girls and boys, based on WHO reference values of weight-for-age. Like adults, weights of children by age and sex were also extracted from the Population Energy Requirements software. Infants' TEE is estimated for each month of age during the first year of life, separately for girls and boys. For both children and infants, energy needed for growth is based on studies estimating the fat and protein mass gain in each single year (or month, for infants) of age, and the caloric energy per gram of fat and protein. In countries where children have a high level of physical activity, energy needs may be increased by 15%.[26] Because the energy consumed by breastfeeding infants is accounted for in the increased energy needs of breastfeeding women, only the energy required for infants 6-11 months are calculated, to avoid double counting the energy of breast milk.

Total and average energy requirements for any given country or region are calculated by applying energy methodology outlined above to the demographic composition of the population. The demographic information needed for each projection year is:

- population of men and women ages 18-29, 30-59, and over 60;
- annual pregnancies;
- percentage of total fertility amongst women above vs. below age 30; and
- children ages 0-17, by single-year age groups and gender.

The following outputs can be calculated by the program, all expressed in terms of daily kcal:

- total energy requirements (for the entire population);
- average kcal per person; and
- energy requirements of men, women, children, pregnant women, breastfeeding women: can be expressed in terms of average per capita kcal, or as a percentage of national energy needs.

Thus, total physiological energy requirements for a given population reflect both the absolute number of people as well as the type of people, or demographic profile, that make up the country. For example, a country with many adolescents will require more kilocalories than a country with an older population.

Childhood Malnutrition

The percentage of children under age five that is underweight is used as the metric for childhood malnutrition; this metric is also referred to as weight-for-age. WHO provides weight (and height) data for a reference group of well-nourished children by gender and

25 FAO, *Human Energy Requirements, op. cit.*:13.

26 Population Energy Requirements [software], user's manual. Rome, Italy: FAO; 2004.

single year age groups.[27] These reference data are the standard against which survey children are compared. Children who fall more than two standard deviations below the median weight of the reference population are considered to be underweight.

Underweight is used as a metric for childhood malnutrition in this model because it can reflect either chronic, long-term or acute, recent malnutrition; it may also reflect a composite effect of the two. In contrast, other common childhood malnutrition indicators describe *only* chronic-long term malnutrition or *only* acute, recent malnutrition. Stunting (or height-for-age) reflects accumulated malnutrition over a long time period. Wasting (weight-for-height) reflects recent, acute nutritional deficient. A child who is underweight for his /her age may be stunted, wasted, or both. Underweight is an overall measure of the population's nutritional status because the measurement does not distinguish between types of malnutrition.

The methodology and equation used to estimate the number of underweight children is developed in *Explaining Child Malnutrition in Developing Countries: A Cross- Country Analysis.*[28] The independent variables are:

- ratio of female to male life expectancy;
- gross female secondary school enrollment;
- percentage of population with access to safe water; and
- per capita kcal availability.

These independent variables are used to predict changes in the percentages of children who are malnourished. Recent survey data, from sources such as United Nations Children's Fund (UNICEF) and Demographic and Health Surveys (DHS), can be used for a baseline value of percentage of all children under five who are malnourished. Once assumptions are made about future values of the independent variables, the percentage of children who are malnourished can be predicted.

The model at hand focuses on kcal consumption, one of the four independent variables used to predict the prevalence of childhood malnutrition. As previously mentioned, we use three scenarios of possible future food consumption, as defined in the previous section about the GLOBE model (no climate change and high population growth, climate change and high population growth, and climate change and low population growth).

Each of these possible trajectories of food consumption can be used to create different predictions of the prevalence of childhood malnutrition. For the purposes of this model, it is best to keep the same assumptions about future values of the first three independent variables constant between our three climate change and population scenarios, in order to isolate their effects.

The size of the population under age five can then be taken from DemProj, in order to calculate absolute numbers of children who are malnourished. It is important when interpreting these absolute numbers of

27 WHO Multicentre Growth Reference Study Group. *WHO Child Growth Standards*. Geneva, Switzerland: World Health Organization; 2006.

28 Smith LC, Haddad LJ. *Explaining Child Malnutrition in Developing Countries: A Cross-Country Analysis*. Washington, DC: International Food Policy Research Institute; 2000.

children to remember that they are influenced by *both* the malnutrition rate, as well as the demographic growth of the population under age five.

Model Limitations

While this model makes an important contribution to the field of climate change adaptation, it has important limitations that must be recognized. Food security is the link between the effects of climate change and population factors. The working definition of food security used in this model is the gap between the average kcal consumed and the average kcal required by the population as computed using international formulae and standards. This definition is very much focused on the macro-level - averages often do not represent the actual experiences of many people - and does not account for inequality and other factors related to poverty or to issues around food distribution. The authors recognize that the approach of using national averages does not comprehensively address the full picture of food security, which affects different sub-populations in different ways.

Another limitation is the simplicity of the malnutrition analysis, which also focuses on the kcal shortfall. The authors recognize that there are many other components to nutrition in addition to total kcal consumed and that adequate food nutrition is not just a matter of food consumption or availability. Such other nutritional factors are not accounted for in the model as currently configured, but are under consideration.

Finally, economic and climate change assumptions are programmed into the GLOBE model, and cannot be changed. While we considered developing our own economic and climate change model for the agricultural sector, we felt it was preferable to use a model that had already been developed and tested.

Despite the above simplifying assumptions, the model described here is complex in terms of having many inter-acting variables. Dynamic models that have complex relationships that are often non-linear and that are projected over long periods of time can often be difficult to understand and may give results that are not intuitive. But such is the power of these models. Also, because the model addresses multiple sectors, each of which has many confounding factors, interpretation of results may be challenging to a person unfamiliar with the model, or to a lay audience. This poses challenges to interpreting the results in a clear and meaningful way in advocacy materials designed for a general audience.

Climate Change, Food Security, and Population in Ethiopia

Context

Ethiopia is a country that has experienced high population growth, food insecurity, and persistent environmental degradation and drought. With 83% of its population living in rural areas,[29] it is one of the most rural countries in the world, implying a high dependence on subsistence agriculture. These factors make Ethiopia a highly relevant country for piloting our model, which can link climate change, food security, and population in Ethiopia. In addition, a lot of data have been collected and are readily available on all three topics in Ethiopia, which also justified the choice of pilot country.

Like many sub-Saharan African countries, Ethiopia is facing climatic changes that are expected to have long range impacts on its food supply. Meteorological data show a persistent upward trend in mean temperatures and climate change scientists' forecasts predict this trend of increasing temperatures will continue. Figure 3 shows changes in temperature over the last 40 years and scenarios in the future.[30] Between 1960 and 2006, the mean annual temperature increased by 1.3 C, an average rate of 0.28 C per decade. We also see that forecasts estimate an additional increase of between 1.5 and 5.1 C by the end of the century.

Another aspect of climate change that is challenging Ethiopia is variation in rainfall patterns. Too little or too much water can be challenging to farmers. A recent survey in Ethiopia found that most farmers have experienced drought and over 20% have faced flooding at some point during a year. As we can see, both of these shocks have increased from 2008 to 2010.[31] A recent Oxfam report on Ethiopia cites a national meteorological agency report that "average countrywide annual rainfall trends remained more or less constant between 1951 and 2006. However, both seasonal and annual rainfall has exhibited high variability."[32]

Historically, Ethiopia has been well known for periods of food insecurity and even famine. Persistent food insecurity remains a major problem in many parts of Ethiopia. Food imports provided by donors provide some relief but the Ethiopian government recognizes the structural nature of the problem. In the last 10 years, there has been a policy shift away from ad hoc responses, such as those that characterized the major drought in 2002, to a planned systematic approach. This was embodied in the Government of Ethiopia's Food Security Program, launched in 2005.

