CHAPTER 5 – LOOKING INTO THE FUTURE FOR AGRICULTURE AND AKST (AGRICULTURAL KNOWLEDGE SCIENCE AND TECHNOLOGY)

DRAFT – NOT FOR CITATION

Coordinating Lead Authors: Mark W. Rosegrant, Maria Fernandez, Anushree Sinha
Lead authors: Jackie Alder, Charlotte de Fraiture, Bas Eickhout, Jorge Fonseca, Jikun Huang, Osamu Koyama, A.M. Omezzine, Prabhu Pingali, Claudia Ringler, Scott Robinson, Phil Thornton, Detlef van Vuuren,
Contributing Authors: Helal Ahammad, Monirul Mirza, Poonam Munjal, Clare Narrod, Ricardo Ramirez, Terri Raney, Sunil Ray, Timothy Sulser, Carla Tamagno, Henk Westhoek, Tingju Zhu

Key Messages

World food markets will become tighter, with increasing scarcity, as indicated by a projected increase in world food prices for key cereals and meat under the reference projections. Real world prices of most cereals and meat are projected to increase in the coming decades, reversing trends from the past several decades. Maize, rice, and wheat prices are projected to increase by 24-41 % in the reference world, and prices for beef, pork, and poultry by 9-11 %. This will, in turn, dampen food demand of poor consumers in all regions and will adversely impact food security and human well-being goals. Greater scarcity will be driven by both demand and supply factors. Rapid growth in meat and milk demand in most of the developing world will put strong demand pressure on maize and other coarse grains as feed. Population growth and recovery and strengthening of economic growth in sub-Saharan Africa (SSA) will drive relatively fast growth in regional demand for food. In developing Asia, rising incomes and rapid urbanization will change the composition of cereal demand. Per capita food consumption of maize and coarse grains will decline as consumers shift to wheat and rice. As incomes rise further and lifestyles change with urbanization, there will be a secondary shift from rice to wheat. Shifts in cereal consumption will be accompanied by strong growth in meat consumption, which in turn will substantially increase cereal consumption as animal feed, particularly maize. However, demand for wheat and rice will be boosted by a different shift in consumption in SSA with increasing income growth: from roots and tubers to rice and wheat. Growth in cereal and meat consumption will be much slower in developed countries. These trends will lead to an extraordinary increase in the importance of developing countries in global food markets.

On the supply side, water scarcity will increasingly constrain production. There will be virtually no increase in water available for agriculture due to little increase in supply and rapid shift of water from agriculture in key water-scarce agricultural regions in China, India, and Central, West Asia and North Africa (CWANA). Climate change will increase heat and drought stress in some regions. In many countries in Asia and Latin America where relatively high rates of input use and crop yields have already been achieved, it is more difficult to achieve further yield gains. With declining availability of water and land that can be profitably brought under cultivation, expansion in area will contribute very little to future production growth. The projected slow growth in crop area places the burden to meet future cereal demand on crop yield growth. Although yield growth will vary considerably by commodity and country and improve in parts of sub-Saharan Africa, in most countries and for developing countries and developed countries as regions it will continue to slow down. Growing scarcity in global markets calls for enhanced investment and effectiveness in implementation of AKST.

There will be only slow improvement in food security in the reference world. The substantial increase in food prices will cause relatively slow growth in calorie consumption, with both direct price impacts and reductions in real incomes for poor consumers who spend a large share of their income on food. This in turn contributes to slow improvement in food security for the poor in many regions. In the reference run, childhood malnutrition (children of up to 60 months) will continue to decline, but cannot be eradicated by 2050. Childhood malnutrition is projected to decline from 146 million children in 2000 to 117 million children by 2025 and 80 million children by 2050. The decline will be fastest in Latin America at 66%, followed by the West Asia and North Africa region, at 60%, and Asia, at 51%. Within Asia, South Asia is expected to house most (88%) of Asian malnourished children in 2050. Progress is slowest in sub-Saharan Africa—despite rapid income growth and significant area and yield growth as well as substantial progress in supporting services that influence well-being outcomes, such as female secondary education, and access to clean drinking water—by 2050, there will be a reduction by only 19% in the number of malnourished children in sub-Saharan Africa.

Growing water constraints affect future benefits of AKST. Irrigation will continue to be the largest water user in 2050 for all regions. However, it is estimated that the share of irrigation consumption in total water depletion will decrease by about 10% from 2000 to 2050. The decline in irrigation water use is largely due to the more rapid growth of non-irrigation water demands that compete for water with irrigation, and also because of projected declines in irrigated areas in some parts of the world. In the reference world, irrigation water supply reliability declines out to 2050, reducing the future benefits from AKST for the development goals. Future AKST investments and directions increasingly need to take into account growing variability and reduced availability of water resources.

Heavy reliance on food imports in sub-Saharan Africa will continue in the reference projections despite accelerated AKST. Sub-Saharan Africa will face the largest increase in food import bills despite faster agricultural production growth expected in the region during the next 50 years in the reference world. With the increase in import needs, the major exporting countries—mostly in the North America and Europe (NAE) and Latin America and Caribbean (LAC) regions--will provide an increasingly critical role in meeting food consumption needs.

Exporting countries will be increasingly important in meeting food demand and reducing upward pressure on food prices in developing countries. With rising food prices due to inability of most developing countries to increase food production rapidly enough to meet growing demand, the major exporting countries will provide an increasingly critical role in meeting food consumption needs. The USA, Brazil, and Argentina are a critical safety valve in providing relatively affordable food to developing countries. Canada, Australia, and Europe also provide significant exports, the latter mainly because of slow or no growth in demand with stable population. For rice, Myanmar joins Thailand and Vietnam as particularly significant exporters.

If society is to head towards a higher level of aquaculture with a reliance on fishmeal/fish oil as expected in the reference run, then there is a tradeoff with biodiversity, more specifically the larger demersal and bentho-pelagic groups such as cod, haddock, halibut etc. There is also limited scope for increasing production of small pelagic fish, even with a 2% increase in effort in all areas of the world's oceans except the polar regions which were not included in this analysis.

Continuing structural change in the livestock sector, driven mainly by rapid growth in demand for livestock products, will bring about profound changes in livestock production systems. These changes will have significant implications for social equity, the environment, and public health. Increases in livestock numbers to 2050 vary by region and species, but substantial growth opportunities exist for livestock producers in the developing world. The increased production of livestock is expected to come from the same or a declining resource base, and without appropriate action there are prospects that this could lead to degradation of land, water, and animal genetic resources in both intensive and extensive livestock systems. For large ruminants grazing intensity (number of animals per ha of grazing land) will more than double globally, while in SSA and CWANA it will increase five- and three-fold, respectively. In addition to the potential environmental impacts of more intensive livestock production systems, there are major challenges in ensuring that livestock growth opportunities do not marginalize smallholder producers and other poor people who depend on livestock for their livelihoods. Tradeoffs are inevitably going to be required between food security, poverty, equity, environmental sustainability, and economic development. Sustained public policy action will be necessary to ensure that livestock system development can play its role as a tool for growth and poverty reduction, even as global and domestic trends and economic processes create substantial opportunities for sector growth.

In India, improvement in average real wage of skilled female workers is more pronounced than male workers. By 2025, there would be positive growth of casual skilled male and female workers' average real wage rate. However, the rise would be more for the female workforce. The average wage rate of the male casual workforce would witness a positive growth only in 2050 with a marginal improvement in 2050. What appears to emerge is that improved agriculture under AKST would lead to growth in such a manner that there would be higher wages for casual female male workforce in the reference world of 2025. Present trend of real wage growth of the female workforce may continue until 2025 narrowing the gender gap. The wage growth of both male and female workforce would then have a downturn and get negative during 2050 with further decline in 2050-1. The AKST measure is sustainable until 2025 for improvement of wages. In the next 25 years, the AKST needs enhanced market penetration to lead to real wage growth.

Food safety regulation will be more difficult for developing countries, and should be accompanied with a strong support toward development of AKST and maximum diversification permissible by the local conditions.

Demand for product with high standards of overall quality and safety will continue to grow in developed countries, a market that will only be accessible to those developing countries with sufficient AKST capacity. On the other hand, in developing countries, better quality standards, perhaps set by supermarkets, will only occur if consumers are educated toward the benefits of consumption of perishable products, if public health regulation and liability laws are established, and if better laboratory infrastructure is built.

Improvement in land tenure systems would enhance enforcement of agricultural land preservation and promote sustainability objectives.

Rural populations under weak land preservation regulations have failed to invest in long-term land improvements on existing agricultural land and have also in many countries abandoned land in favor of migration to forest and other marginal lands. Policies related to land tenure and resources access are of great relevance for the sustainable management and use of natural resources in all countries of the world where the majority of the population rely heavily on land to provide income, employment and livelihoods. In recent years there is a growing recognition of the centrality of the land tenure in sustainable development process as witnessed by new land policies, and increasing local and international demands for relevant and sound land tenure laws and regulations.

Land insecurity is highly widespread and sources from unclear land rights, population overcrowding, land alienation, inappropriate administrative practices and limited women rights to land in Southern Africa (Mzumara 2003). Many countries have already started revision, improvement and reformulation of land policy and tenure. Most policy reforms have addressed country specific problems and issues. However, inappropriate administrative and institutional practices are found on most reform agendas. The results are low productivity of land, migration of rural population and increased poverty rate.

Climate change will increasingly affect AKST. Climate change will have increasing impacts on the agriculture sector. This impact can be positive or negative. For example, CO_2 fertilization, increased precipitation and higher temperature can lengthen the growing season and improve crop yields. However, with higher temperatures and more erratic precipitation crop yield impacts will be negative (IPCC 2007a). Negative impacts, while still relatively small, on average, by 2050, can be severe in developing countries.

A climate policy variant studied has important benefits in reducing climate change – although some of these may only materialize in the long-term. Emission reductions under the alternative variant can reduce greenhouse gas concentration substantially in 2050. At the same time, however, the medium-term (2050) impacts on temperature increase are relatively slow. The latter is due to inertia in the climate system, but also due to the fact that climate policy also reduces SO_2 emissions, reducing atmospheric aerosols that lead to a net cooling. In other words, impacts on agriculture in 2050 are similar in the stringent policy case as in the reference run. Uncertainty does not come from different variants – but differences in climate sensitivity. In the longer run, however, the temperature of the policy case will remain significantly below the reference case.

Growing impacts on agriculture from climate change requires new responses from AKST, including adaptation strategies and investments targeted to those areas and populations most vulnerable to climate change.

Bioenergy might become an important new variable for agriculture and AKST in many regions. Bioenergy or production of liquid fuels from biomass could meet some of the world's growing energy demand, particularly for transportation. Large-scale cultivation of biomass for energy applications could lead to considerable future change in land use and require new AKST and other resources. Under variants in which agricultural land could become available as a result of rapid yield improvement and slow population growth, bioenergy potential is considerably higher than in land-scarce variants. If there is a fast shift towards wood and grassy crops (in cellulose-based reduction routes), this option offers greater CO_2 reduction options and less land use per unit of energy, although technical breakthroughs would be required to achieve this.

Pro-poor biotechnology can become an important AKST instrument. Biotechnology developments can enhance productivity gains in agriculture, potentially with important benefits for small farmers in the developing world. Since most of the world's poorest people live in rural areas and depend on agriculture for their livelihoods, improving agricultural productivity remains the key to poverty reduction. For transgenic crops to be pro-poor, cultivation practices associated with them, IPR (intellectual property rights) and biosafety regimes that apply and the extent to which smallholders have the necessary resources (human, physical, financial and social capital) to enable them to adopt these new technologies are important factors.

With increasing pressure on natural resources in the reference run, advancement in productivity and profits from improved agricultural research and extension can contribute to substantial increases in rural income and poverty alleviation. Investments in conventional breeding and tools of biotechnology such as marker-assisted selection and cell and tissue culture techniques—and likely an increasing contribution from genetically modified crops—can in particular boost crop yield growth in rainfed environments. Resource-poor farmers will be excluded from the benefits of modern science, including biotechnology, if measures are not taken to avoid social exclusion in dissemination of new agricultural technologies. In addition, harmonization of regulatory standards, including biosafety standards, must be put in place.

Evolving consumer preferences have global implications for food prices and food security and require a re-focus of investments in AKST. If consumer demand evolves following the reference world then increased calorie consumption of livestock products, fish, fruits, vegetables, and oils/fats and sugars will require AKST activities that support sustainable production practices and affordable food prices for these commodities. At the same time, health consequences of more affluent diets and their production requirements need to be factored into future AKST investments. If consumers instead were to follow more vegetarian diets, then the primary challenge would be to augment productivity investments for those crops that will need to substitute for less meaty diets. This will also be necessary to ensure that these food items remain affordable to the poor. If consumers would increasingly support organic farming, then additional research and investments in alternative organic inputs for large-scale production that will maintain soil nutrients and improve labor efficiencies will grow in importance.

Competition for land will be one of the key challenges in the coming decades. In the reference world more land will be used for urbanization, infrastructure, food production and bioenergy. Therefore, loss of biodiversity will continue to happen in the coming decades because of land scarcity alone. Combined with increased pressures from climate change, this loss will become even larger in the reference world. Options to combat climate change will improve the situation for crop production and biodiversity through climatic pressures, but will have a trade off with land use through an increased use of bioenergy. This is certainly true for policy options aiming at very ambitious targets for bioenergy specifically. Land availability will therefore be one of the key challenges to sustain human development.

More aggressive investments and better management of AKST can make significant improvements in IAASTD food security goals. Alternative policy experiments show that with higher investments in AKST the share of malnourished children in the group of developing countries are projected to decline to only 64 million from the baseline of 80 million. If these higher investments in AKST are combined with improvements in complementary service sectors, such as health and education, then a further reduction to 47 million is projected.

Optimal AKST investments will require an appropriate mix of strategies, depending on the potential and constraints in different regions. With inevitable increases in world food demand agriculture will require more land and water resources with potential adverse impacts on ecosystems services. The policy experiments show that a major part of the increase in food production can be achieved by further improving crop yields per unit of land and increasing output per unit of water, through appropriate investments in both irrigated and rainfed agriculture. AKST plays an essential role in achieving these improvements. Additional assessment must be made of how alternative policies will cope with increasing land and water scarcity.

Human, animal and plant health, food security and food safety are closely related and need to be understood as an integrated system. For the next decades we will be challenged to assure safer food to consumers and raise the quality of life without creating a barrier to poor countries/producers for opportunities of success. There is a danger that safe food will only be available to some consumers (Schillhorn van Veen 2005). Furthermore, in our search for mechanisms to improve food security in the world we are challenged to develop production and exchange systems that will not cause the emerging of currently unknown health problems.

Rural communities will have a greater say in the future of small-scale agriculture as their access to information via information communication and technology (ICTs) and to financial capital via remittance investment plans increases. The attributes of ICTs are linked directly and indirectly with the MDG, especially those that relate to health and education (Torero and von Braun 2006). As internet access increases in rural areas, technological and market information will become readily available to small-scale producers if private and public institutions take up the challenge of preparing information for a diversity of user groups. In addition there will be an increase of information flow and decision making via cellular phones among national and international migrants. As a result, migrant organizations in receiving countries will reinforce links with their home communities and most likely influence the choice of local development paths. Taken together, increased access to communication technologies (ICTs) and migrant remittances will impact the land management, food security and livelihood strategies of rural communities in new ways.

Differentiation of time periods is important in assessments. The year 2025 can be assessed better and levels of uncertainty are lower, while longer periods, such as out to 2050 reduce the chances of better accuracy.

5.1 Introduction: Scope of the Chapter and How to Use the Results

Merit in assessment of possible future developments have been introduced in the previous chapters. This chapter will focus particularly on looking into the future for agriculture and AKST through both qualitative and quantitative methods. A reference run or baseline is described based on the assessment of drivers of agriculture and AKST as explained in Chapter 4 based on plausible assumptions of future changes combined with a set of modeling tools and qualitative assessments. Inclusion of various tools in the assessment process enables the examination of the various relationships that transpire determined by major drivers.

5.2 Description (Structure) of Selected Tools Used in the Assessment (Quantitative and Qualitative); Justification (Including Strengths and Weaknesses)

5.2.1 Structure of quantitative models

5.2.1.1. The IMPACT-WATER Model

The IMPACT-WATER model combines an extension of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) with a global water simulation model (WATER), based on state-of-the-art global water databases (Rosegrant, Cai and Cline 2002). The water module projects the evolution of availability and demand, with a base year of 2000 (average of 1999-2001), taking into account the availability and variability in water resources, the water supply infrastructure, and irrigation and non-agricultural water demands, as well as the impact of alternative water policies and investments. Water demands are simulated as functions of year-to-year hydrologic fluctuations, irrigation development, growth of industrial and domestic water uses, and environmental and other flow requirements (committed flow). Off-stream water supply for the domestic, industrial, livestock, and irrigation sectors is determined based on water allocation priorities, treating irrigation water as a residual; environmental flows are included as constraints.

The food module is specified as a set of 115 country or regional sub-models, within each of which supply, demand and prices for agricultural commodities are determined for 32 crop, livestock, and fish commodities, including all cereals, soybeans, roots and tubers, meats, milk, eggs, oils, oilcakes and meals, sugar and sweeteners, fruits and vegetables, and low-value and high-value fish. These country and regional sub-models are intersected with 126 river basins—to allow for a better representation of water supply and demand—generating results for 281 Food Producing Units (FPUs). Crop harvested areas and yields are calculated based on crop-wise irrigated and rainfed area and yield functions. These functions include water availability as a variable and connect the food module with the global water simulation model.

The “food” side of the IMPACT-WATER model uses a system of supply and demand elasticities incorporated into a series of linear and nonlinear equations, to approximate the underlying production and demand functions. World agricultural commodity prices are determined annually at levels that clear international markets. Demand is a function of prices, income and population growth. Growth in crop production in each country is determined by crop prices and the rate of productivity growth. Future productivity growth is estimated by its component sources, including crop management research, conventional plant breeding, wide-crossing and hybridization breeding, and biotechnology and transgenic breeding. Other sources of growth considered include private sector agricultural research and development, agricultural extension and education, markets, infrastructure and irrigation.

IMPACT-WATER projects the share and number of malnourished preschool children in developing countries as a function of average per capita calorie availability, the share of females with secondary schooling, the ratio of female to male life expectancy at birth, and the percentage of the population with access to safe water (see also Rosegrant et al. 2001; Smith and Haddad 2000).

