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# ECONOMY-WIDE IMPACTS OF CLIMATE CHANGE ON AGRICULTURE IN SUB-SAHARAN AFRICA

*Alvaro Calzadilla* [a,b,*], *Tingju Zhu* [c], *Katrin Rehdanz* [a,d,e], *Richard S.J. Tol* [f,g,h,i], *and Claudia Ringler* [c]

[a] *Research unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg, Germany*
[b] *International Max Planck Research School on Earth System Modelling, Hamburg, Germany*
[c] *International Food Policy Research Institute, Washington DC, USA*
[d] *Christian-Albrechts-University of Kiel, Department of Economics, Kiel, Germany*
[e] *Kiel Institute for the World Economy, Kiel, Germany*
[f] *Economic and Social Research Institute, Dublin, Ireland*
[g] *Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands*
[h] *Department of Spatial Economics, Vrije Universiteit, Amsterdam, The Netherlands*
[i] *Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA*

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**Abstract**

Two possible adaptation options to climate change for Sub-Saharan Africa are analyzed under the SRES B2 scenario. The first scenario doubles irrigated areas in Sub-Saharan Africa by 2050, compared to the baseline, but keeps total crop area constant. The second scenario increases both rainfed and irrigated crop yields by 25 percent for all Sub-Saharan African countries. The two adaptation scenarios are analyzed with IMPACT, a partial equilibrium agricultural sector model combined with a water simulation model, and with GTAP-W, a general equilibrium model including water resources. The methodology combines advantages of a partial equilibrium approach, considering detailed water-agriculture linkages with a general equilibrium approach, which takes into account linkages between agriculture and non-agricultural sectors and includes a full treatment of factor markets. The efficacy of the two scenarios as adaptation measures to cope with climate change is discussed. Due to the low initial irrigated areas in the region, an increase in agricultural productivity achieves better outcomes than an expansion of irrigated areas. Even though Sub-Saharan Africa is not a key contributor to global food production or irrigated food production, both scenarios help lower world food prices, stimulating national and international food markets.

**Keywords:** Computable General Equilibrium, Climate Change, Agriculture, Sub-Saharan Africa, Integrated Assessment

**JEL Classification:** D58, Q54, Q17, N57

[*] Corresponding author: Research unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science, Bundesstrasse 55 (Pavillion Room 10), 20146 Hamburg, Germany. Tel.: 49 40 42838 4375; fax: 49 40 42838 7009. E-mail address: alvaro.calzadilla@zmaw.de

## 1 Introduction

Agriculture is of great importance for most Sub-Saharan African economies, supporting between 70 to 80 percent of employment, contributing an average of 30 percent of GDP and at least 40 percent of exports (Commission for Africa 2005). However, specific agro-ecological features, small farm sizes, poor access to services and knowledge and the low investment in infrastructure and irrigation schemes have limited agricultural development in Sub-Saharan Africa (FAO 2008).

Rainfed farming dominates agricultural production in Sub-Saharan Africa, covering around 97 percent of total crop land, and exposes agricultural production to high seasonal rainfall variability. Although irrigation systems have been promoted in the region, the impact has not been as expected. Reasons include a lack of demand for irrigated products, poor market access, low incentives to agricultural intensification, unfavourable topography, low quality soils and inadequate policy environments (FAO 2006a and 2008). Although the cost of irrigation projects implemented in developing countries have generally decreased over the last four decades and performance of irrigation projects has improved (Inocencio et al. 2007) the situation in Sub-Saharan Africa is different. This region has higher costs than other regions in terms of simple averages. However, some projects were implemented successfully with lower costs compared to other regions.

Agriculture in Sub-Saharan Africa is characterized by comparably low yields. While Asia experienced a rapid increase in food production and yields during the green revolution in the late 1970s and early 1980s, in Sub-Saharan Africa per capita food production and yields have stagnated. The failure for agriculture to take off in Sub-Saharan Africa has been attributed to the dependence on rainfed agriculture; low population densities; lack of infrastructure, markets and supporting institutions; agroecological complexities and heterogeneity of the region; low use of fertilizers; and degraded soils (Johnson et al. 2003; World Bank 2007).

In Sub-Saharan Africa, 62 percent of the population live in rural areas and depend mainly on agriculture. Rural poverty accounts for 90 percent of the total poverty in the region and approximately 80 percent of the poor still depend on agriculture or farm labour for their livelihoods (FAO and World Bank 2001). High population growth rates, especially in rural areas, increase the challenge of poverty reduction and add pressure on agricultural production and natural resources. According to FAO (2006b), the population in Sub-Saharan Africa could double by 2050 increasing agricultural consumption by 2.8 percent annually until 2030, and by 2.0 percent annually from 2030 to 2050. During the same periods agricultural

production is projected to increase by 2.7 and 1.9 percent per year, respectively. As a consequence, net food imports are expected to rise.

The World Development Report 2008 suggests that the key policy challenge in agriculture-based economies like Sub-Saharan Africa is to help agriculture play its role as an engine of growth and poverty reduction. Development of irrigation and improvements in agricultural productivity have proven to be effective in both aspects. Hussain and Hanjra (2004) identify three main pathways through which irrigation can impact poverty. Irrigation, in the micro-pathway, increases returns to physical, human, and social capital of poor households and enables smallholders to achieve higher yields and revenues from crop production. The meso-pathway includes new employment opportunities on irrigated farms or higher wages on rainfed farms. Lower food prices are also expected since irrigation enables farmers to obtain more output per unit of input. In the macro-pathway or growth path, gains in agricultural productivity through irrigation can stimulate national and international markets, improving economic growth and creating second-generation positive externalities. In a similar way, Lipton et al. (2003) analyze the conditions under which irrigation has positive effects on poverty reduction and classify them into direct and indirect effects.

FAO (2008) suggests that improvements in agricultural productivity can provide a pathway out of poverty for rural households in several ways. Improvements in crop and livestock yields benefit poor households that own land through greater output and higher incomes. Households that do not own land but provide farm labour benefit from higher demand for farm labour and wages. Households that do not own land or provide farm labour, benefit from greater supply of agricultural products and lower food prices. Improvements in agricultural productivity can also benefit non-agricultural rural households and urban households through greater demand for food and other products (stimulated by higher agricultural incomes and higher net incomes in non-agricultural households). Food processing and marketing activities can also be promoted in urban areas. When agricultural productivity improves by means of water management, the incremental productivity of complementary inputs raises and expands the demand for these inputs, which in turn stimulates non-agricultural economic activities.

However, the effectiveness of irrigation and agricultural productivity reducing poverty and promoting economic growth is constrained by the availability of affordable complementary inputs, development of human capital, access to markets and expansion of markets to achieve economies of scale, and institutional arrangements that promote farm-level investments in land and water resources (CA 2007; FAO 2008).

Sub-Saharan Africa has the potential for expanding irrigation and increasing agricultural productivity. The World Bank (2007) points out that the new generation of better-designed irrigation projects and the large untapped water resources generate opportunities to invest in irrigation in Sub-Saharan Africa. New investments in irrigation need complementary investments in roads, extension services and access to markets. The CA (2007) suggests that where yields are already high and the exploitable gap is small projected growth rates are low; whereas low yields present a large potential for improvements. In Sub-Saharan Africa observed yields are less than one-third of the maximum attainable yields. The potential for productivity enhancement is therefore large, particularly for maize, sorghum, and millet. Although water is often the principal constraint for agricultural productivity, optimal access to complementary inputs and investment in research and development are also necessary.

Future climate change may present an additional challenge for agriculture in Sub-Saharan Africa. According to the IPCC (1997), Africa is the most vulnerable region to climate change because widespread poverty limits adaptive capacity. The impacts of climate change on agriculture could seriously worsen the livelihood conditions for the rural poor and increase food insecurity in the region. The World Bank (2007) identifies five main factors through which climate change will affect agricultural productivity: changes in temperature, precipitation, carbon dioxide fertilization, climate variability, and surface water runoff. Increased climate variability and droughts will affect livestock production as well. Smallholders and pastoralists in Sub-Saharan Africa will have to gradually adapt and adopt technologies that increase the productivity, stability, and resilience of production systems (FAO 2008).

As discussed above, development of irrigation and improvements in agricultural productivity are key variables not only for future economic development, poverty reduction and food security in Sub-Saharan Africa but also for climate change adaptation. In this sense, the aim of our paper is to analyze the economy-wide impacts of expanding irrigation and increasing agricultural productivity in Sub-Saharan Africa under the SRES B2 scenario of the IPCC. We use a combination of a partial equilibrium model (IMPACT) and a general equilibrium model (GTAP-W). The interaction between both models allows us to improve calibration and exploit their different capabilities.

The IMPACT model (Rosegrant et al. 2002) is a partial agricultural equilibrium model that allows for the combined analysis of water and food supply and demand. Based on a loose coupling with a global hydrological modelling, climate change impacts on water and

food can be analyzed as well (Zhu et al. 2008). The GTAP-W model (Calzadilla et al. 2008) is a global computable general equilibrium (CGE) model that allows for a rich set of economic feedbacks and for a complete assessment of the welfare implications of alternative development pathways. Unlike the predecessor GTAP-W (Berrittella et al. 2007), the revised GTAP-W model distinguishes between rainfed and irrigated agriculture.

While partial equilibrium analysis focuses on the sector affected by a policy measure assuming that the rest of the economy is not affected, general equilibrium models consider other sectors or regions as well to determine economy-wide effects; partial equilibrium models tend to have more detail. Studies using general equilibrium approaches are generally based on data for a single country or region assuming no interlinkages with the rest of the world regarding policy changes and shocks (e.g. Diao and Roe 2003; Gómez et al. 2004; Letsoalo et al. 2007).

The remainder of the paper is organized as follows: the next section describes briefly the IMPACT and GTAP-W models and the interaction of both models as well as projections out to 2050 undertaken for this study. Section 3 focuses on the baseline results and climate change impacts. Section 4 lays out two alternative adaptation scenarios and discusses and compares results from both models, including outcomes for malnutrition. Section 5 concentrates on discussion and conclusions.