29 *United Nations World Urbanization Prospects.* [2009 revision]. New York, NY: Population Division of the Department of Economic and Social Affairs of the United Nations; 2009.

30 UNDP Climate Change Country Profiles Ethiopia [Web page]. School of Geography and the Environment, Oxford University. Accessed Feb. 27, 2012 at http://country-profiles.geog.ox.ac.uk.

31 *Evaluation of Ethiopia's Food Security Program: Documenting Progress in the Implementation of the Productive Safety Nets Programme and the Household Asset Building Programme*. Washington, DC: International Food Policy Research Institute; 2011.

32 *The Rain Doesn't Come On Time Anymore: Poverty, Vulnerability and Climate Change in Ethiopia.* Oxford, United Kingdom: Oxfam; 2010.

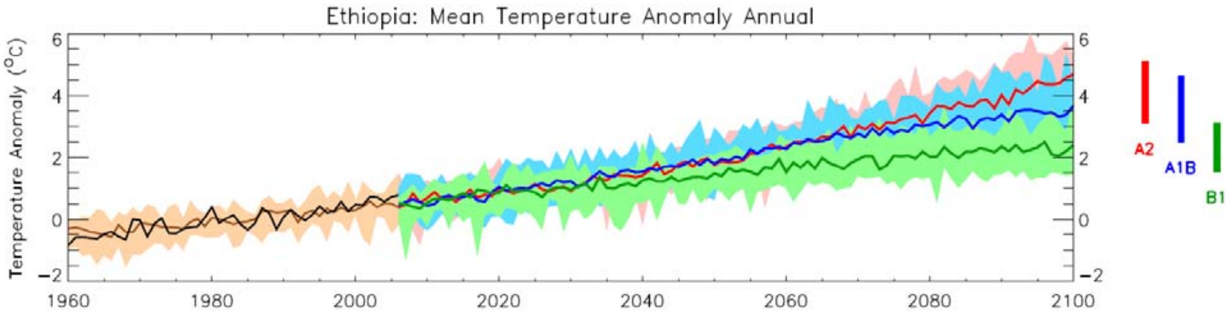


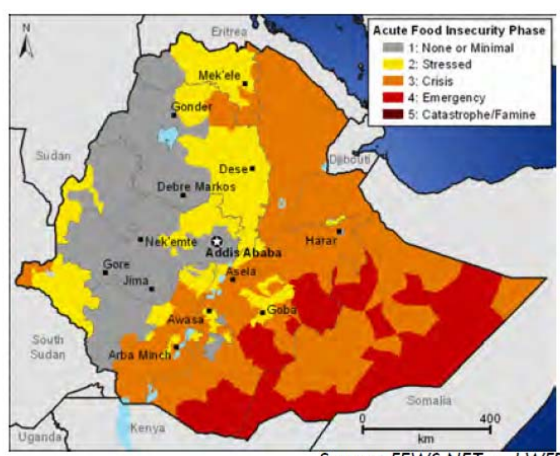
Figure 3. Mean temperature anomaly, Ethiopia 1960-2100.

Source: UNDP Climate Change Country Profiles Ethiopia [Web page]. School of Geography and the Environment, Oxford University. Accessed Feb. 27, 2012 at http://country-profiles.geog.ox.ac.uk.

A major part of that strategy is the Productive Safety Nets Programme (PSNP). More than 7 million people have benefited from the PSNP, enabling them to meet consumption needs, reducing the risks they faced and providing them with alternative options to selling productive assets. While the PSNP has had significant impact, challenges remain.[33]

The US Famine Early Warning System (FEWS) monitors the food situation in Africa on a continuous basis. In its latest assessment, much of Ethiopia was facing a precarious food security situation. Figure 4 shows that large parts of the country are considered in a state of emergency, crisis, or stress.

As in many countries, food insecurity is not just a function of the overall availability of food in the country but also a matter of poverty. In Ethiopia, as in many countries, food consumption is lowest among the poor. For example, recent data show that the calorie consumption of the lowest quintile of the population in terms of expenditures averages 1,672 kcal per day, while the wealthiest quintile consumes 2,367 kcal per day. Using FAO methodology for estimating human energy requirements, we calculated the daily kcal need for an average person in Ethiopia. Kcal requirements for individuals vary according to their age, gender, size, physical activity level, and pregnancy state. We estimated that the average Ethiopian needs about 2,212 kcal of energy per day. As seen in figure 5, only the wealthiest 40% of rural Ethiopians meet this requirement, while the poorest 60% have insufficient food consumption.



Source: *FEWS NET and WFP*

Figure 4. Food security outcomes, Ethiopia, July 2011.

33 Guush B, et al. *Evaluation of Ethiopia's Food Security Program: Documenting Progress in the Implementation of the Productive Safety Nets Programme and the Household Asset Building Programme.* Washington, DC: IFPRI; 2011.

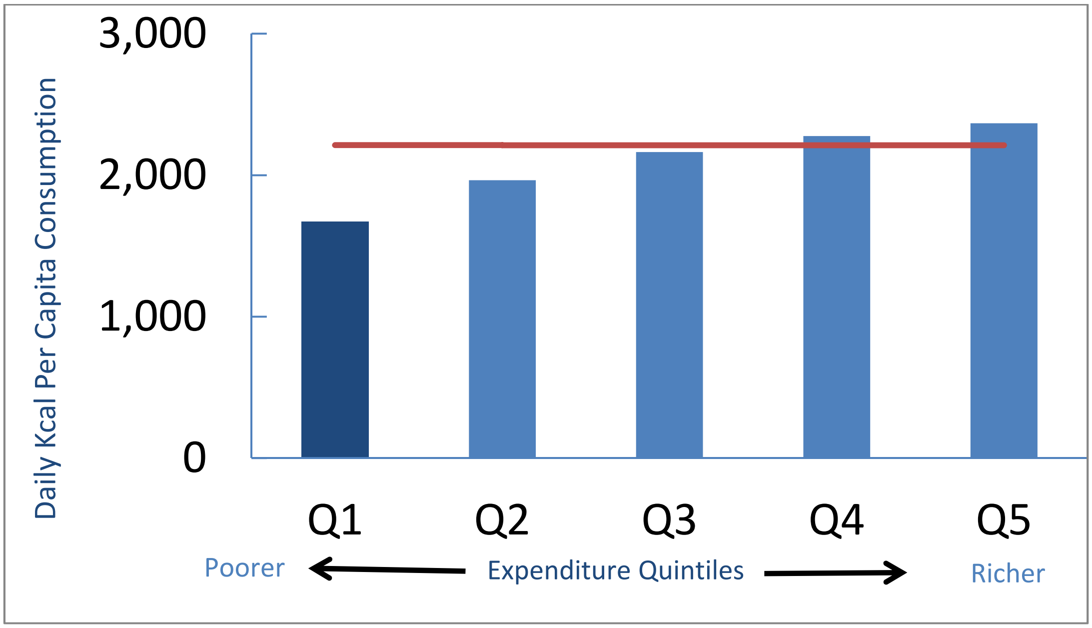


Figure 5. Daily kcal consumption among Ethiopians by wealth quintile, 2004/2005 (red line indicates 2,212 kcal requirements).