The “water” side of the IMPACT-WATER model interacts with the “food” module by simulating the reductions in area and yield that result from deficits in water supply – given that the total water requirements for maximum potential yield may not be met and other non-agricultural demands for water that must be satisfied within the particular basin. Whereas the “food” model simulates trade in a non-spatial way, the “water” model allocates water in each spatial unit, according to the crop irrigation, livestock, industrial and municipal demands that are projected.

IMPACT-WATER generates annual projections for irrigation, livestock, and nonagricultural water withdrawals and depletion as well as irrigated and rainfed crop area, yield, production, demand for food, feed and other uses, prices, and trade; and livestock numbers, yield, production, demand, prices, and trade.

The model incorporates data from FAOSTAT (FAO 2003), commodity, income, and population data and projections from the World Bank (WB 2000), the Millennium Ecosystem Assessment, and the UN (UN 2000) and USDA (USDA 2000), a system of supply and demand elasticities from literature reviews and expert estimates (see Rosegrant et al., 2001), and rates for malnutrition from ACC/SCN (1996)/WHO (1997) and calorie-child malnutrition relationships developed by Smith and Haddad (2000).

5.2.1.2. The IMAGE 2.4 Model

The IMAGE 2.4 framework describes global environmental change in terms of its cause-response chain, and belongs to the model family of integrated assessment models. The IMAGE model consists of two major parts: the socio-economic system, elaborating on future changes in demographics, economy, agriculture and the energy sector, and the biophysical system, comprising land cover and land use, atmospheric composition and climate change (see Figure 5.2.1.2-1). The IMAGE model focuses on linking those two parts through emissions and land allocation. In this report, land allocation follows inputs from the IMPACT-WATER model, allowing an assessment of the environmental consequences of changes in the agricultural sector.

One of the crucial parts of the IMAGE 2.4 model is the energy model TIMER. The TIMER model describes the chain, going from demand for energy services (useful energy) to the supply of energy itself through different primary energy sources and related emissions. The steps are connected by demand for energy and by feedbacks, mainly in the form of energy prices. The TIMER model has three types of sub-models: (i) the energy demand model; (ii) models for energy conversion (electricity and hydrogen production) and (iii) models for primary energy supply. The final energy demand (for five sectors and eight energy carriers) is modelled as a function of changes in population, economic activity and energy efficiency. The model for electricity production simulates investments in various electricity production technologies and their use in response to electricity demand and to changes in relative generation costs.

Supply of all primary energy carriers is based on the interplay between resource depletion and technology development. Technology development is introduced either as learning curves (for most fuels and renewable options) or by exogenous technology change assumptions (for thermal power plants). To model resource depletion of fossil fuels and uranium, several resource categories that are depleted in order of their costs are defined. Production costs thus rise as each subsequent category is exploited. For renewable energy options, the production costs depend on the ratio between actual production levels and the maximum production level.

The TIMER model also simulates the potential importance of biomass as an energy category. The structure of the biomass sub-model is similar to that of the fossil fuel supply models but with a few important differences (see also Hoogwijk 2004). First, in the bioenergy model depletion is not governed by cumulative production but by the degree to which available land is being used for commercial energy crops. Available land is defined as abandoned agricultural land and part of the natural grasslands in divergent land use variants for the 21st century and is based on IMAGE alternative variant calculations. The land is categorized according to productivity levels which are assumed to reflect the cost of producing primary biomass. The biomass model also describes the conversion of biomass (residues, wood crops, maize and sugar cane) to two generic secondary fuel types: bio-solid fuels (BSF) and bio-liquid fuels (BLF). The solid fuel is used in the industry and power sector, and the liquid fuel in other sectors, in particular, transport.

The output of TIMER is affecting the biophysical system of IMAGE through land use changes (for bioenergy) and emissions (from the energy sector). Changes in the food production are taken from IMPACT-WATER. The land cover model of IMAGE simulates the change in land use and land cover in each region driven by demands for food, including crops, feed, and grass for animal agriculture, timber and biofuels in addition to changes in climate. The model distinguishes 14 natural and forest land cover types and 6 man-made land cover types. A crop module based on the FAO agroecological zones approach computes the spatially explicit yields of the different crop groups and grass and the areas used for their production, as determined by climate and soil quality (Alcamo et al. 1998). In case expansion of agricultural land is required, a rule-based ‘suitability map’ determines which grid cells are selected. Conditions that enhance the suitability of a grid cell for agricultural expansion includes potential crop yield (which changes over time as a result of climate change and technology development), proximity to other agricultural areas and proximity to water bodies. The land cover model also includes a modified version of the BIOME model (Prentice et al. 1992) to compute changes in potential vegetation. The potential vegetation is the equilibrium vegetation that should eventually develop under a given climate. The shifts in vegetation zones, however, do not occur instantaneously. In IMAGE 2.4 such dynamic adaptation is modelled explicitly according to the algorithms developed by Van Minnen et al. (2000). The land use system is modelled on a 0.5 by 0.5 degree grid.

Both changes in energy consumption and land use patterns give rise to emissions that are used to calculate changes in atmospheric concentration of greenhouse gases and some atmospheric pollutants such as nitrogen- and sulphur oxides. Changes in concentration of greenhouse gases, ozone precursors and species involved in aerosol formation form the basis for calculating climatic change. Next, changes in climate are calculated as global mean changes which are downscaled to the 0.5 by 0.5 degree grids using patterns generated by General Circulation Models. An important aspect of IMAGE is that it accounts for important feedbacks within the system, such as temperature, precipitation and atmospheric CO_2 feedbacks on the selection of crop types and the migration of ecosystems. This allows for calculating changes in crop and grass yields and as a consequence the location of different types of agriculture, changes in net primary productivity and migration of natural ecosystems.

The IMAGE model has been applied to a variety of global studies. The specific issues and questions addressed in these studies have inspired the introduction of new model features and capabilities, and in turn, the model enhancements and extensions have broadened the range of applications that IMAGE can address. Since the publication of IMAGE 2.1 (Alcamo et al. 1998), subsequent versions and intermediate releases have been used in most of the major global assessment studies and other international analyses, like the IPCC Special Report on Emissions Scenarios (SRES: Nakicenovic et al. 2000), UNEP’s Third and Fourth Global Environment Outlook, The Millennium Ecosystem Assessment (MEA, 2006), the Second Global Biodiversity Outlook (Alkemade et al. 2006a) and Global Nutrients from Watersheds (Seitzinger et al. 2005). For more information on IMAGE, the reader is referred to MNP (2006).

5.2.1.3 WATERSIM

Broadly speaking the model consists of two integrated modules: the ‘food demand and supply’ module, which is adapted from IMPACT (Rosegrant, Cai and Cline 2002); and the ‘water supply and demand’ module which uses a water balance based on the Water Accounting framework (Molden 1997) underlying PODIUM combined with elements from the IMPACT-WATER model (Cai and Rosegrant 2002).

The model estimates food demand as a function of population, income and food prices. Crop production depends on economic variables such as crop prices, inputs and subsidies on one hand and climate, crop technology, production mode (rainfed versus irrigated) and water availability on the other. Irrigation water demand is a function of the food production requirement and management practices, but constrained by the amount of available water.

Water demand for irrigation, domestic purposes, industrial sectors, livestock and the environment are estimated at basin scale. Water supply for each basin is expressed as a function of climate, hydrology and infrastructure. At basin level, hydrologic components (water supply, usage and outflow) must balance. At the global level food demand and supply are leveled out by international trade and changes in commodity stocks. The model iterates between basin, region and globe until the conditions of economic equilibrium and hydrologic water balance are met.

Spatial disaggregation. In order to adequately model hydrology, it makes most sense to use river basin as basic spatial unit. When it comes to food policy analysis, administrative boundaries should be used (trade and policymaking happens at national level, not at river basins scale). Therefore, WATERSIM takes a hybrid approach to its spatial unit of modeling. First, the world is divided into 125 major river basins of various sizes with the goal of achieving accuracy with regard to the basins most important to irrigated agriculture. Next the world is divided into 115 economic regions including mostly single nations with a few regional groupings of nations. Finally the river basins were intersected with the economic regions to produce 282 FPU’s. The hydrological processes are modeled at basin scale by summing up relevant parameters and variables over the FPU’s that belong to one basin. Similarly economic processes are modeled at regional scale by summing up the variables over the FPU’s belonging to one region.

Temporal scale. The baseline year is 2000. Economic processes are modeled at an annual time step, while hydrological and climate variables are modeled at a monthly time-step. Crop related variables are either determined by month (crop ET) or by season (yield, area). The food supply and demand module runs at region level on a yearly time-step. Water supply and demand runs at FPU level at a monthly time-step. For the area and yield computations the relevant parameters and variables are summed over the months of the growing season.

5.2.1.4 GTEM

GTEM is a multi-region, multi-sector, dynamic, general equilibrium model of the global economy. The key structural features of GTEM include:

- A computable general equilibrium (CGE) framework with a sound theoretical foundation based on microeconomic principles, that accounts for economic transactions occurring in the global economy – the theoretical structure of the model is based on the optimizing behavior of individual economic agents (for example, firms and households), as represented by the model equation systems, the database and parameters.
- A recursively dynamic analytical framework characterized by capital and debt accumulation and endogenous population growth, which enables the model to account for transactions between sectors and trade flows between regions over time – as a dynamic model, it accounts for the impacts of changes in labor force and investment on a region's production capabilities.
- The representation of a large number of economies (up to 87 regional economies corresponding to individual countries or country groups) that are linked through trade and investment flows, allowing for detailed analysis of the direct as well as flow-on impacts of policy and exogenous changes for individual economies – the model tracks intra-industry trade flows as well as bilateral trade flows, allowing for detailed trade policy analysis.
- A high level of sectoral disaggregation (up to 67 broad sectors, with an explicit representation of 13 agricultural sectors) that helps to minimize likely biases that may arise from an undue aggregation scheme.
- A bottom-up 'technology bundle' approach adopted in modeling energy intensive sectors, as well as interfuel, inter-factor and factor-fuel substitution possibilities allowed in modeling the production of commodities – the detailed and explicit treatment of the energy and energy related sectors makes GTEM an ideal tool for analyzing trends and policies affecting the energy sector.
- A demographic module that determines the evolution of a region's population (and hence, the labor supply) as a function of fertility, migration and mortality, all distinguished by age group and/or gender.
- A detailed greenhouse gas emissions module that accounts for the major gases and sources, incorporates various climate change response policies, including international emissions trading and quota banking, and allows for technology substitution and uptake of backstop technologies.

For each regional economy, the GTEM database consists of six broad components: the input–output flows; bilateral trade flows; elasticities and parameters; population data; technology data; and anthropogenic greenhouse gas emissions data. For the input–output flows and bilateral trade data, and the key elasticities and parameters values, the GTAP version 6 database[1] has been adapted. The databases for population, energy technology and anthropogenic greenhouse gas emissions – all by GTEM region – have been assembled by ABARE using information from a range of national and international sources. The base-year for GTEM is 2001. For this exercise, the model database has been aggregated to 21 regions that correspond to the five IAASTD sub-global regions, and to 36 commodities that include 12 agricultural sectors and one fisheries sector.

GTEM equations are written in log-change forms and the model is solved recursively using the GEMPACK suite of programs[2]. For IAASTD modeling purposes, the GTEM projection period expends to 2050. The model simulation provides annual projections for a host of variables including gross regional product (a GDP equivalent for GTEM regional economies), aggregate consumption, investment, exports and imports; sectoral production, employment and other input demands; final demand and trade for commodities; and greenhouse gas emissions by gas and by source.

GTEM has been applied to a wide range of medium-to long-term policy issues or special events [3]. A detailed description of the theoretical structure of GTEM can also be found at ABARE's website; also see Ahammad and Mi (2005) for an update on the modeling of GTEM agricultural and forestry sectors. The GEMPACK codes for the standard version of GTEM can be downloaded from ABARE's website.

5.2.1.5 CAPSiM

CAPSiM is a partial equilibrium model for 19 crop, livestock and fishery commodities, including all cereals (4 types), sweet potato, potato, soybean, other edible oil crops, cotton, vegetable, fruits, other crops, 6 livestock products, and 1 aggregate fishery sector, which together account for more than 90% of China's agricultural output. CAPSiM is simultaneously run at the national, provincial (31) and household (by different income groups) level. It is the first comprehensive model for examining the effects of policies on China's national and regional food economies, as well as household income and poverty.

CAPSiM includes 2 major modules for supply and demand balances for each of 19 agricultural commodities. Supply includes production, import, and stock changes. Demand includes food demand (specified separately for rural and urban consumers), feed demand, industrial demand, waste, and export demand. Market clearing is reached simultaneously for each agricultural commodity and all 19 commodities (or groups).

[1] See http://www.gtap.agecon.purdue.edu

[2] http://www.monash.edu.au/policy/gempack.htm

[3] Fr more, visit ABARE's website: www.abareeconomics.com.au

Production equations, which are decomposed by area and yield for crops and total output for meat and other products, allow producer’s own- and cross-price market responses, as well as the effects of shifts in technology stock on agriculture, irrigation stock, three environmental factors--erosion, salinization, and the breakdown of the local environment, and yield changes due to exogenous shocks of climate and other factors (Huang and Rozelle 1998a; deBrauw et al. 2004). Demand equations, which are decomposed by urban and rural consumers, allow consumer own- and cross-price market responses, as well as the effects of shifts in income, population level, market development and other shocks (Huang and Rozelle, 1998b; Huang and Bouis 2001; Huang and Liu 2002).

Most of the elasticities used in CAPSiM were estimated econometrically at CCAP using state-of-the-art econometrics, including assumptions for consistency of estimated parameters with theory. Demand and supply elasticities vary over time and across income groups. Recently, CAPSiM shifted its demand system from double-log to an “Almost Ideal Demand System” (AIDS, Deaton and Muellbauer 1980).

CAPSiM generates annual projections for crop production (area, yield and production), livestock and fish production, demand (food, feed, industrial, seed, waste, etc), stock changes, prices and trade. The base year is 2001 (average of 2000-2002) and is currently being updated to 2004.

5.2.1.6 GEN-CGE

GEN-CGE can be used to decompose the effects of policy changes (Sinha et al. 2003 and Sinha, Siddique and Sangeeta 2003). The model can evaluate feasible policies or “policy packages” in a systematic fashion. Further the model can assist in policy formulation by permitting comparisons across the set of compatible policy combinations. The CGE models are explicitly structural (do not encounter the identification problems associated with econometric models).Such a structure forces modellers to be explicit about assumptions (which can be changed). The model provides considerable scope for altering aggregation (across sectors, institutions, households). CGE models are structured and driven by a SAM base, and therefore require data to be exact and consistent. The GEN-CGE model follows roughly the standard neoclassical specification of general equilibrium models (for example, see the models described in Harriss-White and Sinha 2007; Sinha and Adam 2006). Markets for goods, factors, and foreign exchange are assumed to respond to changing demand and supply conditions, which in turn are affected by government policies, the external environment, and other exogenous influences. Sectoral product prices, factor prices, and the foreign exchange rate are defined relative to a price index, which serves as the numeraire. The production technology is represented by a set of nested CD (Cobb-Douglas) and Leontief functions. Domestic output in each sector is a Leontief function of value added and aggregate intermediate input use. Value added is a Cobb-Douglas function of the primary factors, like capital and labour. Fixed input coefficients are specified in the intermediate input cost function. The model assumes imperfect substitutability, in each sector, between the domestic product and imports. All firms are assumed to be price takers for all imports. Similarly, each sector is assumed to produce differentiated goods for the domestic and export markets. The composite production good is a CET (constant elasticity of transformation) aggregation of sectoral exports and domestically consumed products. Such product differentiation permits two-way trade and gives some realistic autonomy to the domestic price system. Based on the small country assumption, domestic prices of imports and exports are expressed in terms of the exchange rate and their foreign prices, as well as the trade tax. The import tax rate represents the sum of the import tariff, surcharge, and applicable sales tax for each commodity group. The foreign exchange rate, an exogenous variable in the base model, is in real terms. The deflator is a price index of goods for domestic use; hence, this exchange rate measure represents the relative price of tradable goods vis-a-vis non-tradables (in units of domestic currency per unit of foreign currency).

5.2.1.7 Dynamic Livestock Production System Classification Scheme

Model structure. The reference run includes a separate module for livestock production systems. The module uses a dynamic livestock production system classification scheme, based on a "map-able" version of the global livestock systems classification of Seré and Steinfeld (1996), which can be rerun in response to different variations of climate and population change, to give very broad-brush indications of possible changes in livestock system distribution in the future (Thornton et al. 2002, 2006).

The livestock production system proposed by Seré and Steinfeld (1996) is made up of the following types:

- Landless monogastric systems, in which the value of production of the pig/poultry enterprises is higher than that of the ruminant enterprises.
- Landless ruminant systems, in which the value of production of the ruminant enterprises is higher than that of the pig/poultry enterprises.
- Grassland-based systems, in which more than 10% of the dry matter fed to animals is farm produced and in which annual average stocking rates are less than 10 temperate livestock units per hectare of agricultural land.
- Rainfed mixed farming systems, in which more than 90% of the value of non-livestock farm production comes from rainfed land use, including the following classes.
- Irrigated mixed farming systems, in which more than 10% of the value of non-livestock farm production comes from irrigated land use.

The grassland-based and mixed systems are further categorized on the basis of climate: arid –semiarid (with a length of growing period (LGP) < 180 days), humid-subhumid (LGP > 180 days), and tropical highlands/temperate regions. This gives 11 categories in all. This system has been mapped using the methods of Kruska et al. (2003), and is now regularly updated with new datasets (Kruska 2006). For land use/cover, we use version 3 of the Global Land Cover (GLC) 2000 data layer (JRL 2005). For Africa, this included irrigated areas, so this is used instead of the irrigated areas database of Döll and Siebert (2000), which is used for Asia and Latin America. For human population, we use new 1-km data (GRUMP 2005). For length of growing period, we use a layer developed from the WorldCLIM 1-km data for 2000 (Hijmans et al. 2005), together with a new "highlands" layer for the same year based on the same dataset (Jones and Thornton 2005). Cropland, rangeland, and urban areas are based on GLC 2000; and rock and sand areas are included as part of rangelands. To look at alternative futures, the GRUMP population data is pro-rata allocated based o the UN medium-variant population data for each year by country. LGP changes to 2030 and 2050 are projected using downscaled outputs of coarse-gridded GCM outputs, using methods outlined in Jones and Thornton (2003).

The original LGP breakdown into arid-semiarid, humid-subhumid and highland-temperate areas has since been expanded to include hyper-arid regions, defined by FAO as areas with zero growing days. This was done because livestock are often found in some of these regions in wetter years when the LGP is greater than zero. Areas in GLC 2000 defined as rangeland but having a human population density greater than or equal to 20 persons per km^2 as well as a LGP greater than 60 (which can allow cropping) are now included in the mixed system categories.