## 2 Models and baseline simulations

### 2.1. The IMPACT model

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) was developed at IFPRI at the beginning of the 1990s, upon the realization that there was a lack of long-term vision and consensus among policymakers and researchers about the actions that are necessary to feed the world in the future, reduce poverty, and protect the natural resource base (Rosegrant et al. 2005). The IMPACT model encompasses countries and regions and the main agricultural commodities produced in the world. As a partial equilibrium model of agricultural demand, production and trade, IMPACT uses a system of food supply and demand equations to analyze baseline and alternative scenarios for global food demand, supply, trade, income and population. Supply and demand functions incorporate supply and demand elasticities to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Country and regional agricultural sub-models are linked

through trade. Within each country or regional sub-model, supply, demand, and prices for agricultural commodities are determined.

The original IMPACT model assumed "normal" climate conditions, and therefore the impacts of annual climate variability on food production, demand and trade were not reflected. The inclusion of a water simulation module (WSM) enables IMPACT to reflect the effects on food production and consumption of water demand and availability, their inter-annual variability, and the competition for water among various economic sectors (Rosegrant et al. 2002). Within the model, WSM projects water demand for major water use sectors and balances water availability and inter- and intra-sector water uses by simulating seasonal storage regulation and water allocation at river basin scale. Besides variability, long-term trends of water availability and uses for different sectors are projected with exogenous drivers including population and income growth, changes of irrigated areas, and improvement of water use technology such as irrigation efficiency and new water sources (Rosegrant et al. 2002).

The spatial representation of global economic regions and natural river basins have recently been enhanced. The model now uses 281 "food-producing units" (FPU), which represent the spatial intersection of 115 economic regions and 126 river basins. Water simulation and crop production are conducted at the FPU level while food demand projections and agricultural commodity trade are conducted at the country or economic region level. The disaggregation of spatial units improves the model's capability to represent spatial heterogeneity of agricultural economies and, in particular, water resource availability and uses.

Recent progress in climate research has strengthened confidence on human-induced global warming (IPCC 2007) with important implications for socioeconomic and agricultural systems. To analyze the impacts of global change, especially climate change, on regional and global food systems and to formulate appropriate adaptation measures, the IMPACT model was extended to include climate change components such as the yield effects of $CO_2$ fertilization and temperature changes, as well as altered hydrological cycles, and changes in (irrigation) water demand and water availability through the development of a separate global hydrological model. This semi-distributed global hydrology model parameterizes the dominant hydrometeorological processes taking place at the land surface - atmosphere interface at global scope. The model runs at half degree latitude-longitude grid, and global half degree climate, soil and land surface cover data are used to determine a number of spatially distributed model parameters. The remaining parameters are determined through

model calibrations with global river discharge database and dataset available elsewhere, using genetic algorithms. For river basins where data are not available for detailed calibration, regionalized model parameters are applied. The global hydrology model is able to convert projections for future climate from GCM models into hydrologic components such as evapotranspiration, runoff and soil moisture, which are used in this study (Zhu et al. 2008).

In this analysis, we use the intermediate growth B2 scenario[1] from the SRES scenario family (IPCC 2000) for the baseline projections out to 2050. The effects of temperature and $CO_2$ fertilization on crop yields are based on simulations of the IMAGE model (Bouwman et al. 2006). Recent research findings show that the stimulation of crop yield observed in the global Free Air Carbon Enrichment Facilities (FACE) experiments fell well below (about half) the value predicted from chambers (Long et al. 2006). These FACE experiments clearly show that much lower $CO_2$ fertilization factors (compared with chamber results) should be used in model projections of future yields. Therefore, we apply 50 percent of the $CO_2$ fertilization factors from the IMAGE model simulation in IMPACT (Rosegrant et al. 2008).

Besides the effects of higher $CO_2$ concentration levels and changes in temperature, climate change is likely to affect the volume, and the spatial and temporal distribution of rainfall and runoff, which in turn affect the number and distribution of people under water stress and the productivity of world agricultural systems. We use climate input from the HadCM3 run of the B2 scenario that was statistically downscaled to the 0.5 degree latitude/longitude global grid using the pattern scaling method of the Climate Research Unit, University of East Anglia (Mitchell et al. 2004). The semi-distributed macroscale hydrology module of IMPACT derives effective precipitation, potential and actual evapotranspiration, and runoff at these 0.5 degree pixels and scales them up to each of the 281 FPUs, the spatial operational unit of IMPACT. Projections for water requirements, infrastructure capacity expansion, and water use efficiency improvement are conducted by IMPACT. These projections are combined with the simulated hydrology to estimate water use and consumption through water system simulation by IMPACT.

[1] As described in SRES report (IPCC 2000), the B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with a slow, but continuously increasing global population and intermediate levels of economic and technological development. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

To explore food security effects, the model projects the percentage and number of malnourished preschool children (0-5 years old) in developing countries. A malnourished child is a child whose weight-for-age is more than two standard deviations below the weight-for-age standard set by the U.S. National Center for Health Statistics/World Health Organization. The number of malnourished preschool children in developing countries is projected as a function of per capita calorie availability, ratio of female to male life expectancy at birth, total female enrolment in secondary education as a percentage of the female age-group corresponding to national regulations for secondary education, and the percentage of population with access to safe water. These variables were found to be key determinants of childhood malnutrition in a meta-analysis implemented by Smith and Haddad (2000).

### 2.2. The GTAP-W model

In order to assess the systemic general equilibrium effects of alternative adaptation strategies to climate change in Sub-Saharan Africa, we use a multi-region world CGE model, called GTAP-W. The model is a further refinement of the GTAP model[2] (Hertel 1997), and is based on the version modified by Burniaux and Truong[3] (2002) as well as on the previous GTAP-W model introduced by Berrittella et al. (2007).

The revised GTAP-W model is based on the GTAP version 6 database, which represents the global economy in 2001. The model has 16 regions and 22 sectors, 7 of which are in agriculture.[4] However, the most significant change and principal characteristic of version 2 of the GTAP-W model is the new production structure, in which the original land endowment in the value-added nest has been split into pasture land (grazing land used by livestock) and land for rainfed and for irrigated agriculture. The last two types of land differ

[2] The GTAP model is a standard CGE static model distributed with the GTAP database of the world economy (www.gtap.org). For detailed information see Hertel (1997) and the technical references and papers available on the GTAP website.

[3] Burniaux and Truong (2002) developed a special variant of the model, called GTAP-E. The model is best suited for the analysis of energy markets and environmental policies. There are two main changes in the basic structure. First, energy factors are separated from the set of intermediate inputs and inserted in a nested level of substitution with capital. This allows for more substitution possibilities. Second, database and model are extended to account for $CO_2$ emissions related to energy consumption.

[4] See table A1 in Annex I for the regional, sectoral and factoral aggregation used in GTAP-W.

as rainfall is free but irrigation development is costly. As a result, land equipped for irrigation is generally more valuable as yields per hectare are higher. To account for this difference, we split irrigated agriculture further into the value for land and the value for irrigation. The value of irrigation includes the equipment but also the water necessary for agricultural production. In the short run irrigation equipment is fixed, and yields in irrigated agriculture depend mainly on water availability. The tree diagram in Figure A1 in Annex I represents the new production structure.

Land as a factor of production in national accounts represents "the ground, including the soil covering and any associated surface waters, over which ownership rights are enforced" (United Nations 1993). To accomplish this, we split for each region and each crop the value of land included in the GTAP social accounting matrix into the value of rainfed land and the value of irrigated land using its proportionate contribution to total production. The value of pasture land is derived from the value of land in the livestock breeding sector.

In the next step, we split the value of irrigated land into the value of land and the value of irrigation using the ratio of irrigated yield to rainfed yield. These ratios are based on IMPACT data. The numbers indicate how relatively more valuable irrigated agriculture is compared to rainfed agriculture. The magnitude of additional yield differs not only with respect to the region but also to the crop. On average, producing rice using irrigation is relatively more productive than using irrigation for growing oil seeds, for example.

The procedure we described above to introduce the four new endowments (pasture land, rainfed land, irrigated land and irrigation) allows us to avoid problems related to model calibration. In fact, since the original database is only split and not altered, the original regions' social accounting matrices are balanced and can be used by the GTAP-W model to assign values to the share parameters of the mathematical equations. For detailed information about the social accounting matrix representation of the GTAP database see McDonald et al. (2005).

As in all CGE models, the GTAP-W model makes use of the Walrasian perfect competition paradigm to simulate adjustment processes. Industries are modelled through a representative firm, which maximizes profits in perfectly competitive markets. The production functions are specified via a series of nested constant elasticity of substitution functions (CES) (Figure A1). Domestic and foreign inputs are not perfect substitutes, according to the so-called ''Armington assumption'', which accounts for product heterogeneity.

A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, pasture land, rainfed land, irrigated land, irrigation, labour and capital). Capital and labour are perfectly mobile domestically, but immobile internationally. Pasture land, rainfed land, irrigated land, irrigation and natural resources are imperfectly mobile. National income is allocated between aggregate household consumption, public consumption and savings. Expenditure shares are generally fixed, which amounts to saying that the top level utility function has a Cobb-Douglas specification. Private consumption is split in a series of alternative composite Armington aggregates. The functional specification used at this level is the constant difference in elasticities (CDE) form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods. A money metric measure of economic welfare, the equivalent variation, can be computed from the model output.

In the original GTAP-E model, land is combined with natural resources, labour and the capital-energy composite in a value-added nest. In our modelling framework, we incorporate the possibility of substitution between land and irrigation in irrigated agricultural production by using a nested constant elasticity of substitution function (Figure A1). The procedure how the elasticity of factor substitution between land and irrigation ($\sigma_{LW}$) was obtained is explained in more detail in Calzadilla et al. (2008). Next, the irrigated land-water composite is combined with pasture land, rainfed land, natural resources, labour and the capital-energy composite in a value-added nest through a CES structure.

In the benchmark equilibrium, water used for irrigation is supposed to be identical to the volume of water used for irrigated agriculture in the IMPACT model. An initial sector and region specific shadow price for irrigation water can be obtained by combining the social accounting matrix information about payments to factors and the volume of water used in irrigation from IMPACT.

The distinction between rainfed and irrigated agriculture within the production structure of the GTAP-W model allows us to study expected physical constraints on water supply due to, for example, climate change. In fact, changes in rainfall patterns can be exogenously modelled in GTAP-W by changes in the productivity of rainfed and irrigated land. In the same way, water excess or shortages in irrigated agriculture can be modelled by exogenous changes to the initial irrigation water endowment.