Source: Dorsh P. HICE Survey 2004/05, food prices, consumption, and nutrition in Ethiopia: implications of recent price shocks. [Presentation]. Institute of Medicine Workshop on Mitigating the Nutritional Impacts of the Global Food Crisis, July 2009.

Ethiopia's population has grown tremendously in recent years. The 1984 census showed a population of 40 million, growing to 53 million in 1994. The most recent census, in 2007, counted 74 million people within the same borders. Today's population is estimated at 82 million people. The growth rate of the population has been falling due largely to declines in fertility. Ethiopia's fertility has also been falling. In 1990, there was an average of 6.4 births per woman; by 2011, this had declined to 4.8 births per woman. The decline in fertility is due in large part to increases in contraceptive use. Ethiopia has made impressive recent advances in contraceptive use. There has been a large increase in the percentage of married women using family planning in Ethiopia. In 2000, only 8.1% of women used family planning. Ethiopia's CPR increased to 14% in 2005 and jumped to 28.6% in 2011,[34] one of the fastest increases in the world. Most contraceptive use in Ethiopia is modern methods. However, there is wide regional variation in Ethiopia in the use of family planning. Although the national CPR is 28.6%, regional CPRs vary from 4.3% in Somali to 62.5% in Addis Ababa. Due to a built-in demographic momentum linked to the country's young age structure, even if Ethiopia were able to achieve its ambitious targets for 65% CPR by 2015 with a concomitant reduction in fertility, the population is expected to at least double by 2050.

34 Central Statistical Agency, MEASURE DHS. *Ethiopia Demographic and Health Survey, 2011: Preliminary Report.*, Calverton, MD: MEASURE DHS; 2011.

Applying the Model to Ethiopia

The model described in the previous sections was applied to Ethiopia as a pilot test of the approach. The Population Health Environment (PHE) Consortium was selected as a local partner for its knowledge of issues in the field and for its extensive network of organizations working to integrate reproductive health and environmental projects. This partnership allowed for continuous feedback and "ground truthing" throughout the application of the model. It also enabled us to work at the subnational level.

An advisory group of regional professionals in the fields of climate change, food security, and population, was gathered in Hawassa, Southern Nations, Nationalities and Peoples' Regional State (SNNPR), at the onset of the model development. The purpose was to ensure that model development and design were informed by local issues of relevance. Field visits in rural areas of SNNPR were conducted to get a sense of how climate change, food security, and population growth are linked on the ground. Individual meetings with national professionals in the fields of climate change, food security, and population were conducted in Addis Ababa in order to understand the national perspective, gather data, and inform officials of the activity. After development of the beta model, initial results were presented to the same groups in Dilla, Hawassa, and Addis Ababa. Valuable feedback was incorporated into model, especially in terms of presentation of results.

In terms of the model, for the DemProj component of the model, we used high and low projections developed in conjunction with the Population Affairs Directorate in 2009 for use in the RAPID model. These projections were vetted by a multisectoral stakeholder consensus meeting in Addis Ababa in 2009. They are linked to FamPlan, another module in Spectrum, which estimates the level of family planning use needed to achieve the desired fertility rates. Because the original projections ended in 2030, they were extended to 2050 for the purposes of the present model. It was assumed that the UN medium TFR (2010 revision) would be reached by 2050 for the low scenario, and that the high TFR would be reached by 2050 for the high scenario.

For the economic sub-model, the FAO country balance sheet provided the baseline diet, expressed in terms of average daily kcal consumed by food category. The GLOBE model provided indices of per capita household food consumption through 2050. Annual growth rates of consumption of various food categories were calculated from these indices. These growth rates were applied to the baseline diet to estimate average per capita food consumption through 2050.

Food requirements were calculated based on the methodology described in the Food Requirements Sub-model section of this report. Calculations were made for each of the two population projections produced by DemProj. Estimates of kcal requirements by age, sex, and pregnancy/breastfeeding status were added up to estimate total energy requirements for the entire population.

Results

Population - The high and low population growth scenarios, based on the scenarios decided on by consensus during the 2009 RAPID process in Ethiopia, produced the population projections described below.

The main difference between the two population scenarios is in the assumption on the future course of fertility. These are shown in figure 6, in the dashed lines. We see that the TFR starts just below 5.0 in 2010 and declines to 2.3 under the high population scenario and to 1.8 in the low population scenario. These TFR assumptions have implications for the level of family planning use in Ethiopia. The solid CPR lines illustrate the percentage of married women that would need to be using some form of contraception in order to reach the given TFR assumptions.

The impacts of these fertility assumptions on total population are shown in the solid lines in figure 7. Under both fertility assumptions, Ethiopia's population will be greater than 150 million by the year 2050.

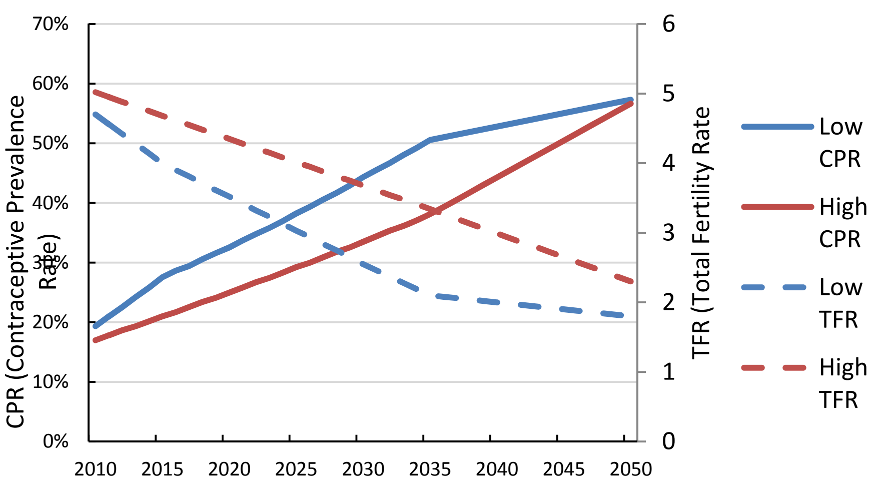


Figure 6. TFR and CPR assumptions, Ethiopia, 2010-2050.

In addition to different total population sizes, the two scenarios also produce different age structures. That is, the different fertility assumptions about the two scenarios create different proportions of people in each age group. Figure 8 shows the percentages of the total population that are children, working age adults, and elderly.

The differences in between these two age structures have implications for the food requirements of each of these different populations. Comparing the solid and dashed lines show that, with time, the age composition of the two populations vary. The low population scenario shows an older population, while the high population scenario shows a higher proportion of children. Notice that the population ages with time under both scenarios. These changes in age structure of the population affect the food requirements of Ethiopia, since people of different ages have different energy intake requirements.