5.2.1.8 EcoOcean

EcoOcean is based on EcoPath with EcoSim approach, which is thoroughly documented in the scientific literature, see e.g., Christensen and Walters (2004). EwE has three main components: Ecopath – a static, mass-balanced snapshot of the system; Ecosim – a time dynamic simulation module for policy exploration; and Ecospace – a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas. The Ecopath software package can be used to

- Address ecological questions;
- Evaluate ecosystem effects of fishing;
- Explore management policy options;
- Evaluate impact and placement of marine protected areas; and
- Evaluate effect of environmental changes.

The foundation of the EwE suite is an Ecopath model (Christensen and Pauly 1992; Pauly, Christensen and Walters 2000), which creates a static mass-balanced snapshot of the resources in an ecosystem and their interactions, represented by trophically linked biomass 'pools'. The biomass pools consist of a single species, or species groups representing ecological guilds. Pools may be further split into linked ontogenetic groups. Ecopath data requirements are relatively simple, and generally already available from stock assessment, ecological studies, or the literature: biomass estimates, total mortality estimates, consumption estimates, diet compositions, and fishery catches.

The parameterization of an Ecopath model is based on satisfying two ‘master’ equations. The first equation describes the how the production term for each group can be divided:

Production = catch + predation + net migration + biomass accumulation + other mortality

It is the aim with the Ecopath model to describe all mortality factors; hence the ‘other mortality’ should only include generally minor factors as mortality due to old age, diseases, etc. The second ‘master’ equation is based on the principle of conservation of matter within a group:

Consumption = production + respiration + unassimilated food

In general, an Ecopath model requires input of three of the following four parameters: biomass, production/biomass ratio (or total mortality), consumption/biomass ratio, and ecotrophic efficiency for each of the functional groups in a model. Here, the ecotrophic efficiency expresses the proportion of the production that is used in the system, (i.e. it incorporates all production terms apart from the ‘other mortality’). If all four basic parameters are available for a group the program can instead estimate either biomass accumulation or net migration. Ecopath sets up a series of linear equations to solve for unknown values establishing mass-balance in the same operation.

Ecosim provides a dynamic simulation capability at the ecosystem level, with key initial parameters inherited from the base Ecopath model. The key computational aspects are in summary form:

- Use of mass-balance results (from Ecopath) for parameter estimation;
- Variable speed splitting enables efficient modeling of the dynamics of both ‘fast’ (phytoplankton) and ‘slow’ groups (whales);
- Effects of micro-scale behaviors on macro-scale rates: top-down vs. bottom-up control incorporated explicitly.
- Includes biomass and size structure dynamics for key ecosystem groups, using a mix of differential and difference equations. As part of this EwE incorporates:
  - age structure by monthly cohorts, density- and risk-dependent growth;
  - Numbers, biomass, mean size accounting via delay-difference equations;
  - Stock-recruitment relationship as ‘emergent’ property of competition/predation interactions of juveniles.

Ecosim uses a system of differential equations that express biomass flux rates among pools as a function of time varying biomass and harvest rates, (see Walters, Christensen and Pauly, 1997; Walters et al., 2000). Predator prey interactions are moderated by prey behavior to limit exposure to predation, such that biomass flux patterns can show either bottom-up or top down (trophic cascade) control (Walters et al., 2000). Conducting repeated simulations Ecosim simulations allows for the fitting of predicted biomasses to time series data, thereby providing more insights into the relative importance of ecological, fisheries and environmental factors in the observed trajectory of one or more species or functional groups.

EwE also has the ability to model trophic and fishing effort dynamics in an explicit spatial setting. The spatial component of EwE, Ecospace, is essentially a grid or two-dimensional matrix of 'cells', each cell incorporating an Ecosim model (initially identical as Ecosim inherits its parameters from Ecopath) and expressed at the user interface level as a map. Each cell in the map, excluding land cells, is linked through two processes: dispersal of organisms and the redistribution of fishing effort due to changing profit patterns and/or the creation of areas closed to fishing (Walters, Pauly and Christensen, 1999). The map can be derived from GIS, with layers of relative fishing cost (effort 'avoids' high cost cells, for example, cells far from their home port that require high fuel costs to reach); patterns of relative primary production; patterns of habitats to which biomass pools and fishing fleets can be assigned; and areas closed to fishing (fleet and season specific). This allows for the exploration of policies that include spatial components, including the evaluation of the size and placement of marine protected areas (MPAs). The Ecospace module is used for the EcoOcean simulations.

The EwE approach, its methods, capabilities and pitfalls are described in detail by Christensen and Walters (2004).

In EcoOcean the FAO statistical areas provide a manageable spatial resolution for how to cut the world into a reasonable number of spatial units (Figure 5.2.1.8-1), each characterized by having limited connection to neighboring areas and each with a manageable number of fleet categories (5) for which it may be possible to evaluate tradeoff effects. Similarly 43 trophic groups were considered as representing the different functional groups that are found in most areas of the world's oceans (Table 5.2.1.8-1).

For each of the 19 regions we use information from the *Sea Around Us* catch database by year to fit the catches. Fleet size data from FAO and regional agencies combined with the Sea Around Us gear analysis is used to approximate fishing effort (the major driver/input into the model) for the fleet categories as described below.

The regional models are tuned by fitting to the catches from 1950 to the present. Once the model have been tuned and are deemed to perform satisfactorily, we use them to perform a series of evaluations based on specified variants. The results, will include predictions of

- the landings for each species group;

- the real and nominal value of the landings expressed in a common currency (but based on regional or national fish prices);
- diversity index of the landings; and
- marine trophic index for the landings.

5.2.2. Description of qualitative methods/tools

Although quantitative models have merits in that they provide clear-cut numeric results, there are a number of aspects that cannot be translated into numbers easily or not at all. The quantitative models described above cannot cover some of the essential aspects of this assessment since those models have been built for specific analytical purposes with limited scope. Thus, qualitative analyses play an important role in this forward looking chapter of the assessment. What is needed for the forward looking impact analyses is a systematic approach where the components of the analyses such as inputs, outputs, external drivers and causal relationships among those variables are treated in a transparent manner to ensure that results can be interpreted logically with minimum ambiguity.

There are many established methods that can make use of non-numerical information in the field of scientific impact assessments. Apart from models, visual schematic descriptions such as causal diagrams, tree-chart classifications and input-output tables are widely used for sorting out complex (inter)relationships. Among the modeling tools that seem to be suitable for this type of assessment that requires qualitative data, ‘system dynamics’ would be the most common one. The models used for a report for the Club of Rome and its revisions are widely known. The results provide strong messages of the possible catastrophic failure of global human systems including agricultural systems under certain conditions (Meadows, Randers and Meadows 2004). ‘Qualitative differential equations’ is another potential method as it can handle qualitative variables with directions, thresholds, ranges and states (Kuipers 1994). Those models are able to identify the consequences of tradeoffs and synergies resulting from complicated causal relationships including feedbacks and dynamics. However, weaknesses include a lack of objective verification of both design (conceptualization) and solution (parameterization).

For this assessment, a large number of numeric and non-numeric variables surrounding AKST have to be considered and must be evaluated in a very broad context. Such a task is generally beyond the capability of thematic qualitative tools. At the same time, it is crucial to avoid possibly misleading information through the application of incomplete modeling tools. Therefore, a compromise is sought in the following qualitative sections. The method used is neither an integrated nor formal model/tool. For each emerging theme, numeric and non-numeric inputs, some of which are the outputs of quantitative model exercises, are collected. Then, directions and pathways of the impacts are carefully examined based on the given storylines of major influencing drivers through the evaluation of past literature, which provide insights on the causal relationships among the variables. In the end, possible consequences at around the year 2050 are described with the help of literature indicating analogous ideas. This process reasonably assures the quality of the qualitative assessment with an acceptable logical and systematic basis.

5.2.3 Justification of selected models

5.2.3.1 Partial equilibrium agricultural sector models

McCalla and Revoredo (2001) who assessed food projections models concluded that 1) projections with shorter time horizons are more accurate than for longer horizons; 2) projections are more accurate for aggregations of components—regions, commodities—than for the component parts themselves; and 3) that projections for larger countries tend to be more accurate than for smaller countries. The authors identify data problems and inaccurate outcomes for individual countries with severe food security problems. Moreover, for developed countries, the modeling of rapidly changing, complex domestic policies, including quantitative border restrictions, is a major issue of concern. Rosegrant and Meijer (2001) point out for the IMPACT model, that main discrepancies in the projections are due to short-term variability, such as the collapse of the Soviet Union or major weather events, which cause large departures from fundamental production and demand trends—variability that long-term projection models are not intended to capture.

Modeling approaches require 1) consistent and clearly defined relations among all variables, 2) a transfer of the structure of interrelationships among variables, which was consistent in the past, to the future; 3) changes in complex cross-relationships among variables over time, 4) the simultaneous and managed interaction of many variables and the maintenance of consistent weights, and 5) an organized and consistent treatment of massive numbers of variables and large amounts of data (McCalla and Revoredo 2001).

Food projection models make major contributions in exploring future food outcomes based on alternative assumptions about crucial exogenous and endogenous variables. Results from alternative policy variants can be used to alert policymakers and citizens to major issues that need attention to avoid adverse food security outcomes. A test for the usefulness of these models may therefore well be whether or not the analysis enriched the policy debate (McCalla and Revoredo 2001).

While models can make important contributions at the global and regional levels, increasingly food insecurity will be concentrated in individual countries with high population growth, high economic dependence on agriculture, poor agricultural resources and few alternative development opportunities. These countries continue to be overlooked in regional and global studies, as on aggregate, resources are sufficient to meet future food demands.

Whereas the methodology and underlying supply and demand functional forms are well established in the literature and have been validated through projections of historical trends, driving forces and elasticities underlying the commodity and country and regional-level supply and demand functions towards the future continue to be debated in the literature. Moreover, income and population growth projections, as well as lasting external shocks contribute to the uncertainty of projection outcomes.

5.2.3.2 CGE models

Applied general equilibrium (AGE) models are widely used as an analytical framework to study economic and environmental issues of national, regional and global dimension. These models provide an economy-wide perspective and are very useful when:

- The numerous, and often intricate, interactions between various parts of an economy are of critical importance. As for agriculture, such interactions occur between agriculture sectors themselves (e.g., competing for limited productive resources including various types of land) as well as between agricultural sectors with other sectors/actors which either service agricultural sectors or operate in the food and fiber chain including downstream processors, traders and distributors, final consumers and governments (e.g., public policies).
- The research objective is to analyze counterfactual policy alternatives and/or plausible scenarios about how the future is likely to evolve. Examples could include the implications for agriculture of likely multilateral trade liberalization in the future; or the implications for agriculture of future growth in food demand and shifts in consumer preference; or the role of bioenergy in climate change mitigation and implications for agriculture.

For analyzing such issues, the modeling of sectoral interactions (e.g., between agriculture, energy, processing and manufacturing as well as services), trade (both domestic and international), and existing policies is fundamental. Given their economy-wide coverage, some variant of this type of models has become an integral part of the Integrated Assessment models (e.g., IMAGE) used in the IPCC Assessments.

Strengths of CGE models include that they provide a useful approach to analyzing the interaction between different sectors such as agricultural sectors, manufacturing sectors and services. In their conventional usage, CGE models are flexible price models and are used to examine the impact of relative price changes on resource allocations (of goods and factors) across a range of economic agents. Thus, in addition to providing insights into the economy-wide general equilibrium effects of policy changes, CGE models allow key inter-industry linkages to be examined.

5.2.3.3 Integrated assessment models

Integrated Assessment models (IAMs) are strong tools to address global environmental change in a consistent manner, using feedbacks from climate change, land use change and changes in atmospheric composition. They provide information on a global scale and take into account the regional interrelations on many aspects like energy demand, land use change and air quality. IAMs are strong in providing insights in consequences of specific policy options and are good discussion support tools.

Although the integration in most models is high from the perspective of the limited (environmental) problems they were developed for, their integration from a perspective of the IAASTD's objective is still rather low. In particular, the number of feedbacks that are included from ecological changes on social-economic drivers are scarce (some exceptions are the impacts of food production and climate policy on socioeconomic drivers).

The processes that change ecosystems and their services mostly occur at rather detailed level. Models need to have regional specificity/be spatially explicit. A tendency to increase the level of geographic explicit information in models (for instance by using a detailed grid) can be seen in literature. Understanding interregional links, but also regional differences will be an important research issue for integrated modeling in the coming years. A nested approach to integrated assessment modeling could be a helpful way forward, in which global models provide context for detailed, regional (ecological) models.

Uncertainties are a key element in IAMs, given the high complexity and its focus on decisionmaking. These uncertainties include, for example, variability of parameters, inaccuracy of model specification or lack of knowledge with regard to model boundaries. Although the existence of uncertainties has been recognized early in the process of developing IAMs, in many of them uncertainty analysis is included only partially or still not at all. Several new projects have been set-up in working on uncertainties in a more specific way.

5.2.3.4 Fisheries models

Fisheries models, such as EcoOcean allow managers to explore how marine systems, especially, fisheries might respond to policy changes at the ocean basin or regional scale which most other fisheries models do not do. This model reduces what is a highly complex and dynamic system that covers 70% of the earth's surface to 19 regions and describes the world's fisheries for the last 50 years with reasonable accuracy (often with 10% or less of what is recorded by FAO between 1950 and 2003). A complete marine system is modeled that ranges from detritus to top predators including marine mammals and seabirds, and provides sufficient detail to assess changes but avoids complexity so that it is computationally possible. The predator-prey relationships between functional groups are also accounted for in the model. Because EcoOcean is based on the Ecopath suite of software and uses a trophic structure as well as predator-prey relationships, consumption rates and fishing effort its provides a description of the ecological dynamics of the system over time and it can also provide an indication of how the diversity of the fisheries will also change over time.

Regarding the weaknesses of such models, the functional groups of EcoOcean are broad groupings of marine organisms, which limits describing in detail how a particular species or groups of species may respond to a specific policy intervention. The model is based on biomass from published time series studies and does not necessarily include a comprehensive suite of species to provide an estimate of the biomass for each functional group. The FAO regions used in the model are broad and cannot include climate/oceanographic features. This limitation makes it difficult to accurately model the small pelagic fish group (e.g. anchoveta) which is highly influenced by changes in oceanographic conditions as seen in the offshore upwelling system in Peru. The tuna groups do not differentiate between long-lived slow-growing species such as bluefin tuna and short-lived ones such as yellow-fin. This can result in overestimation of tuna landings as well as resilience. Effort, based on 7 fleets, is the driver of the model and while some effort is gear specific such as tuna long-line and tuna purse seiners, effort for the demersal fleet is based on a range of gear including trawlers, nets, traps and hook and line which can be difficult to map to the narrative storylines. The lack of artisanal fishing information especially in Asia and several regions in Africa results in some underestimation of landings and effort. Antarctic and Arctic models are incomplete as there is poor catch, effort and biomass data available for these areas. Consequently they are not included in this assessment.

5.3 Description of Reference World, Including Quantification

5.3.1 Rationale of reference world

The reference case is a no-new policies scenario by design. It imagines a world developing over the next decades as it does today, without anticipating deliberate interventions requiring new or intensified policies in response to the projected developments. By implication, the baseline is not necessarily the most plausible future development. For example, the baseline assumes no new policies in the direction of trade liberalization or reform of agricultural subsidies beyond what has been agreed today. The agreed, instrumented policies will continue to have effect, but beyond this no new impulses are assumed in the baseline. This is not a plausible continuation of the “real world”, but it does give a good overview of the consequences of such a development. In Section 5.5 plausible policy interventions are simulated. In the results in subchapter 5.4, we will focus on the differences between the reference case and the policy runs. In the subchapters below, more information on the reference world is given.

5.3.1.1 Population

In the reference case the global population increases from slightly more than 6.1 billion in 2000 to over 8.2 billion in 2050. Most of the growth is concentrated in middle-income and low-income countries like

Brazil, India, China and Russia and the rest of the world. Population growth in high-income countries is small. These data are taken from the medium variant projections of the UN (UN 2005), based on an assessment of previous studies (see also Chapter 4). For details at the regional, IAASTD level, please see Table 5.3.1.1-1 and Figure 5.3.1.1-1. Alternative scenarios of the UN show slightly higher and lower growth rates, ranging in 2050 from about 7.5 to 10.5 billion people worldwide.

5.3.1.2 Overall Economic growth

Economic growth follows loosely the assumptions of the TechnoGarden Scenario of the Millennium Ecosystem Assessment (MEA 2005a). Income values are expressed as MER-based values. The economic growth assumptions of the TechnoGarden scenario are near the mid-range growth scenarios in literature for the world as a whole and most regions. In some regions the scenario is a relatively optimistic scenario (e.g. sub-Saharan Africa). A comparison of economic growth projections in other scenarios is made in Chapter 4. Information at the regional level is provided in Table 5.3.1.2-1 and Figure 5.3.1.2-1.

Box: Scenario in India

In the reference world the growth in agriculture would be slightly lower than the current long-term trend in Indian agricultural growth (i.e., 3 percent) in 2025 and would be slightly higher in 2050. Overall growth increases in the reference period with about 10 percent in the first 25 years and by about 8 percent in the next 25 years till 2050. This is accompanied with healthy investment and decelerating inflation that reaches the 2-percent level by 2050. So, the macro picture is of robust and stable growth in the economy in the reference world. However, the rural-urban divide continues in the first 25 years as urban households continue to improve their real income, but in the longer run this gap declines. Moreover, the wage gap between men and women workers in the first 25 years declines. In the reference world the consumption of the lower deciles of the population improves continuously. Additional details are provided in Box Tables 5.3.1.2-2 and 5.3.1.2-3.

5.3.1.3 Agricultural productivity

Agricultural productivity values are based on the Millennium Ecosystem Assessment [MEA] (TechnoGarden Scenario) and the recent FAO interim report projections to 2030/2050 (FAO 2006a). MA assumptions have been adjusted from the TG assumptions to allow for conformity to FAO projections of total production and per-capita consumption in meats and cereals, and to our own expert assessment. The main recent developments regarding technological change with continued slowing of growth overall have been taken into account. Growth in numbers and slaughtered carcass weight of livestock has been adjusted in a similar fashion.

5.3.1.4 Nonagricultural productivity

Growth in non-agricultural sectors is projected to be lower than in agriculture in the reference case. The non-agricultural GDP growth rates are likewise based on the MA TechnoGarden Scenario but with adjustments to align with World Bank medium term projections. While the relatively higher productivity in agriculture reflects largely the declining trends in the agricultural terms of trade, this is not translated into higher output growth in agricultural sectors relative to non-agricultural sectors.