### 2.3. Baseline simulations

The IMPACT *baseline simulation* out to 2050 incorporates moderate climate change impacts based on the SRES B2 scenario. Results are compared to an alternative *no climate change simulation* assuming normal climate conditions. The GTAP-W model uses these outputs from IMPACT to calibrate a hypothetical general equilibrium in 2050 for each of these two simulations.

To obtain a 2050 benchmark equilibrium dataset for the GTAP-W model we use the methodology described by Dixon and Rimmer (2002). This methodology allows us to find a hypothetical general equilibrium state in the future imposing forecasted values for some key economic variables in the initial calibration dataset. In this way, we impose forecasted changes in regional endowments (labour, capital, natural resources, rainfed land, irrigated land and irrigation), in regional factor-specific and multi-factor productivity and in regional population. We use estimates of regional labour productivity, labour stock and capital stock from the G-Cubed model (McKibbin and Wilcoxen 1998). Changes in the allocation of rainfed and irrigated land within a region as well as irrigation and agricultural land productivity are implemented according to the values obtained from IMPACT. Finally, we use the medium-variant population estimates for 2050 from the Population Division of the United Nations (United Nations 2004).

The interaction of both models allows for improved calibration and enhanced insights into policy impacts. In fact, the information supplied by the IMPACT model (demand and supply of water, demand and supply of food, rainfed and irrigated production and rainfed and irrigated area) provides the GTAP-W model with detailed information for a robust calibration of a new dataset and allows to run climate change scenarios. The links between IMPACT and GTAP-W are shown in Annex II.

## 3 Baseline simulation results

Compared to the 2000 baseline data (Table 1), the IMPACT model projects growth in both crop harvested area as well as crop productivity for 2050 under normal climate conditions (no climate change simulation) (Table 2). The world's crop harvested area is expected to increase by about 3 percent between 2000 and 2050. This is equivalent to a total crop harvested area of 1.35 billion hectares in 2050, 36 percent of which is projected to be under irrigation. In Sub-Saharan Africa, for the same period, irrigated area is projected to grow more than twice as fast as rainfed area (79 percent compared to 34 percent). However the proportion of

irrigated area to total area in 2050 is only one percent higher compared to 2000 (4.5 and 3.4 percent, respectively).

*Table 1 and 2 about here*

Impacts of future climate change on food production, demand and trade are reflected in the 2050 (SRES B2) baseline simulation. Table 3 reports the percentage change in crop harvested area and production by region and by crop for Sub-Saharan Africa as well as changes in regional GDP and welfare between the 2050 no climate change simulation and the 2050 (SRES B2) baseline simulation. According to the analysis, world's crop harvested area and food production decrease by 0.30 and 2.66 percent, respectively. The picture is similar for irrigated production; both area and production are projected to be lower, by 1.55 and 3.99 percent, respectively. Global rainfed production decreases by 1.65 percent, despite an increase in rainfed area by about 0.38 percent. Regional impacts of climate change on rainfed, irrigated and total crop production vary widely. In Sub-Saharan Africa, both rainfed and irrigated harvested areas decrease when climate change is considered (by 0.59 and 3.51 percent, respectively). Rainfed production, on the other hand, increases by 0.70 percent while irrigated production drops sharply by 15.30 percent. As a result, total crop harvested area and production in Sub-Saharan Africa decreases by 0.72 percent and 1.55 percent, respectively. Most of the decline in production can be attributed to wheat (24.11 percent) and sugar cane (10.58 percent). Other crops in Sub-Saharan Africa do in fact better because of climate change and particularly $CO_2$ fertilization.

*Table 3 about here*

The last three columns in Table 3 show the impact of climate change on regional GDP and welfare. At the global level, GDP is expected to decrease with climate change by USD 87 billion, equivalent to 0.09 percent of global GDP. At the regional level, only Australia and New Zealand experience a positive GDP impact under climate change: GDP is expected to increase by USD 1,074 million. Projected declines in GDP are particularly high for the United States, South Asia, and South America (USD 19,768 million; USD 17,271 million; and USD 10,697 million, respectively). In relative terms, declines are largest for South Asia, the former Soviet Union, and Eastern Europe (0.64, 0.58 and 0.38 percent, respectively). For Sub-Saharan Africa, losses in GDP due to climate change are estimated at USD 3,333 million, equivalent to 0.20 percent of regional GDP. These losses in GDP are used to evaluate the efficacy of the two adaptation scenarios to cope with climate change. Alternatively, when yield effects of CO2 fertilization are not considered, GDP losses in Sub-Saharan Africa are estimated to be slightly higher (USD 4,455 million).

Like global GDP, global welfare is expected to decline with climate change (USD 87 billion). However, welfare losses due to declines in agricultural productivity and crop harvested area are not general, in some regions welfare increases as their relative competitive position improves with respect to other regions. This is the case of South America, Australia and New Zealand, Sub-Saharan Africa, and Canada. Projected welfare losses are considerable for South Asia, the USA and Western Europe. The USD 2 billion welfare increase in Sub-Saharan Africa is explained as follows. First of all, only some crops in Sub-Saharan Africa are badly hit by climate change. Secondly, crops in other parts of the world are hit too – and relatively harder than those in Sub-Saharan Africa. The result is an increase in food price and exports. This improves welfare (as measured by the Hicksian Equivalent Variation) but it also increases malnutrition.

Figure 1 shows for the 2050 (SRES B2) baseline simulation a global map of irrigated harvested area as a share of total crop area by country. Approximately 63 percent of the world's irrigated harvested area in 2050 is in Asia, which accounts for about 22 percent of the world's total crop harvested area. By contrast, irrigated agriculture in Sub-Saharan Africa is small, only 4.4 percent of the total crop harvested area is expected to be irrigated by 2050. Most of the countries in Sub-Saharan Africa are expected to continue to use irrigation on less than 5 percent of crop land. Madagascar and Swaziland are exceptions expected to be irrigating 67 percent and 60 percent of their total crop area, respectively. The numbers for Somalia and South Africa are much lower (34 and 24 percent, respectively). The most populous country in the region, Nigeria, accounts for about 23 percent of the region's crop harvested area. However, around 97 percent of Nigeria's production is rainfed.

*Figure 1 about here*

Agricultural crop productivity is commonly measured by the amount of output per unit of area, such as yield in kilograms per hectare.[5] Table 4 presents average yields by crop type for the 2050 (SRES B2) baseline simulation. Displayed are global average levels as well as minimum and maximum levels for rainfed and irrigated harvested area according to the 16 regions defined in Table A1. In addition, average yield levels for Sub-Saharan Africa as well

[5] FAO (2001) subdivides the agricultural productivity measures into partial and total measures. Partial measures are the amount of output per unit of a particular input (e.g. yield and labour productivity). Total measures consider the total factor productivity, which is the ratio of an index of agricultural output to an index of agricultural inputs.

as information on the minimum and maximum yields in individual countries are provided. Clearly the performance of Sub-Saharan Africa is poor when compared to the regional and global averages. Compared with other regions, the average agricultural productivity in Sub-Saharan Africa is the lowest or is close to the minimum for all crops; except for irrigated rice, wheat, and sugar cane with levels close to the global average. Agricultural productivity within the Sub-Saharan Africa region varies widely. Some countries are highly productive on very small areas, for example, Tanzania regarding sugar cane, and South Africa on most agricultural crops. Most countries, however, fare poorly on large rainfed areas with low crop harvested yields.

*Table 4 about here*

Table 5 presents for the 2050 (SRES B2) baseline crop harvested area and production in Sub-Saharan Africa by crop. Only 4.4 percent of the total crop harvested area is expected to be under irrigation by 2050 while irrigated production is expected to account for 12.1 percent of the total agricultural production in the region. The two major irrigated crops are rice and sugar cane. Irrigated rice is expected to account for more than one-fourth of the total rice harvested area and to contribute to almost half of total rice production. For irrigated sugar cane the picture is similar. Almost one-fourth of the total crop area is projected to be under irrigation and around 38.6 percent of the total crop production is expected to be irrigated. Most of the total crop area under irrigation is devoted to the production of cereal grains, rice, and vegetables, fruits and nuts. However, with the exception of rice the share of irrigated harvested area to total crop harvested area is projected to be less than 5.1 percent. Similarly, almost 80 percent of the total rainfed harvested area in Sub-Saharan Africa is projected to be used for the production of cereals; roots and tubers; and vegetables, groundnuts and fruits.

*Table 5 about here*

## 4 Adaptation strategies to climate change

We evaluate the effects on production and income of two possible adaptation strategies to climate change in Sub-Saharan Africa. Both adaptation scenarios are implemented based on the 2050 (SRES B2) baseline. The first adaptation scenario assumes an expansion in the capacity of irrigated agriculture and doubles the irrigated area in Sub-Saharan Africa. The second adaptation scenario considers improvements in productivity for both rainfed and irrigated agriculture; increasing rainfed and irrigated yields in Sub-Saharan Africa by 25

percent through investments in agricultural research and development, and enhanced farm management practices.

According to the first adaptation scenario, irrigated areas in Sub-Saharan Africa are assumed to double by 2050, as compared to the 2050 (SRES B2) baseline, while total crop land does not change. Around 11 million hectares are thus transferred from rainfed agriculture to irrigated agriculture, increasing to near 9 percent the share of irrigated over total crop area in the region. In GTAP-W, the initial irrigated land and irrigation endowments are doubled; the rainfed land endowment is reduced accordingly. In IMPACT, for each FPU and each crop, irrigated area growth is doubled for the region. Rainfed area is reduced by an equal amount to keep total crop area constant. Other growth assumptions remain unchanged.

In the second adaptation scenario, agricultural crop productivity for both rainfed and irrigated crops in Sub-Saharan Africa are increased by 25 percent compared to the 2050 (SRES B2) baseline. In GTAP-W, the primary factor productivity of rainfed land, irrigated land and irrigation are increased by 25 percent. In IMPACT, crop yield growth rates are increased to reach values 25 percent above baseline values.

For both adaptation scenarios, investment or cost implications are not incorporated into the modelling frameworks and the additional irrigation water used does not violate any sustainability constraints.