Food Production and Consumption - The economic sub-model was used to project food production and consumption. Population growth rates used in the economic sub-model follow from the population projections described in the previous section. The growth rates of the total population and the population aged 15-64 are show in table 3. Tables 4-6 show the growth rates in per capita household

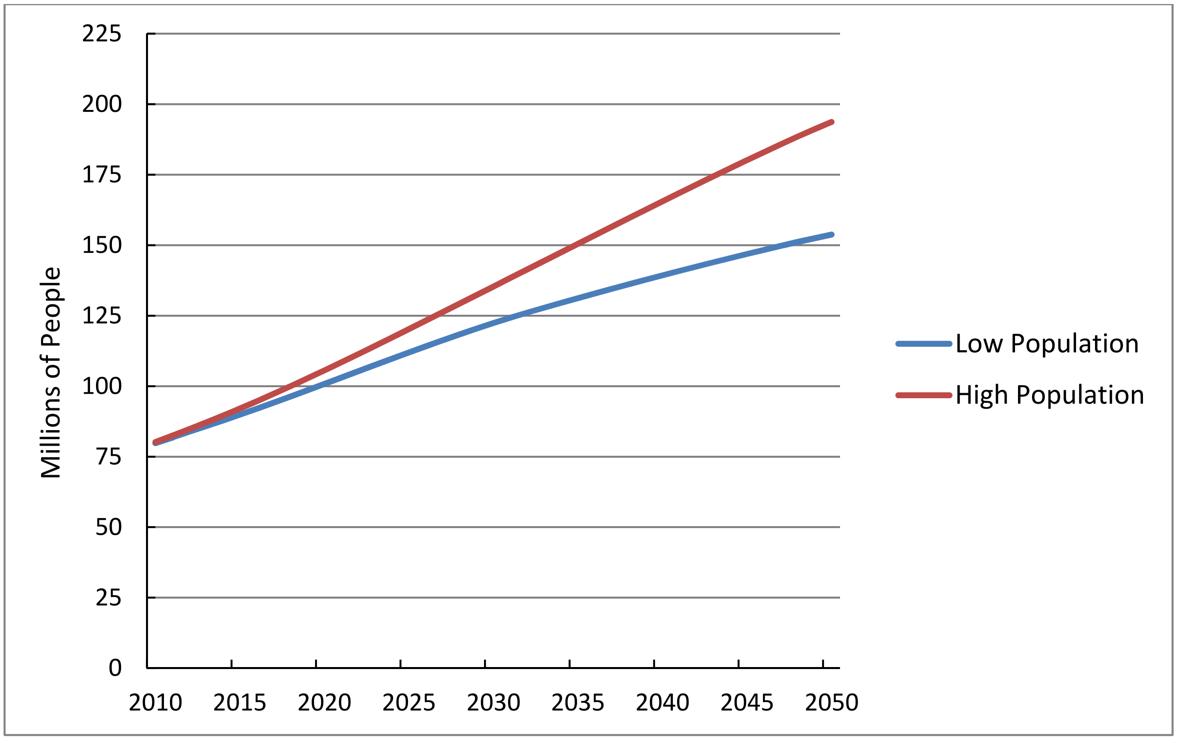


Figure 7. Total population projections for Ethiopia, from about 80 million in 2010 to a low project of 154 million and high of 194 million in 2050. Source: Authors' calculations.

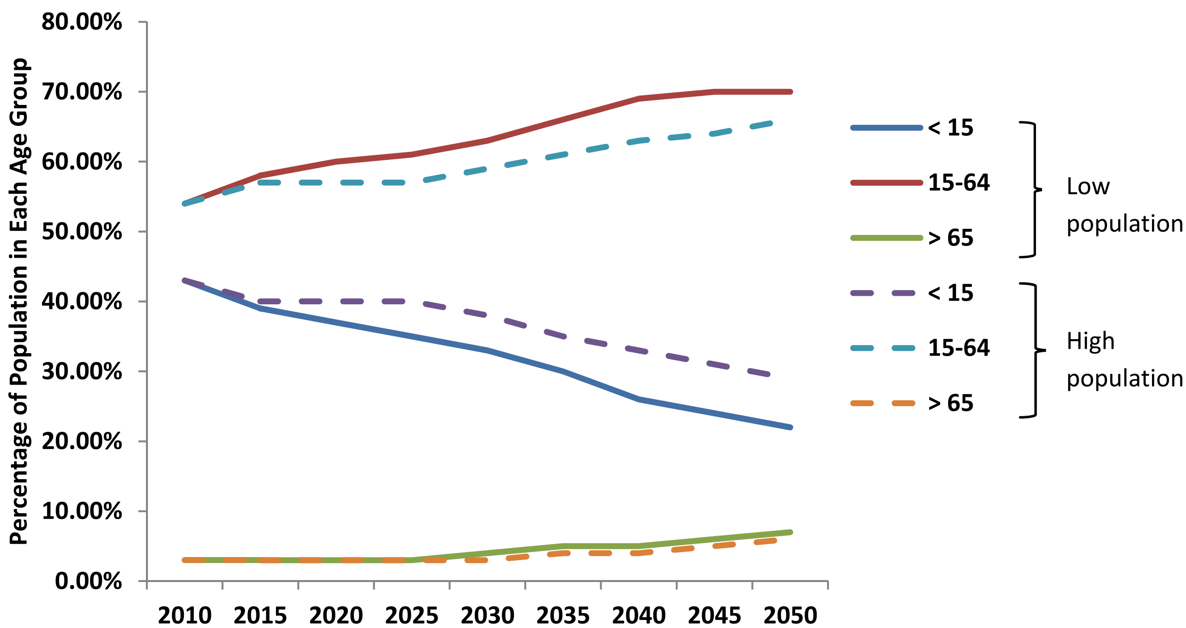


Figure 8. Age structure, Ethiopia 2010-2050 (low population project in solid lines, high population in dashed lines). Source: Authors' calculations.

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consumption for various foodstuffs that correspond to the above population growth rates. All consumption figures were calculated using the GLOBE model.

As can be seen by comparing the growth rates in table 4 with those in table 5, per capita household consumption for all food categories is expected to be lower because of climate change than it would be without climate change. This will later contribute to the larger food gap that is expected with climate change, as compared to a world without climate change.

As can be seen by comparing the growth rates in table 5 with those in table 6, per capita household consumption for almost all food categories (with the exception of fishing) is expected to be equal or higher under a scenario of low population growth than under a scenario of high population growth. This higher per capita consumption of food under the low population growth scenario will later contribute to the smaller food gap expected with low growth as compared to high population growth.