Disparities in growth rates among countries in the developing world will continue to remain high while more developed regions will see more stable growth. Developed regions will see relatively low and stable to declining growth rates between 1 and 4% per year out to 2050. Most of NAE falls into this category while several countries in ESAP (East and Southeast Asia and Pacific) (South Korea, Japan, New Zealand, Australia) and South Africa are quite similar in growth patterns. The LAC region will also see stable growth rates through the projection period, though slightly higher than for developed regions between 3.5 and 4.5% per year out to 2050.

East and Southeast Asia will also see stable to declining GDP growth rates through the projection period, but the rates will remain relatively high between 4 and 7% per year. In particular, China's economy will be slowing from the 10% growth in recent years to a more stable rate of 5.6% per year on average out to 2050. On the other hand, Growth in South Asia will follow the strong reforms and initiatives in India focusing on macroeconomic stabilization and market reforms and should lead to projected improved income growth in that sub-region of 6.5% per year out to 2050. CWANA will also see an increase in GDP growth rates through the projection period though the rates are a bit more modest and will lead to an average 4% per year out to 2050 for the region.

Growth in SSA has been low in the recent past, but there is much room for recovery, which will lead to strong, if modest growth. All of SSA should see an average of 3.9% growth out to 2050. Central and Western SSA will see fairly stable to slightly increasing growth with most countries experiencing annual growth in the 5 to 6% range. The remainder SSA will see strong increases in GDP growth rates as recovery continues. Though many countries in East and Southern SSA will be experiencing growth less than 4% out to 2025, all of these countries are projected to see growth rates reach 6 to 9% by 2050.

5.3.1.5 Livestock

The reference run was implemented in the following way: First, global livestock systems were mapped for the baseline year (2000) and for the reference run for 2030 and 2050, using the reference populations and GCM scenarios for these years. The latter was used to generate surfaces of length of growing period (number of days per year) to 2030 and 2050. In the absence of GCM output for diurnal temperature variation and maximum or minimum temperatures, average monthly diurnal temperature variation was estimated using a crude relationship involving average (24-hour) daily temperature and the average day-time temperature. The 0.5° latitude-longitude grid size of the GCM data was downscaled to 10 arc-minutes (0.17° latitude-longitude), and characteristic daily weather data for the monthly climate normal for the baseline scenario in 2030 and 2050 were generated using the methods of Jones and Thornton (2003).

For the second part of the analysis, the livestock numbers that were generated as output from the IMPACT model at the resolution of the FPUs were converted to live-animal equivalents using country-level ratios of live-to-slaughtered animals from FAOSTAT for 1999-2001 (the same base that was used for the IMPACT simulations). To estimate changes in grazing intensity, the extent of each system type within each FPU was estimated, and livestock numbers within each FPU were allocated to each system within the FPU on a pro-rata basis. Existing global ruminant livestock distribution maps for current conditions were used as a basis for the future scenarios, to derive the livestock allocation proportions appropriate to each system within each FPU.

The 11 livestock systems in the Seré and Steinfeld classification were aggregated to three: rangeland systems, mixed systems (rainfed and irrigated), and "other" systems. These "other" systems include the intensive landless systems, both monogastric (pigs and poultry) and ruminant.

5.3.1.6 Trade

Trade conditions seen today are presumed to continue out to 2050. No trade liberalization or reduction in sectoral protection is assumed for the reference world.

5.3.1.7 Water

Projections for water requirements, infrastructure capacity expansion, and water use efficiency improvement are conducted by IMPACT-WATER. These projections are combined with the simulated hydrology to estimate water use and consumption through water system simulation by IMPACT-WATER (Rosegrant, Cai and Cline 2002). 'Normal' priority has been given to all sectors, with irrigation being the lowest, compared with domestic, industrial and livestock uses.

The hydrology module of the IMPACT-WATER global food and water model derives effective precipitation, potential and actual evapotranspiration and runoff at these 0.5 degree pixels and scale them up to the level of FPUs, which are also used for some of the other analyses, in the spatial operational unit of IMPACT-WATER. Projections for water requirements, infrastructure capacity expansion, and water use efficiency improvement are conducted by IMPACT-WATER. These projections are combined with the simulated hydrology to estimate water use and consumption through water system simulation by IMPACT-WATER (Rosegrant, Cai and Cline 2002).

5.3.1.8 Energy use and production

As discussed in Chapter 4, the energy sector may develop in very different ways. For the reference projection, we have chosen to loosely couple future outcomes to IEA reference scenario – a scenario that lies central in the range of available energy projections. The scenario has been developed using the IMAGE/TIMER model and incorporates the specific assumptions of the IAASTD reference projection with respect to economic growth and land use change. In terms of energy demand growth the IEA scenario is a mid-range scenario compared to full range of scenarios published in literature. For the development of the energy mix, it is a conventional development scenario assuming no major changes in existing energy policies and/or societal preferences. These assumptions are also included in the IAASTD reference projection.

5.3.1.9 Climate Change

Climate change data in the IAASTD scenario is partly developed using the IMAGE scenario (described under results). The IMAGE model uses a global climate model (MAGICC) to calculate global mean temperature change – and uses downscaling techniques and the Hadley‘s Centre HadCM2 run to downscale this data to an 0.5 x 0.5 grid. As shown under results, the climate impacts of the IAASTD reference scenario are very comparable to medium scenarios such as the IPCC-B2 scenario. For the simulations of the reference world, the medium climate sensitivity value is used of the Third Assessment Report (2.5°C), which has been adjusted slightly in the latest IPCC report to a level of 3.0°C (IPCC 2007). Uncertainties in the climate sensitivity are much larger, but are not assessed in the reference world. Specific sensitivity analyses will show the importance of the uncertainties in values of the climate sensitivity.

In parts of the modeling directly results of the HadCM3 model for B2 scenario was used which can be regarded as fully consistent with IMAGE outcomes. The pattern scaling method applied was that of the Climate Research Unit, University of East Anglia (David Viner, personal communications, 2006). The “SRES B2 HadCM3” climate scenario is a transient scenario depicting gradually evolving global climate from 2000 through 2100.

5.3.2 Description of reference world outcomes

5.3.2.1 Food Sector

Food supply and demand. In the reference run, global food production increases 1.26% per year during 2000-2050.[4] This growth is a result of rapid economic growth, slowing population growth, and increased diversification of diets. Growth of demand for cereals as food slows during 2000-2025 and again from 2025-2050, from 1.19% per year to 0.49% per year. Demand for meat products (beef, sheep and goat,

[4] 2050 is average of 2048-2050 unless noted otherwise due to large impact of climate variability on annual outcomes.

pork, and poultry) grow more rapidly, but also slows somewhat after 2025, from 1.78% per year to 0.82% annually. Demand for milk and eggs grow at 1.91 and 1.65% per year during 2000-2050.

Changes in cereal and meat consumption per capita vary significantly among IAASTD region. Results are presented in Figures 5.3.2.1-1 and -2. In both the ESAP and NAE regions, per capita demand of cereals as food declines by about 10 kg over the projections period. On the other hand, demand increases considerably in the SSA region, at 35 kg, and still by 15 kg and 12 kg in the LAC and CWANA, respectively. Recovery and strengthening of economic growth in sub-Saharan Africa will drive relatively fast growth in regional demand for food. In developing Asia, rising incomes and rapid urbanization will change the composition of cereal demand. Per capita food consumption of maize and coarse grains will decline as consumers shift to wheat and rice. As incomes rise further and lifestyles change with urbanization, there will be a secondary shift from rice to wheat. In SSA, growing incomes will lead to a shift from roots and tubers to rice and wheat. Per capita food demand for roots and tubers in SSA is expected to decline from 162 kg to 152 kg between 2000 and 2050, while rice and wheat demand are expected to grow from 18-19 kg to 27 kg each (Table 5.3.2.1-1). The composition of food demand growth across commodities will change dramatically. Total cereal demand is projected to grow by 1,111 million metric tons (mt), or by 60%, of which 48% will be maize; 26%, wheat; 11%, rice; and the reminder, sorghum and other coarse grains.

Demand for meat products continues to grow rapidly across all six IAASTD regions, by 11-17 kilograms per person. The increase is fastest in the LAC and ESAP regions and slowest in the SSA and CWANA regions. Rapid growth in meat and milk demand in most of the developing world will put strong demand pressure on maize and other coarse grains as feed. Globally, cereal demand as feed increases by 489 million metric tons during 2000-2050, 44% of total cereal demand increase (Figure 5.3.2.1-3).

Tables 5.3.2.1-2 to - 5 present results for changes in livestock numbers for beef, sheep and goat, pigs, and poultry, respectively, for the IAASTD regions. The global population of bovines increases from some 1.5 billion animals in 2000 to 3.6 billion in 2050 in the reference run. Substantial increases occur in all regions except NAE: the number of bovines increases five-fold in SSA and three-fold in CWANA, for example. Bovine populations are relatively stable in NAE to 2050 under the baseline scenario. The global population of sheep and goat increases from 1.7 billion in 2000 to 3.3 billion in 2050, again with substantial increases in sub-Saharan Africa to 2050. In CWANA, sheep and goat numbers are also increasing, but at a declining rate of growth. The same is true for ESAP. Sheep and goat numbers rise in NAE to 2030, and then decline somewhat to 2050. In SSA, numbers are continuing to rise quite rapidly in 2050. Globally, pig numbers peak around 2040 and then start to decline, although numbers are still rising in SSA and LAC by 2050. Poultry numbers more than double from 2000 to 2050, to more than 35 billion.

Peak numbers are reached around 2040 in CWANA and NAE, with small declines thereafter, while numbers are continuing to increase rapidly in SSA, LAC and ESAP.

Growth in cereal and meat consumption will be much slower in developed countries. These trends will lead to an extraordinary increase in the importance of developing countries in global food markets.

Sources of food production growth. How will the expanding food demand be met? For meat in developing countries, increases in the number of animals slaughtered have accounted for 80-90% of production growth during the past decade. Although there will be significant improvement in animal yields, growth in numbers will continue to be the main source of production growth. In developed countries, the contribution of yield to production growth has been greater than the contribution of numbers growth for beef and pig meat; while for poultry, numbers growth has accounted for about two-thirds of production growth. In the future, carcass weight growth will contribute an increasing share of livestock production growth in developed countries as expansion of numbers will slow.

For the crops sector, water scarcity will increasingly constrain production with virtually no increase in water available for agriculture due to little increase in supply and rapid shift of water from agriculture in key water-scarce agricultural regions in China, India, and CWANA (see water resources discussion below). Climate change will increase heat and drought stress in many of the current breadbaskets in China, India, and the United States and even more so in the already stressed areas of sub-Saharan Africa.

With declining availability of water and land that can be profitably brought under cultivation, expansion in area is not expected to contribute to future production growth. In the reference run, cereal harvested area expands from 662 million ha in 2000 to 685 million ha in 2025 before contracting to 654 million ha by 2050. The projected slow growth in crop area places the burden to meet future cereal demand on crop yield growth.

Although yield growth will vary considerably by commodity and country, in the aggregate and in most countries it will continue to slow down. The global yield growth rate for all cereals is expected to decline from 1.96% per year in 1980-2000 to 0.97% per year in 2000-2050; in the NAE region, average crop yield growth will decline to 0.87% per year; in CWANA to 0.74% per year, and in ESAP to 0.91% annually, while cereal yield is expected to grow more rapidly in the LAC and SSA regions, at 1.72 and 1.74% per year, respectively.

As can be seen in Figure 5.3.2.1-4, area expansion contributes to food production growth only in sub-Saharan Africa (24%) and in the LAC region (19%) in the reference run.

Table 5.3.2.1-6 presents regional estimates of grazing intensity in the reference world. These were calculated as the number of Total Livestock Units (TLU) (bovines, sheep and goats, where one bovine is equivalent to 1 TLU and one sheep and goat is equal to 0.1 TLU) in the rangeland system per hectare of rangeland system occurring in each FPU. These figures were again aggregated to the five IAASTD regions. Ruminant grazing intensity in the rangelands increases in all regions in the reference run, but there are considerable regional variations. In LAC, for instance, average grazing intensities double from about 0.19 to 0.38 TLU per ha. Most of these increases are due to higher inputs in the grazing systems in the humid and sub-humid savannas. The increases are particularly large in CWANA and SSA (three- and four-fold increases, respectively). Grazing intensities change relatively little in NAE. Again, given typical stocking rates of 10-15 ha per animal in the arid and semi-arid grazing systems, considerable intensification is implied in the humid and sub-humid grazing systems of SSA in the reference run.

It should be noted that the rate of conversion of rangeland to mixed systems will be underestimated in this analysis. The impact of infrastructural development is not taken into account, so the projected changes in grazing intensities are likely to be underestimated as a result. The analysis also makes implicit assumptions about the relative share of production that is projected to come from the rangeland versus the mixed systems in the future, in terms of relative animal numbers. Even so, given the fragility of semi-arid and arid rangelands, particularly in SSA, the massive shifts in production to the wetter and mixed systems that are implied will have considerable environmental impacts in the reference scenario.

Food trade, prices, and food security. Real world prices of most cereals and meat are projected to increase significantly in coming decades, reversing trends from the past several decades. Maize, rice, and wheat prices are projected to increase by 24-41% in the reference world, and prices for beef, pork, and poultry by 9-11%. Only prices for millet and sheep and goat are expected to continue to decline (Table 5.3.2.1-7). Prices of soybean and meals will also increase while those for root and tuber crops will decline more slowly than during the past several years. These substantial changes are driven by new developments in supply and demand—including much more rapid degradation on the food production side, particularly as a result of rapidly growing water scarcity, rapidly growing demands, both food and non-food, combined with slowing yield growth unable to catch up with developments on the supply and demand side.

World trade in food will continue to increase, with trade in cereals projected to increase from 229 million mt annually in 2000 to 612 million mt in 2050, and trade in meat products rising from 15 million mt to 55 million mt. Expanding trade will be driven by the increasing import demand from the developing world, particularly CWANA, ESAP, and SSA, where net cereal imports will grow by 300%, 130%, and 500%, respectively (Figure 5.3.2.1-5). Thus, sub-Saharan Africa will face the largest increase in food import bills despite significant area and yield growth expected during the next 50 years in the reference world.

With rising prices due to the inability of much of the developing countries to increase food production rapidly enough to meet growing demand, the major exporting countries—mostly in the NAE and LAC regions—will provide an increasingly critical role in meeting food consumption needs (Figures 5.3.2.1-5 and -6). The USA, Brazil, and Argentina are a critical safety valve in providing relatively affordable food to developing countries. Maize exports are expected to double in the United States to 100 million mt, and to grow to 24 million mt and 40 million mt, respectively in Argentina and Brazil. Wheat exports are projected to grow to 54 million mt in the United States, and to 27 million mt in Argentina, 30 million mt in Australia, and 34 million mt in Canada. Soybean exports are projected at 21 million mt in Brazil and 14 million mt in Argentina. Net meat exports are expected to double in the United States to 5 million mt, and to increase almost tenfold, to 1.7 million mt in Argentina. Europe will also provide significant exports, mainly because of slow or no growth in demand with stable population. For rice, Myanmar joins Thailand and Vietnam as particularly significant exporters.

Box: Outcomes for China

China's development has major impacts on both current and future food markets. Results using a disaggregated partial agricultural equilibrium model are presented below.

Crop production

Under the reference run, total crop area will gradually decline with rising wage and opportunity cost of land for agricultural production due to industrialization and urbanization as well as slowing population growth, and therefore labor supply. Crop area is projected to decline by about 10% at 0.2% annually over the next 50 years (Box Table 5.3.2.1-1). The decline will be largest for the cereal sector while area for crops with positive income elasticity of demand will expand slightly. Non-staple yield growth in the reference world is expected to continue to grow as increasing demand for these commodities will lead to higher prices which, in turn, induce enhanced productivity and investment in these sectors.

Implications for food security, poverty and equity

China's economic growth and trade liberalization in the reference world will facilitate domestic agricultural structural changes. China's agriculture will be gradually shifting from less comparative advantage sectors (land-intensive sectors such as grain, edible oil crops, sugar and cotton) to more comparative advantage ones (labor-intensive ones such as vegetable, fruits, pork and poultry).

Overall, China's food security will remain high. While there will be a few agricultural and food commodities that could experience a significant decline in national self-sufficiency levels (for example maize, soybean and edible oil crops, sugar and ruminant meats, Box Table 5.3.2.1-2), they will not threaten China's and world food security. Cereal imports will rise and cereal self-sufficiency will remain at about 90% in 2020 and 86% even by 2050. Increasing imported cereals are mainly used as feed (for example, maize) as demand for livestock products grows rapidly. Maize's self-sufficiency will fall from the current more than 100% to less than 70% after 2020. However, due to declining per capita consumption of rice and wheat and projected slowing population growth with nearly no growth in the 2020s and a decline thereafter, China could reach nearly self-sufficiency in wheat and export large amounts of rice in the international market if the rest of the world liberalizes their agricultural sector.

China's economy will help those countries with a comparative advantage in land-intensive products to expand their production and increase their exports to this country. Developing countries can export agricultural products to China, particularly soybeans, other oilseeds, maize, cotton, sugar, tropical and sub-tropical fruits, as well as some livestock products (for example, milk, beef, mutton).

Incomes will increase across all income levels in China from both agriculture and nonagricultural activities—with most of the growth from non-farm activities. On average, per capita income will rise about 6% annually over the next 2 decades and 3-5% during 2020-2050. Income growth from agriculture will be much lower. China's rapid economic growth and the rise in the nation's overall wealth will be accompanied by widening income inequality unless substantial efforts are undertaken to directly support the poor.

China will significantly reduce its population under the poverty line in the coming years. In 2001, about 11% of China's rural population was below the poverty line of US$1/day (Box Table 5.3.2.1-3). With rising incomes from both agricultural and nonagricultural sectors, the share of the poor in the total rural population would be reduced to 5.4% by 2010 and only 0.9% by 2020. Moreover, under the reference run, the rural population in poverty would be completely eliminated after 2022, faster than the target suggested under the Millennium Development Goals of the United Nations. Specifically, the bottom 20% of households based on their income in 2001 is expected to reduce its population share from 22.6% in 2001 to 3.9% by 2030 (Box Table 5.3.2.1-3). After about 2035, the entire rural population in the lowest income class (quintile) is expected to transit to the second or even third income levels.

By 2050, more than 60% of the rural population is expected to reach the income enjoyed by the top 20% of the current rural population (Box Table 5.3.2.1-3).