### 4.1. Adaptation scenario 1: Expansion of irrigated agriculture

In the original GTAP model, land is specific to the agricultural sector but not to individual crops, which compete for land. In the GTAP-W model this proposition also holds. Rainfed land, irrigated land and irrigation are sector-specific, but individual crops compete for them. Pasture land is only used by a single sector, livestock. Therefore, when the capacity of irrigated agriculture is increased by transferring land from rainfed agriculture to irrigated agriculture, the additional land in irrigated agriculture is not allocated uniformly. Irrigated wheat production uses a higher proportion of the new land and irrigation than other crops (Table 6), which is mostly driven by a strong regional consumption of locally produced wheat. Similarly, the reduction in rainfed land is not proportional among crops. While the use of rainfed land decreases for most crops between 0.04 to 0.53 percent, the use of rainfed land for wheat production increases by 1.35 percent. The combined effect is an increase in total wheat production by 2.12 percent, which is consistent with an increase in irrigated and rainfed production by 102.24 and 0.49 percent, respectively. The change in production of oil seeds shows a similar picture, irrigated and rainfed production increases by 100.12 and 0.03

percent, respectively. For the rest of the crops irrigated production increases and rainfed production decreases, resulting in an increase in total crop production. The only exception is the sector “other agricultural products”, for which total production decreases by 0.05 percent.

*Table 6 about here*

The expansion of irrigated areas in the region from a very small base helps farmers to achieve higher yields per hectare. This is followed by an increase in total crop production and a drop in agricultural commodity prices. The last two columns in Table 6 show a reduction in domestic and global market prices for all crops (an exception is the increase in the domestic price of other agricultural products).

As a general equilibrium model, GTAP-W accounts for impacts in non-agricultural sectors as well. Changes in total crop production have a mixed effect on non-agricultural sectors; domestic and world prices of non-agricultural sectors increase under this alternative scenario. An exception is the food products sector, where price declines because its production is promoted by a higher supply and lower price of crops.

Factor market prices change according to the new factor composition. The increase in the supply of irrigated land and irrigation pushes down their market prices, while prices for rainfed land, as it gets scarcer, experience a relative increase. Market prices for the rest of the primary factors increase as the economy expands (Table 6). Regional welfare increases only by around USD 119 million. This adaptation scenario leads to a small increase in GDP in Sub-Saharan Africa (0.007 percent, equivalent to USD 113 million), which is insufficient to compensate for the regional GDP losses expected under climate change (USD 3,333 million) (Table 10).

Results from the IMPACT model are shown in Table 7. The expansion of irrigated areas in Sub-Saharan Africa increases cereal production in the region by 5 percent, and meat production by 1 percent. No change can be seen for root and tuber production. The results are not readily comparable to those obtained by the GTAP-W due to the differences in aggregation. Contrary to the IMPACT results, meat production in GTAP-W decreases slightly, by 0.06 percent.

*Table 7 about here*

For all cereals, real commodity prices by 2050 under the baseline are expected to be higher than prices in 2000. This is a result of increased resource scarcity, for both land and water, as well as the impact from climate change and biofuel development, and increased population and income growth driving food demand diversification with demand shifting towards meat, egg and milk products that require grain as feedstock. Climate change leads to

higher mean temperatures and generally raises crop water requirements but at the same time the availability of water for crop growth may decrease in certain regions. Higher temperature during the growing season in low-latitude regions, where such temperature-induced yield loss cannot be compensated fully by the fertilization effects of higher $CO_2$ levels, will adversely affect food production.

Similar to grain prices, in the 2050 (SRES B2) baseline, meat prices are expected to increase (Table 7). Livestock prices are expected to increase as a result of higher animal feed prices and rapidly growing meat demand. Even though Sub-Saharan Africa is not a key contributor to global food production or irrigated food production, both climate change adaptation scenarios focusing on the region are projected to reduce world food prices. Under this scenario, world food prices declines between 0.8 to 1.6 percent for rice, potato as well as for sweet potato and yams. Reductions in world market prices for both cereals and meat are more pronounced in IMPACT than in GTAP-W.

### 4.2. Adaptation scenario 2: Improvements in agricultural productivity

Improvements in agricultural productivity in both rainfed and irrigated agriculture enable farmers to obtain higher levels of output per unit of input. Table 8 shows an increase in total crop production but the magnitude differs by crop type. The sector "other agricultural products" is the sector with the highest increase in production (25 percent), followed by oil seeds, wheat, and vegetables, fruits and nuts (17, 16 and 11 percent, respectively). Rainfed and irrigated production increase for all crops; with the exception of rainfed sugar cane.

*Table 8 about here*

Higher levels of agricultural productivity result in a decline in production costs and consequently in a decline in market prices. Table 8 shows, for all crop types, a decrease in domestic and world market prices. A 25 percent increase in agricultural productivity leads to a reduction of around 10 to 13 percent in domestic market prices; only sugar cane experiences a smaller decline at 8 percent. World market prices, in turn, decline by 3 to 4 percent.

Total production in non-agricultural sectors is also affected under this scenario. Reductions in total production are more pronounced for energy intensive industries, other industry and services, as well as gas (4.8, 4.1 and 3.7 percent, respectively). The food products sector is affected positively and its production increases by 1.4 percent. Domestic and world market prices increase for all non-agricultural sectors except for food products.

An increase in agricultural productivity reduces the demand (at constant effective prices) for rainfed land, irrigated land and irrigation. Therefore, market prices for these three factors decrease (12.4, 41.7 and 39.9 percent, respectively). Changes in market prices for the rest of the factors are positive. Returns to unskilled labour increase more than returns to skilled labour (3.0 and 2.4 percent, respectively) (Table 8). Regional welfare in Sub-Saharan Africa increases by USD 15,435 million. This adaptation scenario promotes GDP growth by 1.5 percent (USD 25,720 million), which more than offsets the initial reduction of 0.2 percent in GDP due to climate change as projected under the SRES B2 scenario (USD 3,333 million) (Table 10).

Higher rainfed and irrigated crop yields in IMPACT results in higher food production, which lowers international food prices, making food more affordable for the poor. Table 9 shows an increase in cereal production by around 20 percent; meat production increases by 4 percent. As expected world market prices for all cereals and meat products decrease much more under this second adaptation scenario. Prices decline between 15 to 31 percent particularly for those crops that are of primary importance for Sub-Saharan Africa: roots and tubers, maize, sorghum, millet, and other coarse grains. As in the former adaptation scenario, reduction in world market prices are more pronounced in IMPACT than in GTAP-W.

*Tables 9 and 10 about here*

### 4.3. Outcomes for malnutrition

Figure 2 shows the number of malnourished children for the Sub-Saharan Africa region for 2000 and projected to 2050. Under the SRES B2 baseline, the number of malnourished children is projected at 32 million in 2050 compared to about 30 million in 2000. This large number of malnourished children is unacceptably high. However, the share of malnourished children is projected to decline from 28 to 20 percent over the 50-year period.

Under the doubling irrigated area scenario, the number of malnourished children declines by only 0.3 million children. The scenario on increased rainfed and irrigated crop productivity, on the other hand, results in a decline in the number of malnourished children of 1.6 million children, which is close to the no climate change baseline. Thus, improving crop yields in both rainfed and irrigated areas is a strategy that would almost completely offset for the impact of climate change on child malnutrition.

*Figure 2 about here*

## 5 Discussion and conclusions

This paper presents a combined analysis using both a global partial equilibrium agricultural sector model (IMPACT) and a global computable general equilibrium model (GTAP-W) for alternative adaptation strategies to climate change in Sub-Saharan Africa. Special emphasis is placed on the interaction of both models, which allows for improved calibration and enhanced policy insights.

The methodology combines advantages of both types of models. IMPACT considers detailed water-agriculture linkages and provides the data underlying GTAP-W. While IMPACT can provide results for 281 Food Producing Units on water and food supply the model cannot examine impacts on non-agricultural sectors. GTAP-W distinguishes between rainfed and irrigated agriculture and implements water as a factor of production in the production process for irrigated agriculture. The GTAP-W model considers water quantity and prices but ignores non-market benefits or costs of water use. For instance, the model is unable to predict the direct ecological impact of excessive pumping that reduces groundwater and affects the flow of streams but increases the market-based benefits from water use. As in all CGE models, GTAP-W takes into account the linkages between agricultural and non-agricultural sectors as well as a full treatment of factor markets.

Two adaptation scenarios to climate change in Sub-Saharan Africa are analyzed. These scenarios are contrasted with the IMPACT 2050 baseline simulation, which incorporates the SRES B2 scenario and a further scenario assuming no climate change. Model outputs, including demand and supply of water, demand and supply of food, rainfed and irrigated production and rainfed and irrigated area are then used in GTAP-W to calibrate a hypothetical general equilibrium in 2050 for both simulations. The main results of the four scenarios are summarised in Table 10.

Without specific adaptation, climate change would have a negative impact on agriculture in Sub-Saharan Africa. Total food production would fall by 1.6%, with heavy losses in sugar cane (-10.6%) and wheat (-24.1%). The number of hungry children would increase by almost 2 million.

The first adaptation scenario doubles irrigated areas in Sub-Saharan Africa, compared to the 2050 (SRES B2) baseline, but keeps total crop area constant in both models. The second adaptation scenario increases both rainfed and irrigated crop yields by 25 percent for all countries in Sub-Saharan Africa.

Because of the relatively low share of irrigated areas in total agricultural areas in Sub-Saharan Africa, an increase in agricultural productivity achieves much larger benefits for the

region than a doubling of irrigated areas. Because agriculture in Sub-Saharan Africa is far below its potential, substantial productivity gains are technically feasible. Differences between adaptation scenarios are more pronounced in GTAP-W than in IMPACT. Both adaptation scenarios increase total crop production but the magnitude differs according to crop type.

An increase in irrigated areas and agricultural productivity leads to a decrease in the production cost of agricultural products and consequently to a reduction in market prices. Even though Sub-Saharan Africa is not a key contributor to global food production or irrigated food production, both adaptation scenarios help lower world food prices. Both GTAP-W and IMPACT show more pronounced reductions in domestic and world market prices under the scenario simulating enhanced crop productivity.

Lower food prices make food more affordable for the poor. As a result, the number of malnourished children in Sub-Saharan Africa is projected to decline by 0.3 million children by 2050 under the doubled irrigated area scenario and by 1.6 million children under the increased agricultural productivity scenario. The reduction in the number of malnourished children under enhanced crop productivity almost equals the increase in the projected number of malnourished children under the climate change baseline compared to a simulation without climate change.

Changes in total production in non-agricultural sectors have a mixed pattern; however all of them show an increase in domestic and world prices. An exception is the food products sector, where price declines because its production is promoted by a higher supply and lower price of agricultural products.