Table. 3. Annual Percentage Population Growth Rates, Ethiopia, 2010-2050

Years	Low Population Projection		High Population Projection	
	Total Population	Population 15-64	Total Population	Population 15-64
2010-2015	2.62%	3.89%	2.70%	3.89%
2015-2020	2.41%	3.80%	2.71%	3.80%
2020-2025	2.27%	2.50%	2.72%	2.50%
2025-2030	2.15%	2.66%	2.62%	2.91%
2030-2035	1.83%	2.37%	2.38%	2.86%
2035-2040	1.46%	2.15%	2.14%	2.71%
2040-2045	1.20%	1.86%	1.92%	2.48%
2045-2050	1.09%	1.25%	1.72%	2.04%

Source: Authors' calculations

Table 4. Per Capita Household Consumption Growth Rates, Ethiopia, 2010-2050: No Climate Change and High Population Growth

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Paddy rice	0.00%	-0.40%	-0.80%	-1.40%	-1.30%	-0.80%	-0.70%	-0.70%	-0.50%
Wheat	0.00%	0.10%	-0.40%	-1.10%	-1.00%	-0.50%	-0.40%	-0.40%	-0.20%
Other cereal	0.00%	-0.20%	-0.80%	-1.60%	-1.40%	-0.80%	-0.70%	-0.70%	-0.50%
Vegetables and fruit	0.00%	-0.30%	-0.90%	-1.80%	-1.40%	-0.80%	-0.70%	-0.70%	-0.50%
Oil seed	0.00%	-0.20%	-0.80%	-1.80%	-1.60%	-1.20%	-1.10%	-0.90%	-0.60%
Other crops	0.00%	-0.20%	-0.80%	-1.30%	-1.20%	-0.60%	-0.60%	-0.50%	-0.20%
Raw milk	0.00%	0.00%	-0.50%	-1.30%	-1.00%	-0.60%	-0.50%	-0.50%	-0.20%
Fishing	0.00%	0.10%	0.30%	0.10%	1.10%	1.60%	2.20%	2.90%	3.50%
Meat products	0.00%	2.50%	2.70%	7.00%	4.00%	4.10%	3.90%	3.30%	3.00%
Processed rice	0.00%	0.00%	-0.10%	1.50%	1.10%	1.70%	1.90%	1.80%	1.80%
Vegetable oils	0.00%	0.40%	0.00%	0.30%	-0.30%	0.20%	0.30%	0.30%	0.50%
Dairy products	0.00%	2.20%	2.10%	4.50%	2.40%	2.60%	2.50%	2.10%	2.00%
Sugar	0.00%	2.30%	2.20%	4.10%	1.70%	1.90%	1.60%	1.10%	1.00%
Other food products	0.00%	2.60%	2.50%	5.70%	3.20%	3.50%	3.50%	3.10%	3.00%
Sugar cane	0.00%	-0.20%	-0.80%	-1.60%	-1.30%	-0.80%	-0.70%	-0.70%	-0.40%
Livestock	0.00%	0.20%	-0.30%	-1.20%	-0.90%	-0.50%	-0.40%	-0.40%	-0.20%

Source: Authors' calculations.

Table 5. Per Capita Household Consumption Growth Rates, Ethiopia, 2010-2050: Climate Change and High Population Growth

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Paddy rice	0.00%	-0.70%	-1.20%	-1.80%	-1.70%	-1.40%	-1.40%	-1.30%	-1.10%
Wheat	0.00%	-0.20%	-0.90%	-1.50%	-1.50%	-1.10%	-1.10%	-1.10%	-0.80%
Other cereal	0.00%	-0.50%	-1.20%	-2.00%	-1.90%	-1.40%	-1.40%	-1.30%	-1.10%
Vegetables and fruit	0.00%	-0.60%	-1.30%	-2.20%	-1.90%	-1.50%	-1.50%	-1.40%	-1.00%
Oil seed	0.00%	-0.50%	-1.30%	-2.20%	-2.10%	-1.90%	-1.80%	-1.60%	-1.20%
Other crops	0.00%	-0.50%	-1.20%	-1.70%	-1.70%	-1.30%	-1.40%	-1.20%	-0.80%
Raw milk	0.00%	-0.30%	-0.90%	-1.80%	-1.40%	-1.20%	-1.20%	-1.10%	-0.80%
Fishing	0.00%	-0.20%	-0.10%	-0.40%	0.40%	0.80%	1.30%	2.10%	2.90%
Meat products	0.00%	2.20%	2.20%	6.60%	3.60%	3.70%	3.30%	2.80%	2.50%
Processed rice	0.00%	-0.30%	-0.60%	1.10%	0.70%	1.10%	1.20%	1.20%	1.30%
Vegetable oils	0.00%	0.10%	-0.40%	-0.10%	-0.70%	-0.40%	-0.40%	-0.30%	-0.10%
Dairy products	0.00%	1.90%	1.60%	4.10%	2.00%	2.10%	1.80%	1.50%	1.40%
Sugar	0.00%	2.00%	1.70%	3.70%	1.30%	1.30%	0.90%	0.50%	0.40%
Other food products	0.00%	2.30%	2.00%	5.30%	2.90%	3.10%	3.00%	2.70%	2.50%
Sugar cane	0.00%	-0.50%	-1.20%	-2.00%	-1.80%	-1.40%	-1.40%	-1.30%	-1.00%
Livestock	0.00%	-0.10%	-0.70%	-1.60%	-1.30%	-1.20%	-1.20%	-1.10%	-0.70%

Source: Authors' calculations.

Table 6. Per Capita Household Consumption Growth Rates, Ethiopia, 2010-2050: Climate Change and Low Population Growth

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Paddy rice	0.00%	-0.30%	-0.70%	-1.00%	-0.90%	-0.90%	-0.90%	-0.90%	-0.80%
Wheat	0.00%	0.20%	-0.30%	-0.50%	-0.50%	-0.50%	-0.50%	-0.50%	-0.40%
Other cereal	0.00%	0.10%	-0.40%	-0.80%	-0.70%	-0.70%	-0.70%	-0.70%	-0.60%
Vegetables and fruit	0.00%	-0.10%	-0.70%	-1.30%	-0.90%	-1.00%	-1.00%	-0.90%	-0.80%
Oil seed	0.00%	-0.10%	-0.70%	-1.30%	-1.20%	-1.40%	-1.50%	-1.40%	-1.20%
Other crops	0.00%	0.00%	-0.60%	-1.00%	-0.80%	-0.90%	-1.00%	-0.90%	-0.80%
Raw milk	0.00%	-0.10%	-0.60%	-1.30%	-0.90%	-0.90%	-0.90%	-0.90%	-0.80%
Fishing	0.00%	-0.10%	-0.20%	-0.60%	0.10%	0.30%	0.60%	1.10%	1.60%
Meat products	0.00%	2.30%	2.30%	6.70%	3.80%	3.90%	3.70%	3.30%	3.10%
Processed rice	0.00%	-0.10%	-0.30%	1.20%	0.70%	1.10%	1.40%	1.50%	1.50%
Vegetable oils	0.00%	0.40%	0.00%	0.60%	-0.10%	-0.10%	-0.10%	-0.10%	0.00%
Dairy products	0.00%	2.00%	1.80%	4.40%	2.30%	2.20%	2.10%	1.80%	1.70%
Sugar	0.00%	2.20%	2.00%	4.40%	2.20%	2.00%	1.70%	1.40%	1.20%
Other food products	0.00%	2.40%	2.20%	5.60%	3.10%	3.20%	3.10%	2.90%	2.80%
Sugar cane	0.00%	0.00%	-0.60%	-1.10%	-0.80%	-0.90%	-0.90%	-0.90%	-0.70%
Livestock	0.00%	0.10%	-0.50%	-1.10%	-0.80%	-0.80%	-0.90%	-0.90%	-0.70%

Source: Authors' calculations

The food categories in these tables were mapped onto FAO food categories, and then applied to the Ethiopian baseline diet.[35] Figure 9 shows the average daily per capita diet for Ethiopia by food categories. We see that the largest food category is cereals (66%), followed by roots and tubers (13%) and pulses (7%). Average daily per capita consumption at the baseline was 1,981 kcal.