The substantial increase in food prices will slow growth in calorie consumption, with both direct price impacts and reductions in real incomes for poor consumers who spend a large share of their income on food. As a result, there will be little improvement in food security for the poor in many regions. In sub-Saharan Africa, daily calorie availability is expected to only grow to 2,827 kilocalories by 2050, compared to more than 3,000 calories available, on average, in all other regions. Only the South Asia sub-region has equal low gains in calorie availability – at 2,858 calories per capita per day by 2050 [single-year values]. Calorie availability is expected to grow fastest in the Latin America and Caribbean region at 941 kilocalories over the 2000-2050 period (Figure 5.3.2.1-7).

In the reference run, childhood malnutrition (children of up to 60 months) will continue to decline, but cannot be eradicated by 2050 (Figure 5.3.2.1-8). Childhood malnutrition is projected to decline from 146 million children in 2000 to 117 million children by 2025 and 80 million children by 2050 [single-year values]. The decline will be fastest in Latin America at 66%, followed by the West Asia and North Africa region, at 60%, and Asia, at 51%. Within Asia, South Asia is expected to house most (88%) of Asian malnourished children in 2050. Progress is slowest in sub-Saharan Africa—despite rapid income growth and significant area and yield growth as well as substantial progress in supporting services that influence well-being outcomes, such as female secondary education, and access to clean drinking water—by 2050, there will be a reduction by only 19% in the number of malnourished children in sub-Saharan Africa.

Fisheries. The reference run is set up so that the value of landings was optimized throughout the years modeled with effort driving the model. The effort for all fleets is the same as what the effort was in the year 2003 until 2010, and after 2010 only the effort in the small pelagic fleet is allowed to vary. A second reference world was run so that after 2010, the effort in the small pelagic fleet was increased by 2% each year, which represents a modest growth in the sector, in particular carnivorous species which consume much of the small pelagic fish landed through fishmeal and fish oil (Figure 5.3.2.1-9). The 2% value is based on recent FAO reports on the growth of aquaculture (FAO 2006b; FAO/WHO, 2006 – SOFIA and media release, see also Table 5.3.2.1-8).

Atlantic Ocean. Under the baseline scenario there is an overall decline in landings (5.4%) between 2003 and 2048 but under the 2% increase in small pelagic effort scenario there is a 7% increase in landings (Figure 5.3.2.1-10). In both scenarios the trophic level of the catch declines between 2 and 2.5%. Six FAO areas are represented in the Atlantic, and in all areas except 34 and 21 landings increase in the baseline scenario and trophic level declines. In FAO areas where landings continue to decline, the trophic level in Area 34 is the only area where it increases while in Area 21 it continues to decline. In the 2% effort scenario landings in most areas increase or remain steady except in Area 21 where it declines. The trophic level decreases in all but Area 31 where it increases slightly. The changes in biomass of the major species is seen in increases in small pelagic fish (e.g. capeline, herring) as shown in Figure 5.3.2.1-11 and declines in large demersal and large bentho-pelagic fish (e.g. cods, haddock)

Pacific Ocean. The baseline modeling for the Pacific results in declines in landings by 5% from 203 to 2048, while in the 2% increase in effort in the small pelagic fleet there is an overall increase (117%) in landings. The trophic level remains unchanged in the baseline but declines by 1.3% in the small pelagic effort scenario (Figure 5.3.2.1-10). Six FAO areas are included in the Pacific and much of the change in landings in the baseline scenario can be attributed to Areas 77, 67 and 61 and changes in trophic levels can be attributed to Area 87. However, in the 2% effort scenario the landings increase in most FAO areas but the trophic level only declines in FAO Areas 87 and 61. Much of the change in landings and trophic level are due to increasing biomass of small pelagics and declining biomass of most other groups (e.g. Figure 5.3.2.1-12).

Indian Ocean. In the baseline scenario landings initially decline while stocks rebuild and then landings increase but only to 1% more than in 2003 by 2048. However, the trophic level of the catch does not decline with increased landings (Figure 5.3.2.1-10). Landings increase in the 2% effort scenario. The growth is small, less than 5% but also the sustainability of these fisheries policy is uncertain since the trophic level of the catch continues to decline under the 2% policy from 2003 to 2008. The Indian Ocean represents two FAO Areas (51 and 57) and much of the overall increase in landings is due to increased small pelagic biomass in Area 57 (Figure 5.3.2.1-13).

Mediterranean. Landings in the baseline scenario increase by 7% with a corresponding decline in trophic level of 3%. In the 2-percent small pelagic effort scenario, landings increase by 50% then level off while the trophic level declines steadily and by 3% from 2003 (Figure 5.3.2.1-10). The sustainability of this policy is uncertain since small pelagic biomass declines steadily toward the end of the modeled time period and the biomass of the large bentho-pelagic fish also declines (Figure 5.3.2.1-14).

5.3.2.2 Global trends in water availability and emerging challenges to water supply

Changes in human use of freshwater are driven by population growth, economic development and changes in water use efficiency. Historically, global freshwater use had increased at a rate of about 20% per decade between 1960 and 2000, with considerable regional variations due to different development pressures and efficiency changes. Because of uneven distribution of fresh water in space and time, however, today only 15% of the world population lives with relative water abundance, and the majority is left with moderate to severe water stress (Vorosmarty, Levegue and Revenga 2005).

This global water picture may be worsened in the future under climate change and population growth. For the reference run, as shown in Table 5.3.2.2-1, by 2050 internal renewable water (IRW) is estimated to increase in developed countries but is expected to decrease in the group of developing countries. The disparity of changes of IRW and population by 2050 will increase the challenge to satisfy future water demands, especially for the group of developing countries.

Table 5.3.2.2-2 presents total water consumption, which refers to the volume of water that is permanently lost (through evapotranspiration or flow to salty sinks, etc.) and cannot be re-used in the water system, typically a river basin. In the reference world, by 2050 world water consumption is expected to grow by 12%. Regionally, by 2050, SSA will double its water consumption and LAC will increase water consumption by 50%. ESAP is expected to increase water consumption by 12% while in the NAE region the increase is modest, at 4%. Only CWANA reduces its water consumption—as a result of further worsened water scarcity. The IRW reduction of CWANA makes its global share of IRW decrease from 3.4% to 2.7% (Table 5.3.2.2-1). Combined with the increase of population share from 10% to 13%

CWANA will face the largest challenge in meeting demands exerted by socioeconomic development and conservation demands to sustain ecological systems.

Irrigation will continue to be the largest water user in 2050 for all regions (Table 5.3.2.2-3). However, it is estimated that the share of irrigation consumption in total water depletion will decrease by about 10% from 2000 to 2050, largely due to the more rapid growth of non-irrigation water demands that compete for water with irrigation (Table 5.3.2.2-4), and also because of projected declines in irrigated areas in some parts of the world. It is estimated that the actual irrigation water consumption is likely to slightly decrease in the group of developed countries. Regionally, actual irrigation consumption is expected to slightly decline in the NAE and ESAP regions. This is largely due to the large irrigated areas already developed (ESAP) and the pressure to transfer water to other sectors as well as increasing awareness of environmental and ecosystem protection (NAE). Actual irrigation consumption will decline significantly in CWANA due to chronically worsening water scarcity in the reference run. For individual dry river basins the IWSR could be even lower than these spatially-averaged values since abundant water in some basins mask scarcity in the dry river basins.

Constraints to water supply vary across regions. Water shortages today and out in the future are not solely problems of resource scarcity, but are also closely related to stages of economic development. Three types of water scarcity constraints will become more important in the future: first is absolute resource scarcity, which will become more and more a feature of regions characterized by low and highly variable rainfall and runoff, often accompanied by high evapotranspiration potential. They include countries and sub-national regions in CWANA, ESAP (for example, Northwestern China), NAE (for example, Southwestern US), among others. The second type is infrastructure constraints, typically in regions where water availability is not extremely low but infrastructures to store, divert/pump, and convey water is underdeveloped. Despite rapid development of irrigation-related and other water infrastructure in the SSA region, the region will remain infrastructure constrained out to 2050. The third type water scarcity is caused by water quality constraints, which is becoming increasingly normal in regions where rivers and aquifers are contaminated by insufficiently treated or untreated industrial wastewater and non-point source pollution from agricultural practices. An increasing number of countries in ESAP are included in this category, for example, the Huai River Basin in China.

As a result of increased potential irrigation water consumption and reduction or moderate increase in actual irrigation consumption, the irrigation water supply reliability (IWSR) declines in all regions. Globally, the IWSR decreases from 68% to 59% from 2000 to 2050. Regionally, LAC is likely to maintain a stable IWSR over the next 50 years given its abundance in water resource, although its water availability will decline by nearly 20% over this period. The IWSR of CWANA is expected to be below 50% by 2050 due to increased irrigation water demand (largely due to increased potential evapotranspiration) and reduced water availability. This would impose a significant impact on crop yield, and potentially jeopardize food security in this region.

Total harvested irrigated area is expected to increase from 441 million ha in 2000 to 466 million ha in 2025 and to then slightly decline to 455 million ha by 2050. Cereals account for more than half of all irrigated harvested area over the reference run period, declining slowly from 57 million ha in 2000 to 54 million ha by 2050. Over the projections horizon, irrigated area is projected to slightly decline in the NAE and CWANA areas, by 3 and 5%, respectively. At the other extreme, irrigated harvested area is expected to increase in the LAC and SSA regions, by 31 and 47%, respectively. While the increase in SSA is large in percentage terms, by 2050, SSA is expected to account for only 1.3% of global harvested irrigated area (Figure 5.3.2.2-1).

Table 5.3.2.2-4 presents sharp increases in non-irrigation water demands over the next 50 years, with increases concentrated in the group of developing countries. In the reference run, globally, non-irrigation water consumption would double by 2050, approaching 660 km^3 per year. Notably, non-irrigation consumption in 2050 is estimated to be 483 km^3, roughly tripling from 2000. In comparison, total non-irrigation water consumption in developed countries only increases moderately. The most significant increase is domestic water consumption in the group of developing countries, which grows rapidly from 88 km^3 to 236 km^3 over 50 years. This dramatic increase is driven by both population growth and per capita demand increase due to income growth. Industrial demand would also increase significantly, with the largest relative increase in SSA (though still low by population size) and the largest absolute increase in ESAP. Livestock water consumption is expected to double from 2000 to 2050, with fairly minor increases in developed countries.

5.3.2.3 Results for Energy Production and Use

In terms of energy demand, the reference projection shows an increase of 280 EJ in 2000 to around 500 EJ in 2030 and nearly 700 EJ in 2050. This is somewhat faster than the historic trend. This difference is the result of the fact that 1) historically several events have slowed down demand in energy consumption (energy crises, economic transition in FSU, Asia crisis), and 2) the increasing weight of developing countries with typically higher growth rates in the global total.

Most of the increase in energy demand takes place in the group of developing countries. At the same time, however, it should be noted that per capita energy consumption remains much higher in OECD countries than in developing countries. In terms of energy carriers, most of the energy consumption continues to be derived from fossil fuels – in particular oil (for transport). The growth of oil is somewhat slowed down in response to high oil prices. Modern biofuels represent a fast growing alternative to oil – but remain small in terms of overall energy consumption. Coal use increases slightly – as high oil and gas prices imply that coal remains an attractive fuel in the industry sector. This partly offsets the trend away from coal in the buildings sector. Natural gas use increases at about the same rate as the overall growth in energy consumption. Finally, the level of electricity use increases dramatically.

In electric power, the reference scenario expects coal to continue to remain dominant as a primary input into power production. In fact, its share increases somewhat in response to high oil and gas prices – and as a result of high growth in electric power production in countries with high shares of coal and limited access to natural gas supplies (such as India and China). Rapidly growing alternative inputs such as solar/wind power and bioenergy gain market share – but form still only about 10% of primary inputs by the end of the reference run period.

The resulting picture for primary energy consumptions shows that primary energy use more than doubles between 2000 and 2050. During this period, fossil fuels remain dominant in supply despite rapid growth in both bioenergy and solar/wind power. Interestingly, by 2050 coal is expected to have gained market share relative to oil and gas.

In terms of supply, it is expected that oil and natural gas production will concentrate more and more in a small number of producing countries as a result of the depletion of low-cost supply outside these countries. It is also expected that fossil fuel prices remain relatively high. In that context it should be noted that current high oil prices are mostly a result of 1) rapid increases in demand, 2) uncertainties in supply, and 3) underinvestment in production capacity. Some of these factors could continue to be important in the future – although estimates are hard to make (and strongly depend on perspectives of the future with respect to globalization and cooperation, regional tensions etc). In addition, depletion of low-costs resources will lead to upward pressure on prices. As a result, it is likely that fossil fuel prices remain at a relatively high level – although probably somewhat below 2005-7 levels. Continued high price levels will provide incentives to invest in alternative energy sources such as bioenergy.

5.3.2.4 Climate

Under the IAASTD reference scenario, the atmospheric concentration of greenhouse gas rises driven mainly by increasing emission of greenhouse gases from the energy sector (see Figure 5.3.2.4-1 for CO_2). The concentration of greenhouse gases reflects the balance of net fluxes between terrestrial areas, oceans and the atmosphere. By 2030 the CO_2 concentration reaches 460 ppmv, and increases further to 560 ppmv in 2050, a doubling of the pre-industrial level.

The effect of more greenhouse gases and other so-called radiative forcing agents (substances that contribute to the enhanced greenhouse effect) in the atmosphere, combined with cooling forcings from direct and indirect sulfur aerosols, is a rise in global mean temperature above the pre-industrial level to

1.2 degrees C in 2030 and 1.7 degrees C in 2050; see Figure 5.3.2.4-2. The actual changes in global mean temperature strongly depend on the uncertainty in the so-called climate sensitivity. The uncertainty in the climate sensitivity is one of the most important uncertainties remaining in climate science (see Chapter 4). New estimates of IPCC show that a mean estimate of climate sensitivity is 3.0°C – but much higher (e.g. 5°C) or lower (e.g. 1.5°C) values are also possible (IPCC 2007). For the reference projection calculations, we have assumed the climate sensitivity to be 2.5°C, indicating that with a doubling of greenhouse gas emissions, the temperature increase will stabilize at 2.5°C.

The calculations show that in the first few decades of the 21st century, the rate of temperature change is somewhat slightly slowed down compared to the current rate, in response to lower emissions, e.g. due to a slowdown in deforestation, stable methane concentration in recent decades and increasing sulfur emissions with a cooling effect. In the following decades these trends are discontinued, driving the temperature change rate upwards again. Factors that contribute to this increase are increasing greenhouse gas concentration in combination with reduced sulfur emissions. By 2030 the temperature increases by a rate of more than 0.2 degrees per decade. In light of concerns over risks that high rates of temperature change might induce irreversible and very drastic climate changes (very uncertain), rates in excess of 0.2 degrees per decade are considered a notable risk factor, though current knowledge is inconclusive on this issue.

Temperature changes in global means does not show the regional effect that climate change may have on crop yield, water resources and other environmental services for human development. Therefore, the regional aspects of climate change need to be addressed as well, although extent of the regional effect is still very uncertain. In Figure 5.3.2.4-3, the change in temperature between 1990 and 2030 is visualized. Although the global mean temperature change is around 1°C between 1990 and 2030 (Figure 5.3.2.4-2), regionally this can imply changes of more than 2°C (Figure 5.3.2.4-3).

The impact on crop growth is one of the most important direct impacts of climate change on the agricultural sector. Through CO_2 fertilization, the impact can be positive, also when more precipitation and higher temperatures lengthen the growing season. However, as recently concluded by IPCC (IPCC 2007) with higher climate impacts the impacts on crop yield will be negative. In total, the impact in 2050 is still relatively small, although negative impacts are already visible, especially in developing countries (Figure 5.3.2.4-4).

5.3.2.5 Environmental consequences - *Land use change*

The impacts of changes in agriculture and demand for biofuels lead to changes in land use. Although expansion in pastureland is compensated by an increase in grazing intensity, and increase in crop land is partially compensated by technological improvements (Subchapter 5.3.2), total land use for humans is still increasing until 2050 with an expansion of 4 million km^2. The increasing demand for biofuels is one of the important reasons for this development (Figure 5.3.2.5-1). In Figure 5.3.2.5-2, the regional split-up is given for biofuel areas being used for energy purposes. Although Latin America is currently one of the most important energy crop growing regions, in the future Africa and Russia are expected to overtake this market. This is mainly due to a high increase of agriculture in Latin America which leaves little room for any additional energy crops (see also subchapter 5.3.2.3).

These changes in land use also impact air quality and the atmospheric composition of greenhouse gases. Figure 5.3.2.5-3 shows that the land use related emissions will continue to increase, mainly to increase of the animal production (CH_4 emissions) and fertilizer use (N_2O emissions). CO_2 emission due to land use change (deforestation) is expected to stay more or less constant.

5.4 Assessment of Selected, Major Policy Issues

5.4.1 Climate change policies and agriculture

In the previous sections, we have shown that the reference projection leads to a strong increase in greenhouse gas concentration – and thus considerable climate change. In contrast, the recent IPCC reports indicate that avoiding dangerous anthropogenic interference with the climate system may require stabilization of GHG concentration at relatively low levels. Current studies on emission pathways, for instance, indicate that in order to achieve the objective of EU climate policy (limiting climate change to 2^oC compared to pre-industrial) with a probability of at least 50% may require stabilization below 450 ppm CO_2-eq. Stabilization at 450, 550 and 650 ppm CO_2-eq, is likely to lead to a temperature increase of respectively, about 1.2-3^oC, 1.5-4^oC, and 2-5^oC. The Stern review recently concluded that given all evidence, limiting temperature increase to about 2^oC would be an economically attractive goal. This conclusion has been debated by some authors, but also found strong support by others. For the purpose of this report, we have decided to explore the impact of stringent climate policies.

The IPCC AR4 WGIII report concludes on the basis of model-supported scenario analysis that several model studies show that it is technically possible to stabilize greenhouse gas emissions at 450 ppm CO_2-eq. after a temporally overshoot. This is also supported by the model analysis done for IAASTD. Figure 5.4.1-1 shows how the emission reductions required to stabilizing at 450 ppm (around 60% in 2050 and 90% in 2100, globally) can be reached by employed of various emission reduction options. Efficiency plays an important role in the overall portfolio. CCS is another important technology under default assumptions – but may be substituted at limited additional costs against other zero-carbon emitting technologies in the power sector. Obviously, the concentration target forms a tradeoff between costs and climate benefits. The net present value of abatement costs (2010-2100) for the B2 baseline scenario (a medium scenario) increases from 0.2% of cumulative GDP to 1.1%, going from stabilization at 650 to 450 ppm. On the other hand, the probability of meeting the EU climate target (limiting global mean temperature increase to 2^{o}C) increases from 0-10% to 20-70% (compare Figure 5.4.1-1).