Because the first adaptation scenario transfers land from rainfed to irrigated agriculture, market prices for rainfed land increase while market prices for irrigation and irrigated land decrease. In the second adaptation scenario market prices for rainfed land, irrigated land and irrigation decline. In both adaptation scenarios, market prices for the rest of the primary factors increase. The increase in the market price for unskilled labour is higher than for skilled labour under the second scenario.

Both adaptation scenarios enable farmers to achieve higher yields and revenues from crop production. The increase in regional welfare in the first scenario is modest (USD 119 million), however in the second scenario reaches USD 15,434 million.

The efficacy of the two scenarios as adaptation measures to cope with climate change is measured by changes in regional GDP. An increase in agricultural productivity widely exceeds the GDP losses due to climate change; GDP increases by USD 25,720 million

compared to the initial reduction in GDP of USD 3,333 million. The opposite happens for an increase in irrigated area; the GDP increase does not offset GDP losses due to climate change (GDP increases only by USD 113 million). While these results are promising regarding the potential to develop investment programs to counteract the adverse impacts of climate change, the scenario implemented here, SRES B2, is on the conservative side of the range of climate change scenarios.

Several caveats apply to the above results. First, in our analysis increase in irrigated areas and improvements in agricultural productivity are not accompanied by changes in prices. We do not consider any cost or investment associated to irrigation expansion and improvements in agricultural productivity. Therefore, our results might overestimate the benefits of both adaptation scenarios. Second, we implicitly assume, for the expansion of irrigated agriculture, availability and accessibility to water resources. We assume a sustainable use of water resources. Third, we do not achieve a complete integration of both models. Future work will be focused on further integration and accounting possible feedbacks from GTAP-W to IMPACT.

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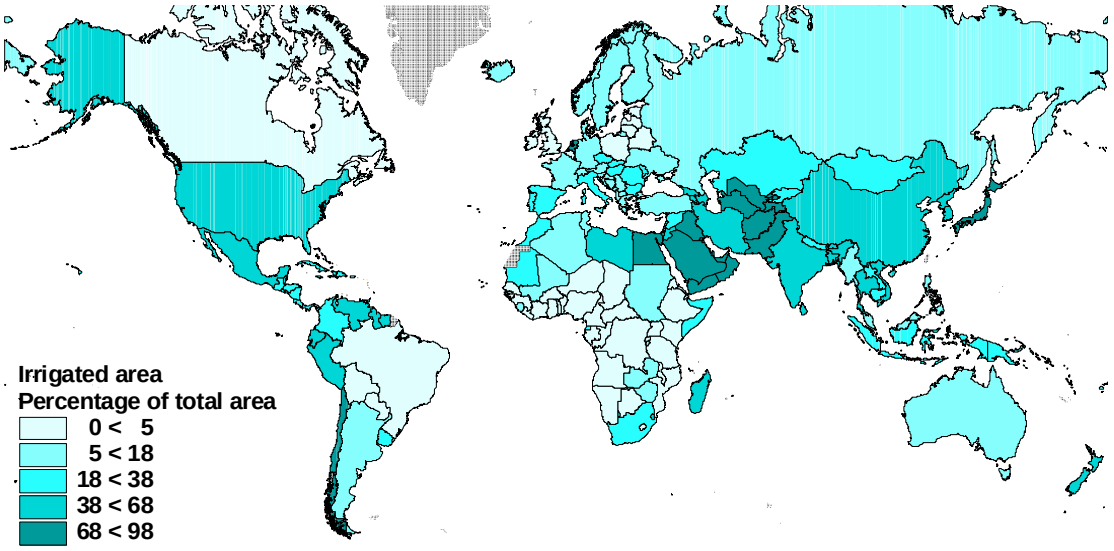


**Figure 1. 2050 SRES B2 baseline simulation: Irrigated harvested area as a share of total crop harvested area**

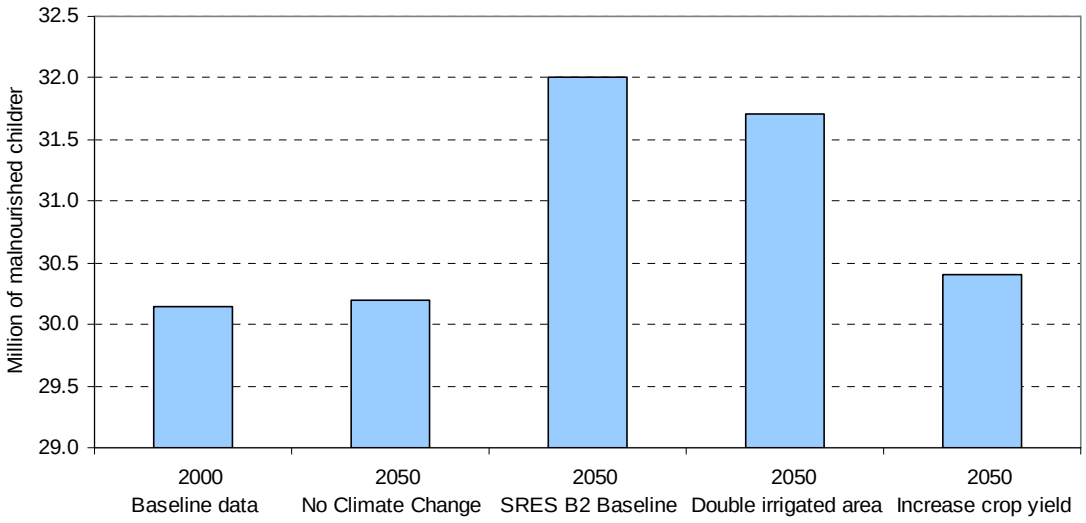


**Figure 2. Number of malnourished children (<5 yrs) in Sub-Saharan Africa, 2000 baseline data and projected 2050 baseline simulations and alternative adaptation scenarios (million children)**

Source: IFPRI IMPACT simulations.

**Table 1. 2000 Baseline data: Crop harvested area and production by region and for Sub-Saharan Africa**

| Description | Rainfed Agriculture | | Irrigated Agriculture | | Total | | Share of irrigated agriculture in total: | |
|---|---|---|---|---|---|---|---|---|
| | Area (thousand ha) | Production (thousand mt) | Area (thousand ha) | Production (thousand mt) | Area (thousand ha) | Production (thousand mt) | Area (%) | Production (%) |
| **Regions** | | | | | | | | |
| United States | 38,471 | 211,724 | 69,470 | 442,531 | 107,942 | 654,255 | 64.4 | 67.6 |
| Canada | 27,267 | 65,253 | 717 | 6,065 | 27,984 | 71,318 | 2.6 | 8.5 |
| Western Europe | 59,557 | 462,403 | 10,164 | 146,814 | 69,721 | 609,217 | 14.6 | 24.1 |
| Japan and South Korea | 1,553 | 23,080 | 4,909 | 71,056 | 6,462 | 94,136 | 76.0 | 75.5 |
| Australia and New Zealand | 21,500 | 67,641 | 2,387 | 27,656 | 23,886 | 95,297 | 10.0 | 29.0 |
| Eastern Europe | 38,269 | 187,731 | 6,091 | 40,638 | 44,360 | 228,369 | 13.7 | 17.8 |
| Former Soviet Union | 86,697 | 235,550 | 18,443 | 75,798 | 105,139 | 311,347 | 17.5 | 24.3 |
| Middle East | 30,553 | 135,872 | 21,940 | 119,626 | 52,493 | 255,498 | 41.8 | 46.8 |
| Central America | 13,030 | 111,665 | 8,794 | 89,698 | 21,824 | 201,364 | 40.3 | 44.5 |
| South America | 80,676 | 650,313 | 10,138 | 184,445 | 90,814 | 834,758 | 11.2 | 22.1 |
| South Asia | 143,427 | 492,718 | 120,707 | 563,161 | 264,134 | 1,055,879 | 45.7 | 53.3 |
| Southeast Asia | 69,413 | 331,755 | 27,464 | 191,890 | 96,876 | 523,645 | 28.3 | 36.6 |
| China | 66,715 | 617,460 | 124,731 | 909,561 | 191,446 | 1,527,021 | 65.2 | 59.6 |
| North Africa | 15,714 | 51,163 | 7,492 | 78,944 | 23,206 | 130,107 | 32.3 | 60.7 |
| Sub-Saharan Africa | 175,375 | 440,800 | 6,243 | 43,398 | 181,618 | 484,199 | 3.4 | 9.0 |
| Rest of the World | 3,813 | 47,467 | 1,094 | 23,931 | 4,906 | 71,398 | 22.3 | 33.5 |
| **Total** | **872,029** | **4,132,597** | **440,782** | **3,015,211** | **1,312,811** | **7,147,808** | **33.6** | **42.2** |
| | | | | | | | | |
| **Sub-Saharan African crops** | | | | | | | | |
| 1 Rice | 6,015 | 6,117 | 965 | 1,606 | 6,979 | 7,723 | 13.8 | 20.8 |
| 2 Wheat | 2,043 | 3,288 | 422 | 1,340 | 2,465 | 4,628 | 17.1 | 28.9 |
| 3 Cereal grains | 65,723 | 65,912 | 2,394 | 3,286 | 68,117 | 69,197 | 3.5 | 4.7 |
| 4 Vegetable, fruits, nuts | 31,570 | 224,570 | 1,111 | 9,846 | 32,681 | 234,415 | 3.4 | 4.2 |
| 5 Oil seeds | 9,969 | 8,804 | 551 | 554 | 10,520 | 9,358 | 5.2 | 5.9 |
| 6 Sugar cane, sugar beet | 822 | 35,280 | 309 | 25,614 | 1,131 | 60,894 | 27.3 | 42.1 |
| 7 Other agricultural products | 59,235 | 96,830 | 490 | 1,153 | 59,725 | 97,983 | 0.8 | 1.2 |
| **Total** | **175,375** | **440,800** | **6,243** | **43,398** | **181,618** | **484,199** | **3.4** | **9.0** |

Note: 2000 data are three-year averages for 1999-2001.
Source: IMPACT, 2000 baseline data (April 2008).