Consumption of food by category is projected forward from this baseline by using the growth rates from GLOBE, thus producing three scenarios of future food consumption. Figure 10 shows these projections in terms of aggregate kcal from all food categories.

In figure 10 we can see the effects of the variation in the growth rates of consumption by food category produced by the GLOBE model. Comparing the blue and red lines shows us the impact of climate change on decreasing kcal per capita consumption with high population growth. Comparing the red and green lines shows us the impact of the different population growth scenarios. The lines in figure 10 reflect the same patterns we saw in tables 4-6, with each food category weighted by its relative contribution to the average diet, shown (for the baseline year) in figure 9.

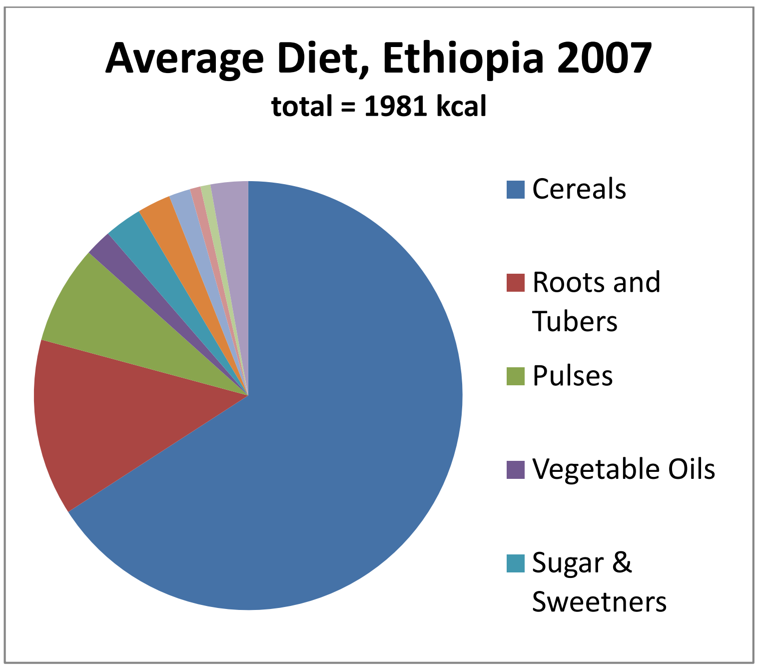

Figure 9. Baseline diet, Ethiopia.

Source: FAO Food Balance Sheet 2007, op. cit.

35 *FAO Food Balance Sheet 2007, Ethiopia*. Rome, Italy: FAO; 2007.

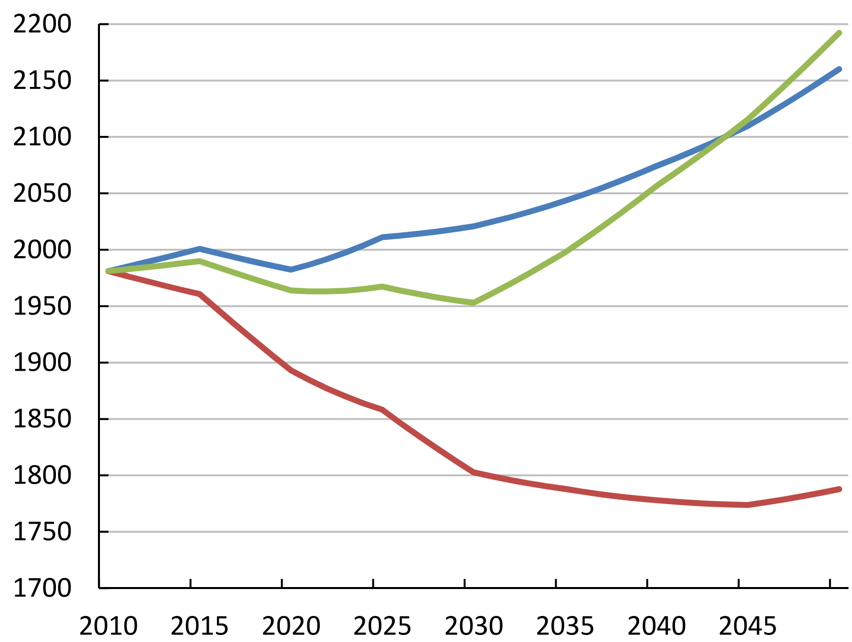

Figure 10. Average daily kcal consumption per capita, Ethiopia, 2010-2050.

Source: Authors' calculations.

Food Requirements — The two population projections also served as the basis for the food requirements calculations. For each scenario, we extracted number of girls, boys, women, and children in each age group, as well as estimates of pregnancies and breastfeeding women. We then multiplied the number of people in each of these demographic groups by our estimate of the number of kcal required by an average person of that demographic profile (see Food Requirements Sub-model section). Tables 7 and 8 show the kcal required for each demographic group. Weights and physical activity levels (based on rural/urban composition) were taken from FAO's Population Energy Requirements software.

Combining the caloric requirements in tables 7 and 8 with each of the two population projections yields two different estimates of the average per capita daily kcal requirements for Ethiopia as a whole. Figure 11shows the results for both projections.

Table 7. Average daily per capita caloric requirements, Ethiopia: Adults*

Age (years)	Men	Women		
		All women	Pregnant	Breast-feeding
18-29	2815	2191	2402	2443
30-59	2753	2220	2431	2472
60+	2276	1977	N/A	N/A

*Caloric requirements vary by weight and physical activity level.

Table 8. Average daily per capita caloric requirements, Ethiopia: Children*

Age (years)	Boys	Girls
6-12 months	823	760
1	1069	979
2	1285	1191
3	1423	1315
4	1550	1418
5	1489	1392
6	1661	1497
7	1714	1609
8	1844	1736
9	1988	1877
10	2147	2038
11	2316	2186
12	2502	2364
13	2717	2495
14	2972	2601
15	3235	2650
16	3454	2693
17	3585	2720

*Caloric requirements vary by weight and physical activity level.

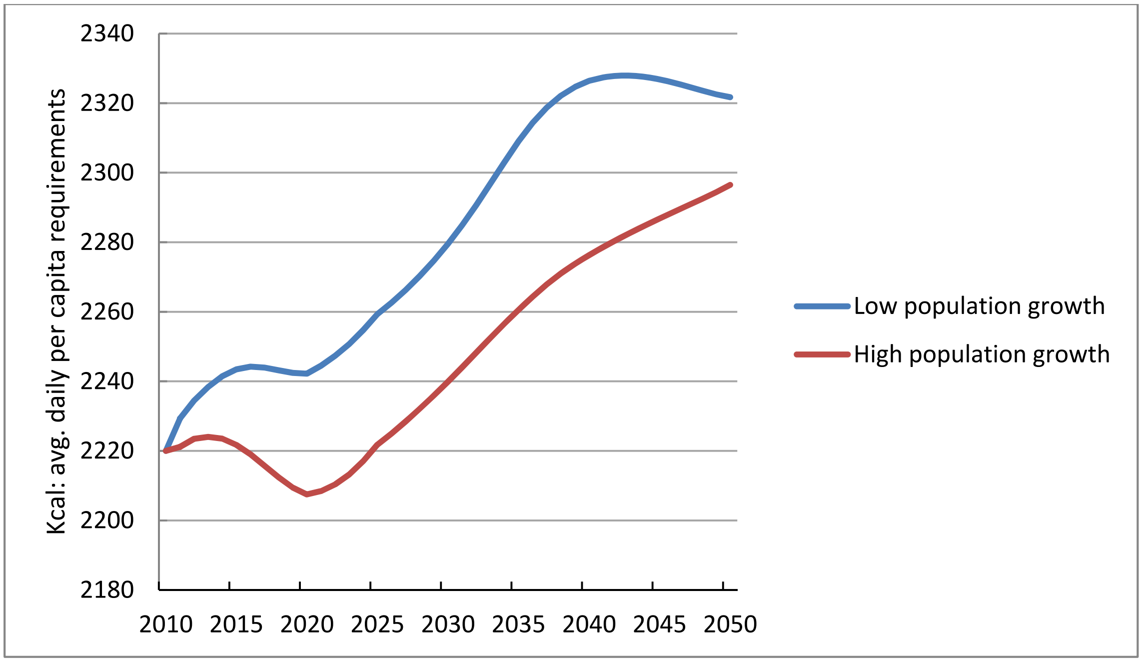

Figure 11. Average per capita daily food requirements, Ethiopia, 2010-2050.