One important option in the overall portfolio is also bioenergy. As discussed in Chapter 4, there is a strong debate on the advantages and disadvantages of bio-energy. The 450 ppm stabilisation case is likely to lead to a strong increase in land use for bioenergy. A recent paper by van Vuuren et al. (2007) on the basis of a comparable scenario found land for bioenergy to increase from 0.4 to 1.0 Gha in 2100 – while at the same time land for carbon plantation increased from 0 to 0.3 Gha.

Obviously, the climate policy scenario has important benefits in reducing climate change – although some of these may only materialize in the long-term as shown in Figure 5.4.1-2. As shown the emission reductions are likely to reduce greenhouse gas concentration substantially in 2050. At the same time, however, the medium-term (2050) impacts on temperature increase are relatively slow. The latter is due to inertia in the climate system, but also due to the fact that climate policy also reduces SO_2 emissions, reducing atmospheric aerosols that lead to a net cooling. In other words, impacts on agriculture in 2050 are similar in the stringent policy case as in the reference scenario. Uncertainty does not come from different scenarios – but differences in climate sensitivity. In the longer run, however, the temperature of the policy case will remain significantly below the reference case.

5.4.2 Trade policies and international market constraints

Support policies and border protection of wealthy OECD countries, valued at hundreds of billions of dollars each year, cause harm to agriculture in developing countries. Evaluating the overall effects of the subsidies and protection among developed countries, assessing the effects of these policies specifically on developing countries, or even more their effects on poverty in developing countries, are complex challenges. The evaluation must rest on counterfactual simulation of alternative policy scenarios leading to a diverse set of policies and application of a range of different models.

A number of model results were reviewed recently by Beierle and Diaz-Bonilla (2003) to describe what is known and the remaining knowledge gaps on whether trade liberalization (in the form of reduced protection and export subsidies and lowered import restrictions) would benefit smallholder farmers and others in poverty in developing countries. Several key findings from their review and other assessments are:

- Most models demonstrate negative impacts of current developed country (OECD) trade protection policies but with positive impacts from developed country liberalization on developing country welfare, agricultural production and incomes, and food security.
- Impacts vary by country, commodity, and sector, and for regions within countries.

- OECD market access restrictions harm developing countries, although effects of production and income-support subsidies are more ambiguous.
- Developing countries tend to gain more from liberalization of their own policies than from reforms by the OECD. Consumers in developing countries benefit widely from these reforms.
- Model results differ on the basis of assumptions such as the scope of commodity coverage, mobility of resources among alternative crops and between farm and non-farm employment, availability of underutilized labor, and static versus dynamic analysis.
- Multilateral liberalization reduces the benefits derived from preferential trade agreements, but these losses are relatively small compared to the overall gains from the broader reforms.
- Most models have not had sufficient resolution to analyze the impacts of reforms on smallholders, subsistence farmers, and other poor households but there is an emerging literature attempting to do so (Hertel and Winters 2004; Beierle and Diaz-Bonilla 2003; Narayanan and Gulati 2002; Tokarick,2002).

As part of this report, GTEM was applied to two hypothetical variants representing two alternative global trade policy regimes. Variant 1 represents a global economy in which import tariffs (and tariff equivalents) on all goods are removed incrementally between 2010 and 2020 across the globe. Variant 2, on the contrary, represents a world in which trade barriers will escalate gradually between 2010 and 2020 such that by 2020 these barriers will be equivalent to twice the size of the existing tariff (and tariff equivalent) barriers across the board.

The key impacts of the two alternative scenarios at 2025 are analyzed below. Unless otherwise stated, the impacts are expressed as deviations from the reference case which represents no trade liberalization or reduced sectoral protection throughout the projection period. It should be noted that the impacts of trade policy changes only represent static gains/losses associated with resource reallocation and do not encapsulate any potential dynamic gains/losses associated with any long-run productivity changes. Furthermore, except for the trade policies in question, all other policies remain unchanged as in the reference case.

Figure 5.4.2-1 shows the overall impacts of trade liberalization under variant 1 in terms of changes in gross regional product (a regional equivalent to gross domestic product or GDP). The world economy is projected to benefit from multilateral trade liberalization. In particular, gross regional products in CWANA and SSA regions are projected to grow the most, by more than 2% relative to the reference case at 2025. However, about two fifths of the global benefits (in today’s dollars) are projected to accrue to the ESAP region.

However, on a global context, the international trade environment has caused serious problems for African agriculture and economic growth. OECD domestic agricultural subsidies, protective tariffs and other trade barriers harm farmers in Africa by reducing export opportunities for the developing country farmers. This is so because consumers will purchase the artificially cheaper products produced by developed countries resulting to displacement of locally produced products in developing countries with subsidized imported products. While estimates of the benefits of removal of global agricultural subsidies and trade restrictions vary, they are large for Africa. One study finds that under full global agricultural trade liberalization (complete removal of trade barriers), Africa would receive annual net economic benefits of US$5.4 billion (Rosegrant, et al. 2005). SSA would be the largest beneficiary on the continent, receiving US$4.6 billion of the total benefits (Hassett and Shapiro 2003). Another study indicated that European Union (EU) agricultural policies have reduced Africa's total potential agricultural exports by half. Without these agricultural policies, the current US$10.9 billion food-related exports annually from SSA could actually grow to nearly $22 billion (Asideu 2004).

Interestingly, while the removal of trade barriers under variant 1 is projected to increase income and food consumption, the global structure of food production appears to undergo significant changes. Compared with the reference case, a significant increase in meat production is projected to occur in LAC and SSA regions with a substantial decline projected for the NAE region (Figure 5.4.2-2). The structural change in global production of non-meat food is not as striking as in the case of meat. In meat production, LAC and SSA regions are projected to register most growth relative to the reference case at 2025 (Figure 5.4.2-3).

Under variant 2 in which trade protection will be doubled between 2010 and 2020, all broad regional economies are projected to decline relative to the reference case (Figure 5.4.2-4). Again, CWANA and SSA regions are projected to be affected the most, declining by about 1.5 per cent relative to the reference case at 2025.

Economic and trade liberalization in developing countries, independent from liberalization in developed countries, has had more mixed and in some cases negative outcomes. In sub-Saharan Africa, economic liberalization structural adjustment, begun in the 1980s, include currency devaluation, liberalization of marketing arrangements, removal of fertilizer and seed subsidies, removal of marketing subsidies for crop outputs and reduction of farm inputs financial services subsidies (Reardon et al. 1999). However, poorly developed private sectors were unable or unwilling to make the transition to generating the benefits of a functional market (Kherallah et al. 2002). Economic reform often contributed to social unrest, associated with loss of power or privileges by the elite and an unwillingness of authorities to grant some concessions to losers in the reform process (Easterly 2005). The relatively poor results of structural adjustment has been attributed to the state of Africa's development when these policies were implemented; the need for an organized government and solid institutions and markets; and imbalances among reforms, which meant that fiscal, political, and social inequities remained (Dorosh and Sahn 2000). While the effects of liberalization in sub-Saharan Africa have been mixed, and were often harsh in the short run, the reforms have contributed to improved macroeconomic stability, which has helped to reduce average annual inflation rates in Africa from 41% in 1994 to 10% in 2005, and improve budget deficits from 5.2% GDP in 1994 to 0.9% in 2005. A recent study of economic performance under ISI (import substitution industrialization) policies, comparing periods before liberalization, and the period after liberalization found that GDP per capita growth for the African countries included in the sample during these three distinct periods were -0.2% during the ISI policy period; below -0.5% during the critical years that preceded liberalization; and slightly over 1% during the years that followed liberalization (Salinas and Aksoy 2006). Trade and exchange rate liberalization tended to benefit the poor in four African countries (Cameroon, Gambia, Madagascar, and Niger), the gains from macroeconomic policies were fairly small in many other countries, suggesting that they needed to be accompanied by additional poverty alleviation measures. These measures include direct aid to the poor to counter the short-term negative distributional effects of reform, prudent borrowing from international donors to assist in further reform, and an effort to build the stock of human and other capital to improve prospects for investment (Salinas and Aksoy 2006).

Liberalization also has had mixed and often negative effects in the agricultural sector in Africa. The success stories mainly occurred where necessary investments in farm level capital were made and where proximity to markets and satisfactory infrastructure enabled markets to function reasonably well. Structural adjustment policies need to be combined with policies and incentives to encourage private investments, supported by investment in rural infrastructure, and institutional development. Macro and sectoral reforms are necessary to establish a stable macroeconomic environment, they are generally insufficient without strong supporting policies to improve the underlying structural problems that generate unsustainable intensification (Reardon et al. 1999).

Box: Trade policy and gender, case of India

The impacts of trade policies on agriculture and AKST are studied as a variant to the reference run based on the GEN-CGE model for 2025 and 2050 for the case of India. The alternative run assumes that the peak tariff rate as an average of both agricultural and non-agricultural goods would fall by 88% in the first 25 years with the backdrop of WTO bindings. This alternative simulation for 2025 is noted as 2025-1. In 2050, the tariff would further fall by close to another 7%. This simulation reflects that tariff in 2050 would not be zero but would be very low at around 2%.

By 2025, there would be positive growth of casual skilled male and female workers' average real wage rate (Box Table 5.4.2-1). However, the rise would be more for the female workforce. The average wage rate of the male casual workforce would witness a positive growth only in 2050 with a marginal improvement in 2050-1. What appears to emerge is that improved agriculture under AKST would lead to growth in such a manner that there would be higher wages for casual female male workforce in the reference world of 2025. Present trend of real wage growth of the female workforce may continue until 2025 narrowing the gender gap. The wage growth of both male and female workforce would then have a downturn and get negative during 2050 with further decline in 2050-1. The AKST measure is sustainable till 2025 for improvement of wages. In the next 25 years, the AKST needs enhanced market penetration to lead to real wage growth. The expanding informal sector may be the only sector demanding casual male labor, which would explain rise of wages for them, in 2050 and 2050-1.

The growth rate of per capita private income would rise in the urban areas at constant prices much more than the rural areas during the periods concerned. Both rural and urban households generally have higher income growth in (see Box Table 5.4.2-2) 2025 and 2050 improving further with trade reforms. The exceptions are the small farmers and petty business owners who would have a deceleration in their income in the first 25 years. The situation however improves in the next 25 years. Interestingly the lower wages in general do not cause per capita income to rise, meaning wage component in household income decline in the future. Moreover, as tariff rates are rationalized the situations of both rural and urban households improve relative to a situation with more restrictive tariff regime. What is important to note is that the difference between average per capita income of both rural and urban areas would not be as significant as one finds today. The divergence occurs only in the case of the informal sector both in the rural and urban areas where non-poor gain more than the poor households. Moreover, rural households would gain gradually through the next 25 years and significantly in the following 25 years to 2050. So the extent of inequality may not be as wide as one finds today, with further improvement with reduced protection.

This goes well with the observations that one makes in (Box Table 5.4.2-3) that shows population deciles with per capita consumption expenditure. Let us concentrate on population deciles of lowest 30 per cent of both rural and urban population. The per capita consumption growth is similar for both rural and urban population. Moreover, per capita consumption of the lowest 30% of the population improves throughout 2025 to 2050 and in the more liberalized regimes, both types of households improve their consumption. The marginally better performance in consumption of rural poor households under AKST reassures that a more agriculture oriented growth process lead to decline of the rural-urban consumption gap in the long run.

The findings in Box Table 5.4.2-4 show that the growth of imports of almost all agricultural crops would be negative in 2025, but, it would be reversed in 2050. It means that there would be large improvement of production of all agricultural crops except ‘maize’ and ‘other crops’ in 2025. ‘Rice’, ‘other coarse grain’ and ‘oilseeds’ would be produced sufficiently in 2050, which is why growth of their imports is estimated to fall for these sectors. The occupational diversification from agricultural to non-agricultural sectors is likely to change cropping pattern and also reduce dependence on agricultural domestic production by 2050.

Box Table 5.4.2-5 shows an improvement of per capita availability of different agricultural crops during the period till 2025 and further till 2050. The domestic supply of total agriculture sector is expected to grow by 4.1% each year till 2025, which further would grow by 10.9% till 2050. While all other agricultural sectors would show significant growth in their availability till 2050, the only sector that would experience a negative growth rate is ‘meat’, which is a livestock sector. However, ‘other livestock’ is expected to grow with the annual growth rate of 23.0%. The availability of non-agricultural sectors in the domestic market is also expected to grow following the positive growth rate in the range of 2 to 5% per annum. Overall, total domestic supply is expected to grow by 4 to 5% every year till 2050. The availability of goods for domestic market indicates that production along with imports even after exports, remain healthy. However, export orientation increase in both the reference world and under trade reforms and that is more significant for the non-agricultural sectors.

The growth of real GDP (see Box Table 5.4.2-6) is associated with real investment. The real investment (at constant prices) is estimated to rise gradually and would be quite by high 2050. The inflation shown by CPI reflects that without tariff reduction, this is higher in the longer time horizon as both demand and income grows over the years (noted earlier). However a less protective regime would depress the price rise. Real GDP would grow with higher demand both in consumptions and investment reflecting that AKST would drive overall growth, with further boost under trade reforms.

5.4.3 Investment in AKST (private vs. public)

As has been described above, the reference run describes slowly declining rates of growth in agricultural research (and extension). In the following, two alternative variations are analyzed using two sets of changing parameters. The first set of variations looks at different levels of investments in agriculture during 2005-2050. Different levels of investments can result in either higher (AKST_high) or lower crop yield and livestock numbers growth (AKST_low). The second set of variations analyzes the implications of even more aggressive or reduced growth in agricultural R&D together with advances in other, complementary sectors (AKST_high_pos and AKSt_low_neg with 'pos' for higher investments in complementary infrastructure and social services and 'neg' for decelerating growth in these services). Such other sectors include investments in irrigation infrastructure (represented by accelerated or slowing growth in irrigated area and efficiency of irrigation water use and by accelerated or reduced growth in access to drinking water, and changes in investments of secondary education for females, an important indicator for human well-being. Details of all four variants are described in Tables 5.4.3-1 and 5.4.3-2.

Results of the four alternative variations are presented in Figures 5.4.3-1 to 5.4.3-8 and Table 5.4.3-3. The AKST_high variant, which presumes increased investment in AKST results in higher food production growth which, in turn, reduces food prices and makes food more affordable to the poor when compared to the reference world. As a result, demand for cereals increases both as food and as feed increases by 249 million metric tons or 8% (Figure 5.4.3-1 and Table 5.4.3-2). The combination of even more aggressive investment in AKST with sharp increases in expenditures for supporting social services results in even higher demand for cereals as both food and feed, 517 million metric tons or 17%. Similarly, if levels of investment in AKST drop somewhat faster than in recent decades and if investments in key supporting services are not strengthened, food prices would rise, and demand would be depressed. Despite these strong changes in AKST behavior, yield growth will continue to contribute most to future cereal production growth under both the AKST_low and AKST_high variants (Figures 5.4.3-2 and 5.4.3-3). However, under AKST_low, area expansion would contribute 28, 27, and 17% to cereal production growth in SSA, LAC, and CWANA, respectively, compared to 24, 19, and 0% under the reference world. This could lead to further forest conversion into agricultural use. At the same time, rapid expansion of the livestock population under AKST_high requires expansion of grazing areas in SSA and elsewhere, which could also contribute to accelerated deforestation.

What are the implications of more aggressive production growth on food trade and food security? Under AKST_high, SSA cannot meet the rapid increases in food demand through domestic production alone. As a result, imports of both cereals and meats increase compared to the reference run, by 79 and 113%, respectively (Figure 5.4.3-4 and 5.4.3-5). Under AKST_high, CWANA and ESAP would also increase their net import positions, while LAC and NAE would strengthen their net export positions for these commodities. For cereals, on the other hand, CWANA and LAC would increase imports, while NAE and ESAP would increase their export positions. Under AKST_low_neg, on the other hand, high food prices lead to depressed global food markets and reduced global trade in agricultural commodities.

Water scarcity is expected to increase considerably in the AKST_low_neg variant as a result of a sharp degradation of irrigation efficiency. The irrigation water supply reliability index drop sharply (Table 5.4.3-4).

Sharp increases in international food prices as a result of the AKST_low and combined variants as shown in Table 5.4.3-3 depress demand for food and reduce availability of calories as shown in Figure 5.4.3-6. In the most adverse, AKST_low_neg variant, average daily kilocalorie availability per capita declines by 669 calories and average calorie supply in sub-Saharan Africa falls below the minimum of 2,000 calories and thus below the levels of the year 2000. Similarly, the group of Asian developing countries would fall below the 2000 calorie level under this policy variant. Calorie availability together with changes in complementary service sectors can help explain changes in childhood malnutrition levels (see also Rosegrant, Cai and Cline 2002). Under the AKST_high and AKST_high_pos variants, the share of malnourished children is expected to decline to 12% and 9%, respectively, from 15% in the reference world and 27% in 2000 (Figure 5.4.3-7). This translates into absolute declines of 17 million children (21%) and 33 million children (42%), respectively under the more aggressive AKST and supporting service variations. On the other hand, if investments slow much faster, and supporting services degrade then absolute childhood malnutrition levels could return to close to 2000 values at 127 million children under the AKST_low_neg variation and still to 99 million children under the AKST_low variation.

5.4.4 Focus on bioenergy

Among the renewable sources, bioenergy deserves special attention (energy from crops or other biological waste material). Studies into this potential confirm that the production of liquid fuels from biomass could meet the demand in the global transport sector. Bioenergy can also be used to produce electricity and heat. Part of the bioenergy can be derived from waste products. However, large-scale application will mean that bioenergy will primarily be derived from specific crops that are cultivated for energy production. The eventual contribution from biomass greatly depends on the expectations for future land use. The large-scale cultivation of biomass for energy applications can mean a considerable change in future land use, and could compete with the use of this land for food production. Other aspects of sustainability, such as maintaining biodiversity and clean production methods, also play a role here. In Chapter 4, we have summarized the discussion on the advantages and disadvantages of bioenergy. That discussion showed that under scenarios in which agricultural land could become available as a result of rapid yield improvement and slow population growth bioenergy potential is considerably higher than in land-scarce scenarios. If there is a fast shift towards wood and grassy crops (in cellulose-based reduction routes), this option offers greater CO_2 reduction options and less land use per unit of energy, although technical breakthroughs would be required to achieve this.