**Table 2. 2050 no climate change simulation: Crop harvested area and production by region and for Sub-Saharan Africa**

| Description | Rainfed Agriculture | | Irrigated Agriculture | | Total | | Share of irrigated agriculture in total: | |
|---|---|---|---|---|---|---|---|---|
| | Area (thousand ha) | Production (thousand mt) | Area (thousand ha) | Production (thousand mt) | Area (thousand ha) | Production (thousand mt) | Area (%) | Production (%) |
| **Regions** | | | | | | | | |
| United States | 34,549 | 363,602 | 71,736 | 877,262 | 106,285 | 1,240,864 | 67.5 | 70.7 |
| Canada | 21,827 | 97,335 | 620 | 9,640 | 22,447 | 106,975 | 2.8 | 9.0 |
| Western Europe | 39,852 | 452,311 | 8,310 | 188,656 | 48,162 | 640,967 | 17.3 | 29.4 |
| Japan and South Korea | 1,107 | 27,348 | 3,770 | 72,337 | 4,876 | 99,685 | 77.3 | 72.6 |
| Australia and New Zealand | 20,143 | 109,878 | 2,281 | 49,614 | 22,424 | 159,492 | 10.2 | 31.1 |
| Eastern Europe | 29,491 | 232,568 | 4,983 | 70,048 | 34,474 | 302,616 | 14.5 | 23.1 |
| Former Soviet Union | 81,142 | 413,531 | 18,703 | 144,623 | 99,845 | 558,154 | 18.7 | 25.9 |
| Middle East | 31,498 | 212,401 | 24,624 | 280,975 | 56,122 | 493,376 | 43.9 | 56.9 |
| Central America | 13,501 | 259,872 | 10,425 | 221,510 | 23,926 | 481,382 | 43.6 | 46.0 |
| South America | 101,888 | 2,232,862 | 13,842 | 675,526 | 115,729 | 2,908,388 | 12.0 | 23.2 |
| South Asia | 101,386 | 646,745 | 152,776 | 1,293,716 | 254,161 | 1,940,461 | 60.1 | 66.7 |
| Southeast Asia | 77,618 | 602,683 | 27,764 | 451,772 | 105,382 | 1,054,454 | 26.3 | 42.8 |
| China | 61,100 | 813,928 | 120,562 | 1,191,019 | 181,662 | 2,004,948 | 66.4 | 59.4 |
| North Africa | 16,849 | 114,127 | 8,426 | 159,367 | 25,274 | 273,494 | 33.3 | 58.3 |
| Sub-Saharan Africa | 235,169 | 1,074,930 | 11,194 | 175,561 | 246,363 | 1,250,491 | 4.5 | 14.0 |
| Rest of the World | 4,439 | 117,191 | 1,428 | 78,063 | 5,867 | 195,254 | 24.3 | 40.0 |
| **Total** | **871,559** | **7,771,313** | **481,443** | **5,939,688** | **1,353,002** | **13,711,001** | **35.6** | **43.3** |
| | | | | | | | | |
| **Sub-Saharan African crops** | | | | | | | | |
| 1 Rice | 6,068 | 11,829 | 2,362 | 9,893 | 8,430 | 21,722 | 28.0 | 45.5 |
| 2 Wheat | 2,885 | 12,576 | 574 | 3,589 | 3,458 | 16,165 | 16.6 | 22.2 |
| 3 Cereal grains | 83,488 | 180,022 | 3,505 | 12,972 | 86,994 | 192,994 | 4.0 | 6.7 |
| 4 Vegetable, fruits, nuts | 40,634 | 535,837 | 2,213 | 40,862 | 42,846 | 576,700 | 5.2 | 7.1 |
| 5 Oil seeds | 13,456 | 15,782 | 655 | 1,115 | 14,110 | 16,897 | 4.6 | 6.6 |
| 6 Sugar cane, sugar beet | 1,661 | 117,818 | 727 | 101,199 | 2,388 | 219,016 | 30.4 | 46.2 |
| 7 Other agricultural products | 86,978 | 201,066 | 1,159 | 5,930 | 88,136 | 206,997 | 1.3 | 2.9 |
| **Total** | **235,169** | **1,074,930** | **11,194** | **175,561** | **246,363** | **1,250,491** | **4.5** | **14.0** |

Source: IMPACT, 2050 simulation without climate change (April 2008).

**Table 3. Impact of climate change in 2050: Percentage change in crop harvested area and production by region and for Sub-Saharan Africa as well as change in regional GDP**

| Description | Rainfed Agriculture | | Irrigated Agriculture | | Total | | Change in GDP* | | Change in Welfare* |
|---|---|---|---|---|---|---|---|---|---|
| | Area | Production | Area | Production | Area | Production | Percentage | Million USD | Million USD |
| **Regions** | | | | | | | | | |
| United States | 1.56 | -1.68 | -3.26 | -7.18 | -1.70 | -5.57 | -0.07 | -19,768 | -17,076 |
| Canada | 2.02 | -2.99 | 3.32 | 7.67 | 2.05 | -2.03 | -0.05 | -992 | 1,737 |
| Western Europe | 1.21 | -0.18 | 1.64 | 0.10 | 1.28 | -0.10 | -0.01 | -1,942 | -12,612 |
| Japan and South Korea | -0.74 | 0.26 | 0.02 | 1.20 | -0.15 | 0.94 | 0.00 | -582 | -2,190 |
| Australia and New Zealand | 2.24 | 3.16 | 2.64 | 1.05 | 2.28 | 2.51 | 0.09 | 1,074 | 5,784 |
| Eastern Europe | 1.20 | -1.73 | 2.18 | -1.21 | 1.34 | -1.61 | -0.38 | -5,201 | -9,537 |
| Former Soviet Union | 1.55 | -4.16 | 0.51 | 2.97 | 1.36 | -2.31 | -0.58 | -8,734 | -12,039 |
| Middle East | 0.44 | -3.85 | -9.02 | -9.76 | -3.71 | -7.22 | -0.23 | -6,724 | -8,853 |
| Central America | 0.98 | -8.59 | -0.01 | -3.13 | 0.55 | -6.08 | -0.21 | -5,133 | -914 |
| South America | 0.22 | -3.43 | -2.42 | -8.42 | -0.10 | -4.59 | -0.21 | -10,697 | 6,055 |
| South Asia | 0.20 | 1.71 | 1.47 | -2.06 | 0.96 | -0.80 | -0.64 | -17,271 | -24,573 |
| Southeast Asia | 0.19 | -0.28 | -0.70 | -1.94 | -0.04 | -0.99 | -0.12 | -4,073 | -9,644 |
| China | 0.37 | -0.38 | -3.61 | -1.65 | -2.27 | -1.14 | -0.01 | -677 | -2,710 |
| North Africa | 0.66 | -3.42 | -2.87 | -1.78 | -0.52 | -2.47 | -0.14 | -1,146 | -108 |
| Sub-Saharan Africa | -0.59 | 0.70 | -3.51 | -15.30 | -0.72 | -1.55 | -0.20 | -3,333 | 1,786 |
| Rest of the World | 0.60 | -2.85 | -2.87 | -4.86 | -0.25 | -3.65 | -0.22 | -1,716 | -2,111 |
| **Total** | **0.38** | **-1.65** | **-1.55** | **-3.99** | **-0.30** | **-2.66** | **-0.09** | **-86,914** | **-87,004** |
| | | | | | | | | | |
| **Sub-Saharan African crops** | | | | | | | | | |
| 1 Rice | -1.95 | 0.88 | -2.50 | 5.44 | -2.10 | 2.96 | | | |
| 2 Wheat | 2.14 | -24.86 | -7.86 | -21.47 | 0.48 | -24.11 | | | |
| 3 Cereal grains | 0.63 | 1.26 | -1.24 | -1.63 | 0.55 | 1.07 | | | |
| 4 Vegetable, fruits, nuts | -0.34 | 1.14 | -1.53 | -1.93 | -0.41 | 0.92 | | | |
| 5 Oil seeds | -1.16 | 0.33 | -0.67 | 1.68 | -1.14 | 0.42 | | | |
| 6 Sugar cane, sugar beet | 1.27 | 2.11 | -23.85 | -25.35 | -6.37 | -10.58 | | | |
| 7 Other agricultural products | -1.81 | -0.19 | -2.95 | 0.16 | -1.83 | -0.18 | | | |
| **Total** | **-0.59** | **0.70** | **-3.51** | **-15.30** | **-0.72** | **-1.55** | | | |

Source: IMPACT, 2050 (SRES B2) baseline simulation and simulation without climate change.
* Data from GTAP-W.

**Table 4. 2050 baseline simulation: Crop yields (kilograms per hectare)**

| Agricultural products | Global average | Regional crop yield* | | Crop yield in Sub-Saharan Africa | | |
|---|---|---|---|---|---|---|
| | | Minimum | Maximum | Average | Minimum | Maximum |
| **Rice** | | | | | | |
| Rainfed | 2,446 | 1,965 | 6,787 | 2,006 | 685 | 6,184 |
| Irrigated | 4,251 | 3,444 | 8,977 | 4,530 | 1,074 | 11,461 |
| **Wheat** | | | | | | |
| Rainfed | 3,781 | 1,745 | 6,906 | 3,207 | 753 | 9,225 |
| Irrigated | 5,183 | 3,311 | 9,123 | 5,330 | 934 | 10,442 |
| **Cereal grains** | | | | | | |
| Rainfed | 3,868 | 1,435 | 9,656 | 2,170 | 550 | 4,958 |
| Irrigated | 9,087 | 3,686 | 13,906 | 3,686 | 1,567 | 8,062 |
| **Vegetables, fruits, nuts** | | | | | | |
| Rainfed | 15,356 | 10,940 | 35,855 | 13,384 | 2,920 | 27,451 |
| Irrigated | 24,650 | 18,390 | 57,046 | 18,390 | 2,506 | 37,986 |
| **Oil seeds** | | | | | | |
| Rainfed | 2,080 | 901 | 2,926 | 1,191 | 432 | 1,875 |
| Irrigated | 3,865 | 1,743 | 4,616 | 1,743 | 713 | 3,464 |
| **Sugar cane, sugar beet** | | | | | | |
| Rainfed | 99,303 | 34,494 | 129,276 | 71,501 | 9,113 | 203,921 |
| Irrigated | 129,646 | 50,363 | 187,128 | 136,497 | 36,924 | 232,523 |
| **Other agricultural products** | | | | | | |
| Rainfed | 4,669 | 2,022 | 26,371 | 2,482 | 287 | 16,602 |
| Irrigated | 9,484 | 2,640 | 81,150 | 8,912 | 1,138 | 11,579 |

* Regional average according to the 16 regions defined in Table A1.