Source: Authors' calculations.

As we can see in figure 11, food requirements are slightly higher under low population growth throughout the projection period. This is due to the age structure: we saw in figure 8 that the low population scenario has a lower proportion of the population under 15. Figure 12 illustrates the impact this age structure has on the food requirements of Ethiopia: by 2050, under low population scenario, only 23% of kcal is going to children. 77% are going to adults, who have higher food requirements, thus increasing the national average of kcal required.

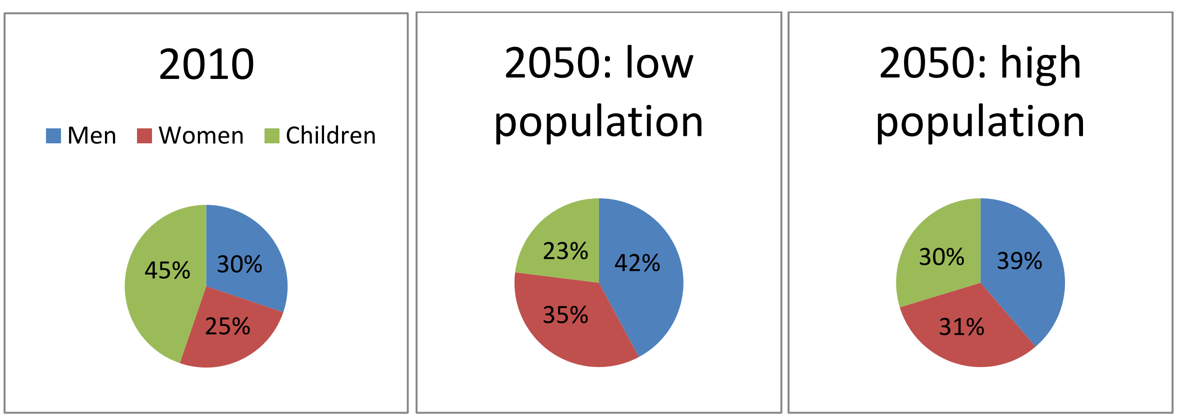

Figure 12. Breakdown of national caloric needs.

Source: Authors' calculations.

Food Security Gap — Results from Ethiopia show a food gap (food requirements greater than food consumption) under all three scenarios (table 9).

Table 9. Food Gap in Ethiopia in 2050 (Average Daily kcal per Capita)

Requirement	Consumption	Gap
No climate change and high population growth		
2322	2160	136
Climate change and high population growth		
2296	1788	509
Climate change and low population growth		
2322	2192	129

Source: Authors' calculations.

A food gap is also estimated for all 40 years of the projection is shown in figure 13.

Although a food gap is estimated for all scenarios and all years, the magnitude of the gap varies significantly between scenarios. As we can see in the red line scenario in figure 13, the combination of the effects of climate change and high population growth produces the most severe food gap. In this scenario, climate change affects food production, including ramifications for the international trade of foodstuffs and increasing food prices. At the same time, higher population growth means a larger population to feed. We can isolate the effects of climate change only by comparing the red line with the blue line, which assumes no climate change. By 2050, climate change alone accounts for almost 400 fewer kcal consumed per person per day.

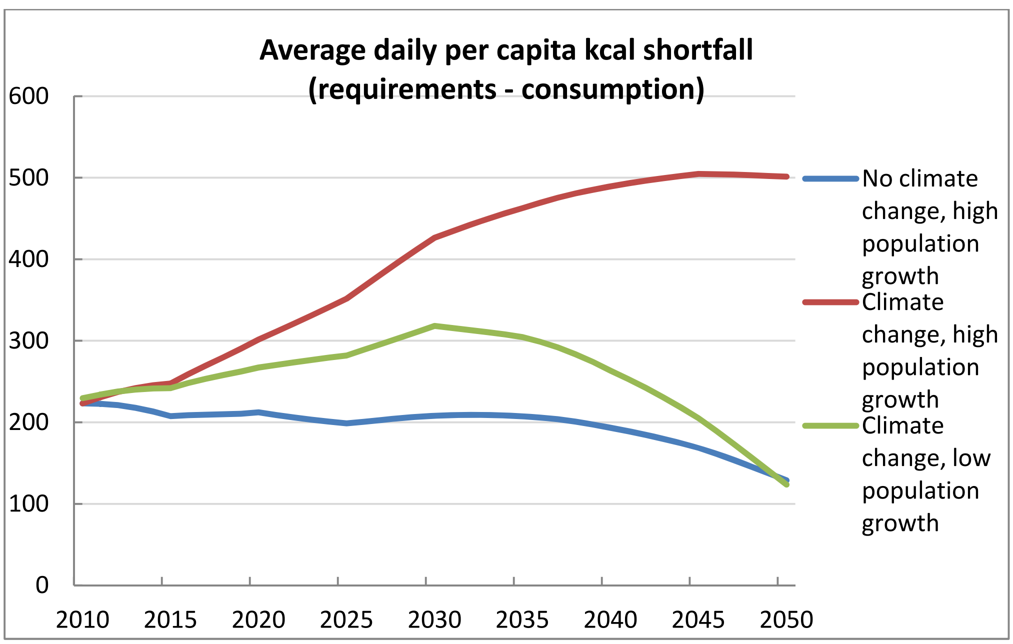

Figure 13. Food gap in Ethiopia, 2010-2050 (average daily kcal per capita).

Source: Authors' calculations.

We can also isolate the effects of population growth by comparing the red and green lines. Both these scenarios assume the same effects of climate change on the food system. However, they differ in the size and composition of population that must be fed in a climate change-affected future. As we can see in figure 13, the world with lower population growth (in green) has a smaller kcal food gap.

This suggests that, in a future world affected by climate change, population growth is one lever that can be addressed to ameliorate the impacts of climate change, particularly in the area of food security. This analysis provides a basis for viewing family planning as one adaptation strategy to climate change by reducing population growth and thereby addressing the demand side of food security.

Childhood Malnutrition — Results of the number of underweight children under age 5 also demonstrate the effects of climate change, as well as the potential for mollifying these affects by slowing population growth. Figure 14 estimates the number of underweight children in Ethiopia under each of the three scenarios.