To explore the bio-energy potential under the IAASTD baseline projection – we follow the procedure of the de Vries, Hoogwijk and van Vuuren (2007) that defined the potential for bioenergy as the amount of bioenergy that could be produced from 1) abandoned agricultural land and 2) 40% of the natural grass areas. Under these assumptions, the potential in 2050 is around 180 EJ in the absence of residues mainly from USA, Africa, Russia and Central Asia, South East Asia and Oceania. Obviously this number is very uncertain – and depends, among others, on 1) agricultural yields for food production, 2) yields and conversion rates for bioenergy, 3) restrictions in supply of bioenergy (to reduce biodiversity damage), 4) uncertainty in water supply. The potential supply from residues is also very uncertain and estimates range from very low numbers to around 100 EJ. In the reference projection, we have assumed a potential supply of 80 EJ.

5.4.5 Policy experiment: the scope for water productivity and basin efficiency improvement

The baseline scenario foresees a substantial increase in water consumption in agriculture, and particularly in non-agricultural sectors. This may be reason for concern. Many studies foresee global water problems in near future unless appropriate action is taken to improve water management and increase water use efficiency (Rosegrant et al., 2006; SEI 2005; Falkenmark and Rockström 2004; Bruinsma 2003; Rosegrant, Cai and Cline 2002; Seckler et al. 2000; Shiklomanov 2000; Vörösmarty et al. 2000; Alcamo et al. 1998). First, already more than a billion people live in river basins characterized by physical water scarcity (CA 2007). In these areas water availability is a major constraint to agriculture. With increased demand for water existing scarcity will deepen while more areas will face seasonal or permanent shortages. Second, competition for water between sectors will intensify. With urbanization demand for water in domestic and industrial sectors will more than between 2000 and 2050. In most countries water for cities receives priority over water for agriculture –by law or de facto (Molle and Berkoff 2006), leaving less water for agriculture, particularly near large cities in water-short areas -such as MENA, Central Asia, India, Pakistan, Mexico, and northern China. While major trade-offs will occur between all water using sectors, they will be particularly pronounced between agriculture and the environment as the two largest water demanding sectors (Rijsberman and Molden 2001). Water for energy – i.e. hydropower and crop production for biofuels- will further add to the pressure on water resources. Third, signs of severe environmental degradation because of water scarcity, over-abstraction and water pollution are apparent in a growing number of places (CA 2007; Khan et al. 2006; MEA 2005; Pimentel et al. 2004). The adverse impacts of irrigation on ecosystems services other than food production are well documented (Pimentel et al. 2004; MEA 2005; Khan et al. 2006; CA 2007). Reduction in ecosystem services often has severe consequences for the poor who depend heavily on ecosystems for their livelihoods (Falkenmark, Finlayson, and Gordon 2007). Lastly, climate change leads to different rainfall patterns. While substantial uncertainty remains, most climate models indicate a strengthening of the summer monsoon and increased rainfall in Asia. But in semiarid areas in Africa the absolute amount of rain may decline, while seasonal and inter-annual variation increases. Hence, climate change may aggravate water scarcity problems in semi-arid and arid tropics (Alcamo et al 2005; Kurukulasuriya et al 2006; Barnett, Adam and Lettenmaier 2005; Wescoat 1991; Rees and Collins 2004).

It is clear that the baseline may not be the most desirable scenario. Fortunately, there is ample scope to improve water productivity and basin efficiency, to minimize additional water needs. AKST plays an important role to achieve these improvements. Three broad avenues to increase agricultural production while minimizing water use are (CA 2007) 1) improve productivity in rainfed settings, 2) increase productivity in irrigated areas, and 3) expand international agricultural trade. The scope and relevant policy measures differ considerably by region (Table 5.4.5.1).

SSA

Considering the ample physical potential and the willingness by donors to invest in African agriculture the scope of irrigated area expansion is large. But the contribution of irrigation to food supply will likely remain limited (less than 11% of total food production), even after doubling its area. The investment cost of doubling the irrigated area is high and to make this investment economically viable massive investments in marketing infrastructure are needed (roads, storage, communication) (Rosegrant et al. 2005). On the other hand, investments in irrigated area expansion for high-value crops (vegetables, cotton, fruits) can be an important vehicle for rural growth, and poverty alleviation particularly when geared to smallholders. Without substantial improvements in the productivity of rainfed agriculture, food production in SSA will fall short of demand. From a biophysical point of view, water harvesting techniques have proven successful in boosting yields, often up to a two or threefold increase (Rockstrom 2003, 2007). But, low adoption rates of water harvesting techniques indicate that upscaling local successes pose major challenges for AKST.

South Asia

In South-Asia 95% of the areas suitable for agriculture are in use, of which more than half irrigated. The biggest scope for improvement lies in the irrigated sector where yields are low compared to the obtainable level. Under a high productivity scenario all additional water and land for food can be met by improving land and water productivity in irrigated areas (CA 2007). The scope for productivity improvement in rainfed is equally promising. In the high yield scenario all additional land and water for food can be met by improving water productivity (CA 2007). But there is considerable risk associated with this strategy. Yields improvements in rainfed areas are more uncertain than in irrigated areas because of high risk for individual farmers. If yield improvement targets are not achieved (i.e. adoption of water harvesting techniques is low or fluctuations in production due to climate variability are too high), the shortfall has to be met mainly by imports, because the scope of area expansion is limited. The scope for irrigated area expansion is limited, though groundwater expansion by private well owners will continue.

MENA

In the MENA region the scope to expand irrigated areas is very limited due to severe water shortages. Rainfed agriculture is risky due to unreliable rainfall. With climate change variation in rainfall within the year and between years will further increase particularly in semiarid areas. Trade will play an increasingly important role in food supply.

5.4.5.1 Outcomes

Table 5.4.5-2 shows the outcomes of a scenario in which all high potential options are successfully implemented. The results show that a major part of additional water use to meet future food demand can be met by increasing output per unit of water, through appropriate investments in both irrigated and rainfed agriculture, thus relieving pressure on water resources. The output per unit water in rainfed areas increases by 31%. The potential in sub-Saharan Africa is highest (75%), while in OECD countries where productivity already is high the output per unit water increases by 20%. Overall the scope for enhancing water productivity in irrigated areas is higher than in rainfed areas (48% and 31%, respectively). In South Asia the output per unit of water can be improved by 62%. Improvement of water productivity is often associated with higher fertilizer use, which may result in increased polluted return flows from agricultural areas. A challenge for AKST is to develop ways in which the tradeoff between enhanced water productivity and polluted return flows is minimized.

While a major part of additional water demand in agriculture can be met by improvement in water productivity on existing areas, further development of water resources is essential, particularly in sub-Saharan Africa where infrastructure is scarce. In total irrigated areas expand by 50 million hectares (16%). In sub-Saharan Africa the expansion is largest (78%), in the MENA region the expansion is negligible because of severe water constraints. Agricultural water diversions will increase by 15% globally. A major challenge is to manage this water with minimal adverse impacts on environmental services, while providing the necessary gains in food production and poverty alleviation.

5.4.5.2 Challenges for AKST

In the realization of an optimistic water productivity and efficiency scenario AKST plays an essential role. Challenges for AKST are listed in Table 5.4.5-3.

5.4.6. Agricultural resources management and land tenure issues

5.4.6.1 Introduction

Management has become a key term in most debates on natural resources, agriculture included. The multi-functional character of agriculture has implied a serious consideration of the links with the ecosystems in which agricultural systems are embedded beyond measures and policies addressing specific resources such as land. Agricultural resources management in general is a core component of land policy defined as a governmental instrument that states the strategy and objectives for the social, economic and environmental use of the land and natural resources of a country. The organization of land use and ownership is very important. It should start with the development of a land policy that fits in the national objectives and leads to concrete actions (Williamson and Ting 2001). Land is and remains the main source of income and employment for a big proportion of populations in the world. Land ownership, size and quality are potential determinants of rural income and state of poverty. Improved land ownership and distribution accompanied with modernizing agriculture has potential to reduce noticeably incidence of poverty (APROSC and JMA 1995). Land tenure issue as a determinant to poverty has been looked upon from different sides involving potential links with other factors that have bearings on agricultural development, poverty, community well-being and sustainability. These factors include resources management, gender, land degradation, structure of agriculture, past and current policies, and forest and ecosystems.

5.4.6.2 Resources management and land tenure

Land tenure is an interdisciplinary concept with various meanings. Land tenure refers to the bundle of rights and responsibilities, under which land resources are held, used, transferred and succeeded (La Croix 2002). In general, land tenure arrangements vary enormously across urban and rural areas because of the end uses of land either for agriculture in rural areas or for residential and business in urban areas. The economics of land resources have generally focused on the tenure systems of agricultural land as it has always provided livelihood for many people in the world and accumulated and transferred wealth to current and future populations.

Land tenure has had different forms in different countries including owner cultivation of small, private lands, squatting on public or private lands, large estates, communal tenures and small holders leasing from public or private landowners as the most important systems. The owner-cultivated farms are predominant in all countries of the world. On one side they have been praised as ideal arrangements to foster relevant and democratic institutions for an optimal uses of land resources (La Croix 2002). On the other side family managed farms in some countries may not be the most efficient forms of agricultural organization because the may have inadequate managerial skills, may not have sufficient family labor; and may not reap full economies of scale. Squatting is still observed in some countries of Latin America such as Costa Rica, Brazil and Columbia on privately and state owned lands.

To a lesser extent squatting also exists on state lands in some African countries mainly in the ex-French colonies in North Africa. Squatting has had negative impacts on economic development as it has encouraged disorderly settlements and impeded growth in the urban areas by forsaking the use of land for collateral and restricted transfers of parcels and reduced the price of land. Large estates have emerged historically through what was called the Latifundia known as large farms or ranches consolidated from different parcels and owned managed by wealthy people. Some economists have agued that land laws in South America were heavily influenced by this initial allocation of lands and were structured to enhance the position of large property owners to the detriment of small independent farmers (La Croix 2002). Communal tenure system has been prevalent in the Pacific Islands and Africa. In this system families carry out cultivation on scattered plots distributed by chiefs or village elders on the basis of family size and land fertility. This system has been described as efficient response to social and economic environments although it has significant environmental risks, high information costs, and weak input, output and insurance markets (La Croix 2002). Nevertheless economists have in many cases viewed communal land systems as an impeding factor to the growth of a modern economy. In Russia as well as China communal systems have been abolished through land reforms to the advantage of individual agricultural land parcels where farmers are free to make production decisions on their own and under commercial objectives. Land tenure based on contracts between owners and labor have had different provisions including mainly land owner's role in farm management, type of land rent and, contract duration. Sharecropping is one of the options used in this system. Economists have had controversial opinions about share copping. Some of them argue that share cropping reduces incentives for tenants to overuse valuable land and provides incentives for landlords to provide managerial services. Others argue that output decreases under sharecropping. However, with respect to adoption of new technologies available studies show that sharecroppers and other tenants use new technologies at the same rate (La Croix 2002)

Land tenure and property rights are an integrated issue of land resources management in all countries. It is well acknowledged by policy makers as well as by land lords that lack of clear property rights laws and insecure tenure regulations have affected the land management decisions of small rural households in developing countries and lead to a fall in resources productivity and therefore to increased poverty in rural populations (Sharma 1999; WB 2006a)

5.4.6.3 Land degradation in relation to land tenure

Land degradation is another land tenure issue that has bearings on the relationship between customary communal tenure and land degradation. Recent studies confirm that there is a high correlation between customary tenure and lack of land resources conservation because of ignorance about land conservation, unsustainable traditional agricultural production.

Soil is an essential for plant growth and is therefore the primary environmental stock that supports agriculture. The condition of the soil resource varies widely but global estimates suggest that 23% of all used land is degraded to some degree which is cause for serious concern (Oldeman, 1994, Wood, Sebastian and Scherr 2000). The key soil degradation processes include: erosion, salinization and water logging, compaction and hard setting, acidification, loss of soil organic matter, soil nutrient depletion, biological degradation, and soil pollution. Agricultural activities influence all these processes (Scherr 1999).

While water and wind erosion are the most important causes of such degradation, the direct influence of agricultural practices can not be neglected: it accounts for about a quarter of total degradation (GACGC 1994). AKST is - and has always been - crucial to address these problems both through more classical approaches - proposing mechanical protection such as bunds and terraces to control surface run-off - and through more comprehensive frameworks aiming at greater integration of water conservation and soil protection and the use of biological methods (Shaxson et al. 1989; Sanders et al. 1999; WOCAT 2006).

Soil degradation is one of the core components of land resources management regulations. From the economic point of view there is focus on identifying the necessary policy reforms in order to improve the incentives for better land management mainly in developing countries. Policies that reduce price distortions, promote efficient operation of rural financial markets and make property rights enforceable should reinforce these incentives (Coxhead 1997). Reducing import tariffs and export taxes in the Philippines may have reduced the degradation of up land degradation in the Philippines (Coxhead and Jayasuriya 1995). Likewise, reduction of agricultural input subsidies for irrigated rice in Indonesia may be the reason for improved investment in land conservation in the uplands of Java.

Policies that have increased processes of land degradation and deforestation as an unintended side effect should be mitigated (Barbier, 1997). Examples of these policies include expansion of road network in frontier areas that have opened up forest lands making them artificially cheap and abundantly available. They also include tax policies that encourage the holding of agricultural land as a speculative asset that has artificially inflated the price of existing arable land and promoted much idling of potentially productive land. Small land holders may find it more profitable to extract short term profits by erosive farming practices, abandoning existing agricultural land, and moving to marginal and frontier land areas.

Land tenure has had closer effects on sustainable agriculture and agro forestry. Traditional agriculture in some countries has been relatively sustainable though extensive land use practices (Denevan 1989) indigenous farmers in some Latin American countries have applied swidden agricultural practices of annual crops, but have laid relatively unchallenged claim to large tracts of land (Alcorn 1990).

5.4.6.4 Gender and land tenure

Another potential issue pertaining to land tenure, ownership rights is women's rights to own land. In many countries of the world women are subjected to discrimination in land ownership and management. Examples of this discrimination are found mainly in Southern Africa region as well as some Latin

American countries. Women discrimination has been held as a constraint to agricultural development as few countries in these regions have started recognizing the independent land rights of women.

Gender is a key category for understanding agrarian societies, as anthropological and historical research has consistently shown (Boserup 1970; Netting 1993). The category refers not, as is often assumed, to the role of women as such, but to the specific social ascription of roles and functions according to gender. In agrarian societies, these roles and responsibilities have been, in most cases, clearly and specifically assigned to either the male or the female gender in productive households. In addition, not only work, but also assets are as a rule accessed and controlled according to gender-based patterns. These patterns vary with time and place, a persistent feature is that women have a key role in agricultural work, yet they have often limited access to, or control over, the resource base such as land.

Agricultural development has sometimes strengthened patterns not favoring women. Two factors are considered in this context: first, the bias of agricultural extension systems towards the male gender: it is men – representing the state and its agencies – talking to men – representing the community or farming household. Second, as agricultural modernization often implies the need for investments, market integration – handling larger sums of money – this has favored men in many contexts.

With growing awareness of this serious flaw in land tenure, the international agricultural research community has developed research to address the issues of women in agriculture. This often went together with establishing a participatory research agenda (Lilja et al. 2000), such as in the CGIAR Systemwide Program on Participatory Research and Gender Analysis. While this is a welcome trend towards research products that have been developed with a greater involvement of women, it is not a sufficient condition to change a social fabric that discriminates against women.

5.4.6.5 Structure of agriculture

Agricultural production per unit of land area is determined by, among other factors, farm size. Economic theory does not always favor large size farming and does not always condemn small size. Economics theory recommends the optimal size farm that gains sufficiently from availability of technical innovation, gains from institutional support and provides for competitive cost advantage and secure property and lease conditions. The rule that small farms may have high productivity is not always true and has driven a great deal of discussions (Binswanger et al. 1995). In many regions where interest in farming is lost due to alternative employment and sources of revenue, small farm productivity is low (Anonymous 2003). In regions with strong technological improvements in agriculture, the small farms do not necessarily have the highest productivity because they cannot afford the required investments and cannot realize economies of scale adequately (GTZ 2002).

In the USA the number of farms has declined dramatically from 6.8million in 1935 to 2.1 million in 2002. Farms have a much larger average size today. However, farms now range from very small residential and retirement farms to highly industrialized farms with total sales in the millions (Hoppe 2006). The same phenomenon exists in other countries.

On the other hand large areas of agricultural land still suffer from fragmented parcel structure in many countries of the world. Land consolidation has taken place in few countries in order to gain economies of scale and use new technologies. While land consolidation has proved economically beneficial it has been taken responsible for loss of village and rural life as subsistence farming was replaced by commercial farming (Pettri-Torhonen 2003).

There is evidence that globalization has encouraged corporate development that extended the frontiers of discourse beyond the international system of state to wider and deeper levels analysis to understanding world dynamics. Within this context the tendency has been to focus on transnational forces, process and institutions that cut across borders but do not derive their power from the state (Sklair 1999), processes, and institutions, not based on the state due to its changing role. The drivers of this role change are transnational corporations and transnational capitalist class (Joab 2005).

There is an argument that corporations are forced to be good corporate citizens because they operate within strict regulatory regimes imposed by local, national and international government authority (Sklair 1999). This argument does not hold in many countries, developed and developing alike. Many developing nations in Africa, South America and, Asia are still under the sway of transnational corporations operating directly or indirectly in agriculture, with high economic power capable of eluding state control and neutralizing any constraining economic policies. However, aware about the negative consequences on the expansion and sustainability of their business, multinational corporate have initiated corporate philanthropic activities that engaged mostly in local community development local communities.

It is hypothesized that the agricultural sector will go through serious structural adjustments that may have remarkable impacts on the production / marketing systems and consequently on rural populations and the demand for food. Access to KST and to capital will be a constraint to small landlords in developing and may be in developed countries as well. It will lead to domination of local and foreign capital holders (individual and corporation) that will have incentives to buy or rent agricultural resources from small farmers (who most of them inheritants of land), and may not be interested in agriculture as a profession. Some of them have jobs outside agriculture; others do not see any future in agriculture and will be looking for jobs in urban areas. This situation is encouraged by pressure resulting from future agriculture production capital and knowledge requirements. It is fair to expect that small farmers will go back to traditional / subsistence system of production in a first stage but it is difficult to expect them to bounce back into modern agriculture. Large producers will block the route and put tough entry constraints. Market as well as capital and access to knowledge constraints will be reinforced under free market system. Small land lords once chased out from production will not come back easily. The only chance for survival will come from farmer's organization at the early stages and a government assistance to “protect “small farmer's organizations through policies regulating land ownership and use. This may not happen at the early years once governments have commitments themselves to global regulations for free market. At later stage in the government’s interventions and small farmers organization may be too late to change the production systems.