Note: Crop yields are computed as a weighted average by area.

Source: IMPACT, 2050 (SRES B2) baseline simulation.

**Table 5. 2050 baseline simulation: Crop harvested area and production in Sub-Saharan Africa**

| Agricultural products (according to GTAP-W) | Rainfed Agriculture Area (thousand ha) | Rainfed Agriculture Production (thousand mt) | Irrigated Agriculture Area (thousand ha) | Irrigated Agriculture Production (thousand mt) | Total Area (thousand ha) | Total Production (thousand mt) | Share of irrigated agriculture in total: Area (%) | Share of irrigated agriculture in total: Production (%) |
|---|---|---|---|---|---|---|---|---|
| 1 Rice | 5,950 | 11,933 | 2,303 | 10,432 | 8,253 | 22,364 | 27.9 | 46.6 |
| 2 Wheat | 2,946 | 9,450 | 529 | 2,818 | 3,475 | 12,268 | 15.2 | 23.0 |
| 3 Cereal grains | 84,012 | 182,298 | 3,462 | 12,761 | 87,474 | 195,058 | 4.0 | 6.5 |
| 4 Vegetable, fruits, nuts | 40,493 | 541,953 | 2,179 | 40,072 | 42,673 | 582,025 | 5.1 | 6.9 |
| 5 Oil seeds | 13,300 | 15,834 | 650 | 1,134 | 13,950 | 16,968 | 4.7 | 6.7 |
| 6 Sugar cane, sugar beet | 1,683 | 120,306 | 553 | 75,545 | 2,236 | 195,851 | 24.8 | 38.6 |
| 7 Other agricultural products | 85,400 | 200,684 | 1,125 | 5,939 | 86,525 | 206,623 | 1.3 | 2.9 |
| **Total** | **233,784** | **1,082,457** | **10,801** | **148,701** | **244,585** | **1,231,158** | **4.4** | **12.1** |

Source: IMPACT, 2050 (SRES B2) baseline simulation.

**Table 6. Adaptation scenario 1: Percentage change in the demand for endowments, total production and market price in Sub-Saharan Africa (outputs from GTAP-W, percentage change with respect to the 2050 baseline simulation)**

| | Change in demand for endowments (%) | | | | | | | | Change in production (%) | | | Change in market price (%) | Change in world market price (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GTAP-W sectors** | **Irrigation** | **Irrigated land** | **Rainfed land** | **Pasture land** | **Unskilled labour** | **Skilled labour** | **Capital** | **Natural Resources** | **Irrigated** | **Rainfed** | **Total** | | |
| 1 Rice | 99.57 | 99.60 | -0.18 | | -0.17 | -0.17 | -0.17 | | 99.59 | -2.57 | 0.16 | -1.12 | -0.06 |
| 2 Wheat | 102.63 | 102.66 | 1.35 | | 1.73 | 1.73 | 1.73 | | 102.24 | 0.49 | 2.12 | -1.17 | -0.05 |
| 3 Cereal grains | 99.85 | 99.87 | -0.04 | | 0.00 | 0.00 | 0.00 | | 99.87 | -0.47 | 0.05 | -0.14 | -0.02 |
| 4 Vegetable, fruits, nuts | 99.94 | 99.96 | 0.00 | | 0.06 | 0.05 | 0.05 | | 98.06 | 0.00 | 0.09 | -0.10 | -0.01 |
| 5 Oil seeds | 100.14 | 100.17 | 0.11 | | 0.18 | 0.18 | 0.18 | | 100.12 | 0.03 | 0.24 | -0.18 | -0.02 |
| 6 Sugar cane, sugar beet | 98.87 | 98.89 | -0.53 | | -0.61 | -0.61 | -0.61 | | 98.88 | -7.32 | 0.17 | -1.87 | -0.17 |
| 7 Other agricultural products | 99.76 | 99.78 | -0.09 | | -0.05 | -0.05 | -0.06 | | 99.78 | -0.17 | -0.05 | 0.01 | -0.01 |
| 8 Animals | | | | 0 | 0.02 | 0.02 | 0.02 | | | | 0.00 | 0.07 | 0.01 |
| 9 Meat | | | | | -0.06 | -0.06 | -0.06 | | | | -0.06 | 0.05 | 0.00 |
| 10 Food products | | | | | 0.11 | 0.11 | 0.11 | | | | 0.11 | -0.17 | -0.01 |
| 11 Forestry | | | | | 0.00 | 0.00 | 0.00 | 0.00 | | | 0.00 | 0.02 | 0.00 |
| 12 Fishing | | | | | 0.04 | 0.04 | 0.04 | 0.00 | | | 0.02 | 0.12 | 0.01 |
| 13 Coal | | | | | -0.01 | -0.01 | -0.01 | 0.00 | | | -0.01 | 0.01 | 0.00 |
| 14 Oil | | | | | -0.02 | -0.02 | -0.02 | 0.00 | | | -0.02 | 0.01 | 0.00 |
| 15 Gas | | | | | -0.04 | -0.04 | -0.04 | 0.00 | | | -0.03 | 0.01 | 0.00 |
| 16 Oil products | | | | | -0.01 | -0.01 | 0.01 | | | | 0.01 | 0.01 | 0.00 |
| 17 Electricity | | | | | -0.01 | -0.01 | -0.01 | | | | -0.01 | 0.02 | 0.00 |
| 18 Water | | | | | 0.01 | 0.01 | 0.01 | | | | 0.01 | 0.02 | 0.00 |
| 19 Energy intensive industries | | | | | -0.03 | -0.03 | -0.03 | 0.00 | | | -0.03 | 0.01 | 0.00 |
| 20 Other industry and services | | | | | -0.02 | -0.02 | -0.02 | | | | -0.02 | 0.01 | 0.00 |
| 21 Market services | | | | | 0.00 | 0.00 | 0.00 | | | | 0.00 | 0.01 | 0.00 |
| 22 Non-market services | | | | | 0.00 | 0.00 | 0.00 | | | | 0.00 | 0.01 | 0.00 |
| **Change in market price (%)** | -90.57 | -90.63 | 0.19 | 0.09 | 0.02 | 0.02 | 0.02 | 0.08 | | | | | |

**Table 7. Adaptation scenario 1: Regional production and world market prices for cereals and meats, 2000 baseline data and 2050 baseline simulations (outputs from IMPACT)**

| Description | 2000 | 2050 | | Percentage |
|---|---|---|---|---|
| | Baseline data | Baseline | Scenario 1 | change* |
| **Cereal production (mmt):** | | | | |
| North America and Europe | 779 | 1,188 | 1,196 | 0.67 |
| Central West Asia and North Africa | 116 | 240 | 233 | -2.80 |
| East and South Asia and Pacific | 745 | 1,010 | 1,009 | -0.06 |
| Latin America and the Caribbean | 133 | 262 | 263 | 0.57 |
| Sub-Saharan Africa | 78 | 211 | 222 | 5.34 |
| **Root and tuber production (mmt):** | | | | |
| North America and Europe | 171 | 198 | 198 | 0.36 |
| Central West Asia and North Africa | 21 | 48 | 46 | -2.56 |
| East and South Asia and Pacific | 281 | 371 | 371 | -0.05 |
| Latin America and the Caribbean | 51 | 107 | 108 | 1.17 |
| Sub-Saharan Africa | 164 | 379 | 379 | 0.00 |
| **Meat production (mmt):** | | | | |
| North America and Europe | 93 | 122 | 122 | 0.04 |
| Central West Asia and North Africa | 11 | 33 | 33 | 0.90 |
| East and South Asia and Pacific | 88 | 202 | 203 | 0.56 |
| Latin America and the Caribbean | 30 | 82 | 83 | 1.13 |
| Sub-Saharan Africa | 6 | 15 | 16 | 1.05 |
| **World market prices (USD/mmt):** | | | | |
| Rice | 186 | 299 | 296 | -0.80 |
| Wheat | 109 | 205 | 209 | 1.76 |
| Maize | 91 | 180 | 181 | 0.46 |
| Other grains | 68 | 108 | 108 | 0.08 |
| Millet | 255 | 310 | 312 | 0.62 |
| Sorghum | 93 | 169 | 172 | 1.72 |
| Potato | 213 | 210 | 206 | -1.62 |
| Sweet potato and yams | 470 | 405 | 398 | -1.53 |
| Cassava | 65 | 58 | 59 | 0.99 |
| Beef | 1,917 | 2,521 | 2,548 | 1.06 |
| Pork | 906 | 1,226 | 1,236 | 0.86 |
| Sheep and Goat | 2,705 | 2,782 | 2,780 | -0.09 |
| Poultry | 1,196 | 1,661 | 1,684 | 1.39 |

* Percentage change with respect to the 2050 (SRES B2) baseline simulation.