The general trend is for the number of underweight children to first increase, due to high population growth and increasing numbers of children, followed by a decrease in the number of underweight children, due to increasing living standards. Again, we can isolate the effects of climate change by

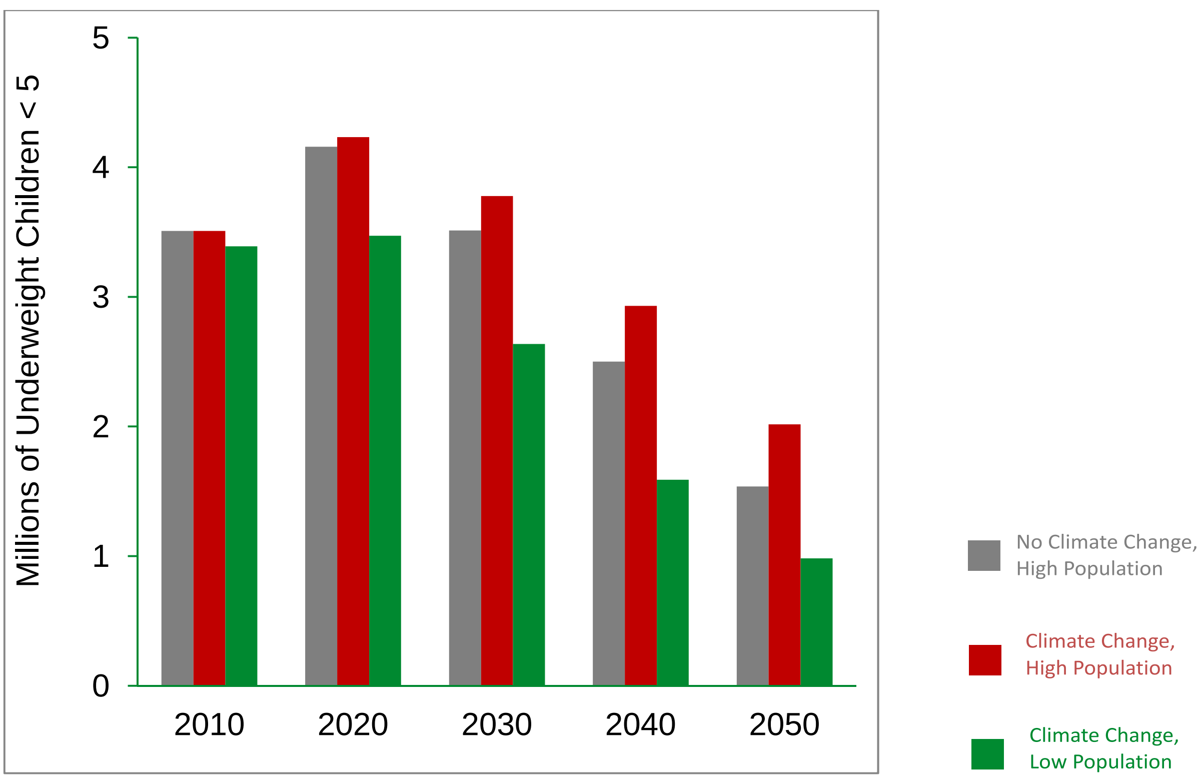

Figure 14. Number of underweight children in Ethiopia 2010-2050 under three scenarios.

Source: Authors' calculations.

comparing the red and grey bars. We can see that, in all future years, we can expect climate change to increase the number of underweight children. This is because, as we saw in the previous section, kcal food consumption is expected to be lower with climate change, and this lower kcal consumption in turn increases malnutrition.

Once again, we can isolate the effects of population growth by comparing the red and green bars. Both these scenarios make the same assumptions about climate change and its effects on the food system. In all years, we expect there to be fewer malnourished children under a scenario of low population growth, even in the face of climate change. By the year 2050, we expect 51% fewer malnourished children under a scenario of low population growth, as compared to a scenario of high population growth, keeping constant the climate change assumptions.

Summary of the Ethiopia Pilot — The Ethiopia pilot demonstrated the usefulness of this model in quantifying the contribution of family planning in adapting to potential climate change-induced food security challenges. Food insecurity — as measured in terms of the gap between kcal consumed and kcal required — is expected to worsen in the face of climate change. The model shows that the food security gap is expected to be greater with climate change than the food security gap without climate change. The model also shows the potential of family planning to address this gap; the food security gap under an assumption of low population growth and climate change is lower compared to the gap with climate change and high population growth. In fact, by the year 2050 the model estimates that slower population growth will compensate completely for the effects of climate change on food security.

The low population growth scenario is achievable by scaling up access to family planning services. In Ethiopia, 25% of married women express the desire to delay or avoid another child, yet are not using any method of family planning to achieve their expressed fertility preferences. Giving access to family planning to these women would increase family planning use, as illustrated in figure 6, leading to lower fertility rates and therefore lower population growth.

The model application also shows implications for the number of malnourished children in Ethiopia. Although we expect childhood malnutrition to decrease with development (due to factors such as increased access to clean drinking water, improvements in female education, etc.), the model shows that these improvements are hampered by climate change Slowing population growth, on the other hand, can accelerate declines in childhood malnutrition.

Conclusion

The development and piloting of this model provide a sound quantitative exploration into linkages often mentioned qualitatively in the climate change adaptation literature. Climate change affects human populations through a variety of mechanisms. One such pathway is food and agriculture; climate change can affect food production via changes in temperatures, rainfall patterns, and growing seasons. Like other commodities, changes in food production can spur changes in prices and international trade. These set of relationships from climate change to food consumption are quantified in the GLOBE economic model, elucidating what food consumption changes we may expect to see in the future that could be attributable to climate change. At the same time, the GLOBE economic model takes into account population growth rates, and thus can also be used to isolate the effects of different demographic scenarios.

Different demographic scenarios also have different implications for the amount of food required by the population to satisfactorily fulfill its physiological requirements. A larger population requires more food; different members of any population also have different food requirements. Thus, both population size and composition affect a population's food requirements.

Analyzing the gap between food consumption and food requirements under different assumptions about climate change and population growth can help to shed light on one effect of climate change on human populations. Family planning, especially in countries with high unmet need, provides a potential solution not only for women's reproductive health, but also for adapting to the effects of climate change.

Results of this model serve as an excellent starting point for the dialogue about the importance of taking into account population factors when adapting to climate change. While technological interventions on the supply side will surely be vital in adapting to climate change and achieving food security, addressing the demand side will also be paramount to increasing standards of living and decreasing our environmental footprint.

Additional References and Background Sources

The Hertel et al. study used in this analysis (see page 8, note 22) is based upon the following studies:

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Schlenker W, Roberts MJ. Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proceed National Acad Sci.* 2009;106(37):15594-15598.

Xiong W, Lin E, Ju H, Xu Y. (2007) Climate change and dritical thresholds in China's food security. *Clim Change.* 2007;81(2):205-221.

The findings of the Hertel and colleagues study are consistent with the following:

Easterling W et al. (2007) Food, fibre, and forest products. In: Parry ML, Canziani OF, Palutikof JP, Linden PJVD, Hanson CE. (Eds.) *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom: Cambridge University Press; 2007: 273-313.

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Tebaldi, C., Lobell, D.B. (2008) Towards Probabilistic Projections of Climate Change Impacts on Global Crop Yields. *Geophysical Research Letters* 35, L08705.

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