**Table 8. Adaptation scenario 2: Percentage change in the demand for endowments, total production and market price in Sub-Saharan Africa (outputs from GTAP-W, percentage change with respect to the 2050 baseline simulation)**

| | Change in demand for endowments (%) | | | | | | | | Change in production (%) | | | Change in market price (%) | Change in world market price (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **GTAP-W sectors** | **Irrigation** | **Irrigated land** | **Rainfed land** | **Pasture land** | **Unskilled labour** | **Skilled labour** | **Capital** | **Natural Resources** | **Irrigated** | **Rainfed** | **Total** | | |
| 1 Rice | -5.10 | -5.24 | -12.21 | | -3.00 | -2.85 | -2.88 | | 18.50 | 1.58 | 2.03 | -13.51 | -2.82 |
| 2 Wheat | 6.06 | 5.89 | -1.90 | | 11.31 | 11.48 | 11.38 | | 32.42 | 15.40 | 16.13 | -10.14 | -2.56 |
| 3 Cereal grains | -4.98 | -5.13 | -12.12 | | -2.87 | -2.73 | -2.77 | | 18.63 | 2.21 | 2.29 | -13.60 | -3.32 |
| 4 Vegetable, fruits, nuts | 1.99 | 1.83 | -5.66 | | 6.04 | 6.21 | 6.15 | | 27.34 | 10.88 | 10.95 | -12.77 | -2.60 |
| 5 Oil seeds | 6.44 | 6.27 | -1.55 | | 11.80 | 11.97 | 11.92 | | 32.90 | 16.82 | 16.93 | -12.90 | -2.91 |
| 6 Sugar cane, sugar beet | -5.13 | -5.28 | -12.25 | | -3.06 | -2.91 | -2.96 | | 18.45 | -0.10 | 1.21 | -7.52 | -2.81 |
| 7 Other agricultural products | 12.55 | 12.37 | 4.09 | | 19.79 | 19.97 | 19.92 | | 40.52 | 25.22 | 25.24 | -11.58 | -4.15 |
| 8 Animals | | | | 0 | 0.36 | 0.51 | 0.45 | | | | 0.06 | 3.65 | 0.78 |
| 9 Meat | | | | | -3.29 | -2.59 | -2.70 | | | | -2.96 | 2.86 | 0.17 |
| 10 Food products | | | | | 1.00 | 1.73 | 1.61 | | | | 1.38 | -1.72 | -0.99 |
| 11 Forestry | | | | | -0.06 | 0.06 | 0.03 | 0.00 | | | 0.02 | 2.49 | 0.67 |
| 12 Fishing | | | | | 1.28 | 1.41 | 1.36 | 0.01 | | | 0.51 | 5.51 | 0.76 |
| 13 Coal | | | | | -1.74 | -1.62 | -1.61 | -0.01 | | | -1.25 | 0.99 | 0.43 |
| 14 Oil | | | | | -2.86 | -2.73 | -2.75 | -0.01 | | | -2.35 | 0.67 | 0.36 |
| 15 Gas | | | | | -5.02 | -4.64 | -4.47 | -0.01 | | | -3.70 | 0.84 | 0.33 |
| 16 Oil products | | | | | -2.00 | -1.21 | 0.47 | | | | 0.41 | 1.13 | 0.32 |
| 17 Electricity | | | | | -2.50 | -1.71 | -1.51 | | | | -1.47 | 2.09 | 0.22 |
| 18 Water | | | | | -0.52 | 0.29 | 0.28 | | | | 0.14 | 2.12 | 0.15 |
| 19 Energy intensive industries | | | | | -5.57 | -4.85 | -4.81 | 0.00 | | | -4.81 | 1.93 | 0.14 |
| 20 Other industry and services | | | | | -4.50 | -3.73 | -3.81 | | | | -4.14 | 1.43 | 0.09 |
| 21 Market services | | | | | -0.83 | 0.07 | 0.07 | | | | -0.30 | 2.09 | 0.12 |
| 22 Non-market services | | | | | 0.04 | 0.85 | 0.79 | | | | 0.57 | 1.68 | 0.12 |
| **Change in market price (%)** | -39.86 | -41.70 | -12.44 | 4.58 | 3.03 | 2.38 | 2.49 | 1.83 | | | | | |

**Table 9. Adaptation scenario 2: Regional production and world market prices for cereals and meat in 2050 baseline simulations (outputs from IMPACT)**

| Description | 2050 | | Percentage change* |
|---|---|---|---|
| | Baseline | Scenario 2 | |
| **Cereal production (mmt):** | | | |
| North America and Europe | 1,188 | 1,156 | -2.73 |
| Central West Asia and North Africa | 240 | 227 | -5.41 |
| East and South Asia and Pacific | 1,010 | 987 | -2.29 |
| Latin America and the Caribbean | 262 | 254 | -3.05 |
| Sub-Saharan Africa | 211 | 254 | 20.29 |
| **Root and tuber production (mmt):** | | | |
| North America and Europe | 198 | 196 | -0.88 |
| Central West Asia and North Africa | 48 | 47 | -1.21 |
| East and South Asia and Pacific | 371 | 361 | -2.91 |
| Latin America and the Caribbean | 107 | 101 | -4.99 |
| Sub-Saharan Africa | 379 | 441 | 16.27 |
| **Meat production (mmt):** | | | |
| North America and Europe | 122 | 123 | 0.90 |
| Central West Asia and North Africa | 33 | 33 | 0.91 |
| East and South Asia and Pacific | 202 | 205 | 1.31 |
| Latin America and the Caribbean | 82 | 84 | 2.38 |
| Sub-Saharan Africa | 15 | 16 | 4.30 |
| **World market prices (USD/mmt):** | | | |
| Rice | 299 | 279 | -6.58 |
| Wheat | 205 | 190 | -7.50 |
| Maize | 180 | 153 | -15.05 |
| Other grains | 108 | 85 | -21.46 |
| Millet | 310 | 228 | -26.41 |
| Sorghum | 169 | 130 | -23.07 |
| Potato | 210 | 190 | -9.37 |
| Sweet potato and yams | 405 | 286 | -29.39 |
| Cassava | 58 | 40 | -30.75 |
| Beef | 2,521 | 2,507 | -0.54 |
| Pork | 1,226 | 1,213 | -1.04 |
| Sheep and Goat | 2,782 | 2,752 | -1.09 |
| Poultry | 1,661 | 1,642 | -1.18 |

* Percentage change with respect to the 2050 (SRES B2) baseline simulation.

**Table 10. Summary of the impact of climate change and adaptation on Sub-Saharan Africa**

| Description | 2050 No climate change | 2050* SRES B2 baseline | 2050** Double irrigated area | 2050** Increase crop yield |
|---|---|---|---|---|
| Total Production (thousand mt) | 1,250,491 | -1.5% | 0.1% | 18.0% |
| Rainfed production (thousand mt) | 1,074,930 | 0.7% | -0.6% | 17.9% |
| Irrigated production (thousand mt) | 175,561 | -15.3% | 99.5% | 23.4% |
| Total Area (thousand ha) | 246,363 | -0.7% | 0.0% | 0.0% |
| Rainfed area (thousand ha) | 235,169 | -0.6% | -4.8% | 0.0% |
| Irrigated area (thousand ha) | 11,194 | -3.5% | 100.0% | 0.0% |
| Change in welfare (USD million) | -- | 1,786 | 119 | 15,435 |
| Change in GDP (USD million) | -- | -3,333 | 113 | 25,720 |
| Change in GDP (percentage) | -- | -0.2% | 0.0% | 1.5% |
| Malnutrition (million children) | 30.2 | 32.0 | 31.7 | 30.4 |

* Percentage change with respect to the 2050 no climate change simulation.

** Percentage change with respect to the 2050 (SRES B2) baseline simulation.

**Annex I:**

**Table A1. Aggregations in GTAP-W**

***A. Regional Aggregation***

**1. USA -** United States
**2. CAN -** Canada
**3. WEU -** Western Europe
**4. JPK -** Japan and South Korea
**5. ANZ -** Australia and New Zealand
**6. EEU -** Eastern Europe
**7. FSU -** Former Soviet Union
**8. MDE -** Middle East
**9. CAM -** Central America
**10. SAM -** South America
**11. SAS -** South Asia
**12. SEA -** Southeast Asia
**13. CHI -** China
**14. NAF -** North Africa
**15. SSA -** Sub-Saharan Africa
**16. ROW -** Rest of the World

***B. Sectoral Aggregation***

**1. Rice -** Rice
**2. Wheat -** Wheat
**3. CerCrops -** Cereal grains (maize, millet, sorghum and other grains)
**4. VegFruits -** Vegetable, fruits, nuts
**5. OilSeeds -** Oil seeds
**6. Sug_Can -** Sugar cane, sugar beet
**7. Oth_Agr -** Other agricultural products
**8. Animals -** Animals
**9. Meat -** Meat
**10. Food_Prod -** Food products
**11. Forestry -** Forestry
**12. Fishing -** Fishing
**13. Coal -** Coal
**14. Oil -** Oil
**15. Gas -** Gas
**16. Oil_Pcts -** Oil products
**17. Electricity -** Electricity
**18. Water -** Water
**19. En_Int_Ind -** Energy intensive industries
**20. Oth_Ind -** Other industry and services
**21. Mserv -** Market services
**22. NMServ -** Non-market services

***C. Endowments***

**Wtr -** Irrigation
**Lnd -** Irrigated land
**RfLand -** Rainfed land
**PsLand -** Pasture land
**Lab -** Labour
**Capital -** Capital
**NatlRes -** Natural resources

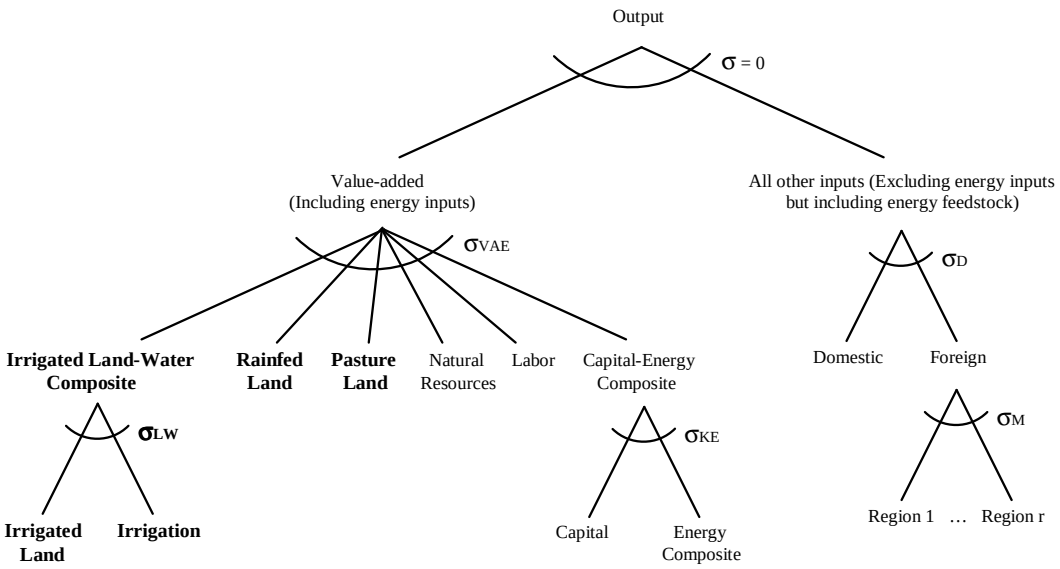


**Figure A1. Nested tree structure for industrial production process in GTAP-W (truncated)**

Note: The original land endowment has been split into pasture land, rainfed land, irrigated land and irrigation (bold letters).

## Annex II: Model linkages between IMPACT and GTAP-W