There is concern about the future of small landholders. Again in many countries corporations may dominate production and resources use supported by government protection and security objectives. In this case small land holders are expected, if they do not migrate to other jobs outside agriculture to be integrated as labor in their own land operated by the corporations. A reasonable hypothesis may be stated with high confidence that subsistence farming will not attract future generations who will be looking for jobs in urban areas or outside agriculture. Consequently, land will be rented to corporation and the equation involving corporation versus small land owners' survival will result in a structure that favor large scale farming. Again small farmers may escape from this forced exit through organization and compliance with scientific production and distribution management. Traditional/Small farmers may shift from a system where farming is a way of life to another where farming is a profession, a job, a business that future generations will accept. The main policy issues that may arise from the structure of agricultural production due to land tenure problems are:

- In many countries land ownership is still skewed towards large proportion of land owners are small and occupy small proportion of total agricultural land. Smaller farm have proved to produce more in some countries but this not the rule.
- Small farming has been associated with low productivity and then with poverty in developing countries. Therefore, giving access to more land may break the poverty cycle.

5.4.6.6 Forest ecosystems and land tenure

Forest ecosystems as an integral part of land resources and land tenure issue have also drawn a great attention in many parts of the world with respect to the management and sustainability to Forrest resources. In Latin America Davis has demonstrated that fundamental changes need to take place in the legal recognition and demarcation of indigenous territories in order to preserve land and forestry resources. Davis indicates that there is growing evidence that tropical deforestation contributes to adverse changes in global climate loss of genetic diversity which may be critical to human survival and the impoverishment of local communities and economies. The role of indigenous people as potential managers of threatened tropical forest ecosystems has received considerable attention in national and international arenas. The United Nations Conference on Environment and development (UNCED) held in Rio de Janeiro in 1993 and the 48th International Congress of Americas held in Sweden in 1994 focused on this role and the importance of indigenous populations in the management of forest resources (Davis and Wali 2003). Indeed attempts were made in many LA countries to incorporate indigenous environmental knowledge, land use practices, and conceptions of space into an indigenous territorial model incorporating ethnographic, historical and ecological research

Many models of land tenure for indigenous populations have emerged in LA countries. In Brazil the Indian reserve system was the predominant land tenure system with a protectionist approach till the late of the 20th century when the Brazilian constitution which have facilitated the demarcation of indigenous territories but has not solved the structural problems of the protectionist approach. In the Andean countries (Peru, Ecuador, Bolivia) land tenure legislation has an integrationists approach where indigenous populations are integrated into regional development plans (Schminck1984). All three countries rely on laws provide by the agrarian reform codes under which land titles are granted to separate Indian communities (Davis and Wali 2003). Cooperative organizations formed by peasant populations where the only mean to obtain land titles in Peru and Ecuador as provided by the agrarian reform. In Bolivia land tenure was through rural syndicate introduced after the 1952 revolution as the major community organization. Preservationism is another trend for land tenure that emerged in 1960 in some countries of LA such as Venezuela, Brazil, Peru, and Bolivia where indigenous populations were left within national parks and wildlife refuges as long as they can maintain their traditional subsistence practices. These land tenure management systems were supported by UN organizations like UNESCO that contributed to the creation of several Parks which contain indigenous populations in their buffer zones in Costa Rica, Honduras and Bolivia. These systems have not deemed efficient in providing sustainable resources management and poses problems of land tenure.

In many countries as a result of either statutory or communal laws small communal and family land holdings have become overpopulated and fragmented within a single generation. Sustainable Land management on these holdings is no longer possible and returns from land recourses are far below optimal level. Davis argues in a study on Indigenous land tenure in Latin American countries that the conventional models of land tenure contained in agrarian laws have not provided enough protection to the targeted populations and to the ecosystems they live in. Recently the important role of the indigenous population has been acknowledged by many Latin American governments in the development of alternative land tenure and management models in the tropical forest of South America.

5.4.6.7 Land tenure policies and effects on development, poverty and sustainability

Land resources in African countries are increasingly governed by modern systems of tenure and less by customary systems. However, appropriate reforms in policies, laws and institutions have not accompanied changes in land uses, and land ownership patterns. Kagwanja (2006) argues that regulations on land uses in Africa has for a long time tended to protect large –scale export oriented farms at the expense of small-scale customary lands oriented mainly towards foods crops for the local population. He also argues that the unequal land distribution is hampering agricultural development by limiting access to land to many needy Africans or relegating them to marginal lands. Moreover, investments in land development have been hindered by insecure land tenure and in many case non-transferable nature of land.

While there is no quantitative date on land tenure effects on productivity and poverty alleviation many studies confirmed that tenure security for smallholders can play an important role in increasing productivity and reducing poverty. Lopez (1996) argues that more secure land tenure can enhance farm productivity and income by providing incentives to smallholders to make relevant investment, facilitate access to credit and production input. The estimated effect of land tenure security on productivity provided and annual rate of return of 17% was measured in Honduras (Lopez 1996).

Land resources conflicts are very frequent in many countries and raise a great concern. Ownership, demarcation, inheritance of land is the main subject of these disputes. Causes of these disputes as indicated by Kagwanja (2006) include unsuitable land legislation, dysfunctional and inaccessible administration. These disputes are further fuelled by population increases and consequently increasing demand for food. In countries with predominant customary land tenure systems households mainly from peasant and rural populations have security for access and land tenure. However, this security does not provide full and easy access to credits and input markets and only land titling is a solution to grant tenure security and land access. Land titling is at the same time costly and requires a lengthy procedure. It is considered very impractical for small farmers and raises questions on alternative options to improve the land legislation that optimize land resources uses.

In general land reforms agendas are either driven by efficiency or equity objectives or both. Land reforms should address all processes, including the capability of governments to undertake the relevant necessary reforms. With respect to reforming customary land tenure systems may involve legal recognition of customary land rights in order to improve efficiency by enhancing tenure security and land transfer. Consequently land resources productivity may improve as a result of easy access to formal credit lines and production inputs (WB 2006a). These reforms should also address the issues of improving land ownership rights, land tenure administration, dispute resolution.

In European Union countries the issue of ownership of agricultural land and natural resources has been at the core of the founding treaties of the EU. Historically, land policy has been a matter of national responsibility and there has been no attempt to produce harmonized land and inheritance laws (Grover, 2006). However, the Common Agricultural Policy requires Member states to follow certain policies mainly on land data collection and to create cadastres for agricultural land for the purpose of making payments to farmers. Member states of the EU are responsible for administering the Common, Agricultural Policy that has changed recently to become a system for supporting agricultural production to one of providing income support to land. Moreover, because of free mobility of capital in The EU countries investment is not possible without ownership rights. Therefore, restrictions on land ownerships are considered incompatible with EU treaties on the mobility of capital and protection of property markets against foreign ownership is not accepted. Restrictions on land ownership are likely to limit the free mobility of key assets by individuals and companies from other member states and therefore, will prevent investment. However, a number of new members from Central and Eastern Europe had imposed restrictions on the ownership of agricultural land by foreigners and sometimes on domestic companies. There has been the fear that individuals and companies within the EU will take advantage of their greater wealth to buy up relatively cheap farm land and housing so that nationals of the applicant country could find themselves priced out of their own land markets (Grover 2006). Many countries have argued that lifting the ban on the purchase of agricultural land by foreigners would lead to speculative land purchases and impede the development of viable family farms. Meanwhile some fear that opening up of land markets in all EU member States will probably open –up the past disputes. The fear that land may be purchased by wealthy Western Europeans is not unrealistic. Opportunities are open to businesses in Western Europe with remarkable economic power and wealth to acquire land in Eastern Europe. Prices of land are by far cheaper in these countries than in the East. Grover (2006), Vrbova (2005), Popp and Stauder (2003) have documented high discrepancies between land prices in Eastern and Western European countries since 2003 till 2006. For example, the average price per hectare of mixed and unequipped farm land in Scotland was 5300 euros, while average price of fertile land in Poland ranged from 1600 to 3100 euros.

It is expected that housing, including farmhouses and housing for rural population, and that in coastal and scenic areas and borders land areas with winter or water sports, fishing and hunting will be purchased as secondary residences by citizens, companies and investors from elsewhere in the EU. Most Central and Eastern European countries have been granted transitional exemptions from opening up their rural markets for period not longer than 5 years after their accession. The question that may be raised is what happens after these exemptions are removed. Eventually, rural land and secondary residential markets are expected to be accessible to wealthy purchasers from everywhere of EU countries.

5.4.6.8 Relevant policy issues

There is evidence of failing land tenure laws to enforce agricultural land preservation and to promote sustainability objectives (Mzumara 2003; Kagwanja 2006). Rural populations under weak land preservation regulations have failed to invest in long term land improvements on existing agricultural land and have also in many countries abandoned land in favor of migration to forest and other marginal lands.

Policies related to land tenure and resources access are of great relevance for the sustainable management and use of natural resources in all countries of the world where the majority of the population rely heavily on land to provide income, employment and livelihoods. However, the issue of land tenure has not received sufficient attention in many countries of the world (Maxwell and Wiebe, 1998). In recent years there is a growing recognition of the centrality of the land tenure in sustainable development process as witnessed by new land policies, and increasing local and international demands for relevant and sound land tenure laws and regulations.

In spite of the widely acknowledged importance of land security, cases of insecurity of rights have been reported in many developing countries. There are potential sources of land rights insecurity in these countries. In a study conducted by the Economic Commission for Africa to review the land tenure systems in selected countries in Southern Africa it is indicated that land insecurity is highly widespread and sources from unclear land rights, population overcrowding, land alienation, and inappropriate administrative practices and limited women, rights to land (Mzumara 2003). Many countries have already started revision, improvement and reformulation of land policy and tenure. Most policy reforms have addressed country specific problems and issues. However, inappropriate administrative and institutional practices are found on most reform agendas. The results are low productivity of land, migration of rural population and increased poverty rate.

In many developing countries customary tenure systems remain the predominant means through which management and access to land is possible. These customary systems are characterized by a high degree of inalienability of land to the extent that in many countries owners have secure and inheritable land holdings cannot be traded freely in a market. In the Niger delta for example these systems are based on values of the local people to the extent that these values confer legitimacy on the decision making process (Joab 2005).

With respect to natural resources Schlager and Ostrom (Davis and Wali 2003) argue that the most relevant operational level property rights are access and withdrawal rights. Access is defined as the right to enter a defined physical property and withdrawal is the right to obtain the product of the resource. Participatory land management involves collaborative, joint and community based management (Joab 2005). The point of interest is each of these discourses arose out of a much greater concern for the rural poor and disenchantment with large scale, top-bottom, centrally planned and managed development projects (Joab 2005).

Despite some progresses made by some counties in Africa, Eastern and central Europe, and Latin America much remains to be done in the field of land management. Land tenure reform is not a matter of changing the rules, but of implementing these rules at reasonable transaction costs. At the core of land tenure reforms and policy changes is the capacity building issue. The study of Economic Commission for Africa argues that adequate and relevant land tenure reforms requires the development of training programs that enhance capacity building and skills development in the field. Providing security of land tenure has been seen as a precondition for intensifying agricultural production and as a prerequisite for better natural resources management and sustainable development and therefore a factor for poverty alleviation (Mzumara 2003).

Extensive literature suggests that increased security of tenure in productive resources leads to enhanced and sustainable agricultural production (Maxwell and Wiebe 1998). Land tenure security leads to higher investment and higher agricultural production. There is evidence that secure property land rights have a high link with higher propensity to invest in tree planting, manuring, soil and water conservation and other permanent improvements (Maxwell and Wiebe 1998). The World Bank has focused since the 90's on land tenure security through financing projects in Central and Eastern Europe, Latin America and East Asia as a potential media for agricultural development (WB 2006a).

Here AKST could shift towards the integrated and systemic analysis of land resources tenure and management regimes that respect to a greater extent the multifunctional base and effects of agricultural production. Research agenda should focus on social, economic and institutional aspects of land management. As noted by Michael Cernea, in a review of social research in the CGIAR, there is now a strategic understanding that “the management of natural resources clearly has social and behavioral components the understanding of which is indispensable for orienting biophysical research to these resources. Behavioral and socio-cultural-variables of resource management are no less important for resource sustainability than physical parameters” (Cernea 2005)

Small farmers and land tenants in developing countries and under customary systems need extension services that focus on land conservation and environmentally friendly technologies of farming. AKST may also focus on developing relevant extension programs. Management of resources in agriculture is related to gender. What does this imply for sustainability? It certainly means that research needs to closely look at existing gender-related patterns of resource access and control, to arrive at meaningful conclusions. While sustainability has to be a target of the farm operation, there may be differential factors at work here.

5.4.7 Food safety and food security

5.4.7.1 Food safety and its impact on food security

Food safety is receiving heightened attention in both Developed Countries (DCs) and Less Developed Countries (LCDs) (Unnevehr 2003). There are several reasons for this growing interest. First, the "demand" for safe food rises as income increases; consumers become willing to pay more for food with lower risk of microbial contamination, pesticides, and other disease-causing substances. Second, as technology improves, it is easier to measure contaminants in food and document their impact on human health. Third, trade liberalization has increased opportunities for agricultural exports, and food safety regulations have become the binding constraint on food trade in many cases. Fourth, international food scares, such as BSE and avian flu, have made consumers, producers, and legislators more aware of the risks associated with food safety problems.

A food hazard is defined as "a biological, chemical, or physical agent in or property of food that may have an adverse health effect" (WHO 1995), involving also any negative impact of elements of nutrition such as additives, functional foods and natural supplements (FAO/WHO 2006). Food is particularly vulnerable to hazards since its conception involves numerous practices and because harvested food passes through many hands and often through a number of channels before reaching the majority of consumers (e.g. those in urban areas). Food safety hazards can be encountered anywhere, from the farm to the table. Therefore efficient control programs are needed throughout the whole supply chain (Todd et al. 2006).

Many food safety hazards stem from problems associated with inputs into production and handling of commodities. The supply chain in many LDCs is now often based on anonymous transactions in spot markets, implying limited communication and coordination between farmers, traders, and consumers. This lack of coordination coupled with poor infrastructure and insufficient cold storage systems create an environment in which market participants have little incentive to reduce microbial pathogens and pesticide residues (Narrod et al. 2005). As supply chains become more complex, supply chain management (SCM) plays an increasingly important role in the delivery of high-value agriculture (HVA) products to distant markets. Given the perishable nature of HVA and the demand for quality and safety attributes, networks, skills, and coordination mechanisms are needed to manage commodities between intermediaries and ensure meeting the quality specifications (Narrod et al., forthcoming).

These increased food safety standards are particularly worrisome in terms of food security and the livelihood of the poor as multinational companies that establish production centers in LDCs often exclude poor households who do not export, and find it difficult to meet foreign as well as domestic standards. Producers face four distinct problems: 1) how to produce safe food; 2) how to be recognized as producing safe food; 3) how to identify cost-effective technologies for reducing risk; and 4) how to be competitive with larger producers who have the advantage of economies of scale in compliance for food safety requirements (Narrod et al. 2005).

Indeed, while production and marketing to domestic markets has long been associated with lower food safety standards, rising incomes and globalization has increased the desire for safe food in LDCs and could further compromise market access by poorer farmers in the future.

In addition to ensuring that food is produced in a safe manner farmers aim markets that demand food of a certain standard size and of a certain visual quality. Many smallholders are growing in marginal areas that require the use of pesticides, which often are applied in an unregulated manner. Overuse or poor timing in the use of pesticides and food borne diseases are some of the most widespread health problems in the world, with direct implications both on the individuals' health and the development of the societies (WHO 2000). Improvements in safe agricultural practices, such as integrated production and pest management, can lead to substantial improvements in yield gains but also in health and safety of workers. In addition to over use of pesticides, other threats to contaminated agricultural products and consumer health includes lack of clean water for produce washing, contamination by dust and airborne pollutants, poor handlers hygiene, improper storage and deteriorating urban environments. Good agricultural practices (GAPs) have been suggested to help developing countries cope with globalization while not compromising their sustainable development objectives, especially because no intervention mechanism, other than irradiation, is currently available to completely decontaminate agricultural commodities eaten raw (Fonseca 2006). In recent years, a number of initiatives has been developed to support the adoption of GAPs and Good Manufacturing Practices (GMPs) and to help public institutions implement them in developing countries.

5.4.7.2 Nature of market and products and the relevance of AKST

Consumer attitudes and expectations on food safety clearly differs depending on the targeted market is, a situation that will likely not be changing anytime soon. Producers in most developing countries are supplying three distinct markets; the domestic traditional markets, modern urban markets, and export markets (Narrod et al., forthcoming). These markets differ in several organizational respects but most importantly in their demand for food safety. The food safety requirements are most stringent in the export markets (in high income countries) followed by the modern domestic urban markets.

In the urban domestic markets and most importantly in the export markets, the supply chains are highly coordinated with requirements of high food safety standards and in some cases traceability, which will become more sophisticated during the next few decades. The domestic traditional markets exhibit low levels of food safety requirements and are thus characterized by several spot market transactions. The narrower the gap between the traditional and urban market, the more likely a country will find its way to comply with food safety expectations in the international arena (Kurien 2004), however very little change will occur if not major effort is pose in either education of local consumers or production for the export market.

The export markets are considered a very lucrative market, due to higher margins for which producers can receive compared to the local market. However, in order to receive these higher prices producers in developing countries are faced with meeting the increasingly set of public and private standards, including those on GAPs, which limits the penetration of product into developed countries' markets, but also creating opportunities for improvement. Private rather than public standards are becoming the predominant drivers of the agri-food systems (Henson and Hooker 2001; Henson and Reardon 2005). In developing countries where institutional capacity often limits the enforcement of mandatory public standards, firms are also increasingly relying on private standards (Loader and Hobbs 1999).

These new market opportunities, which demand a certain level of food safety compliance and the ability to ensure traceability often disfavor smallholders due to the high associated coordination costs. The problem is exacerbated by geographic dispersion, low education, and poor access to capital and information (Poulton 2005; Humphrey 2005; Rich and Narrod 2005). Because of high transaction and marketing costs of sourcing from smallholders, major exporters produce HVA in their own farms or source from medium and large out growers trained and trusted to deliver both traceability and food safety (Narrod et al,. forthcoming).

Appropriate food safety regulation is considered fundamental to expand products from LDC into developed and other developing countries (Babu and Reidhead 2000; Pinstrup-Andersen 2000). Labeling will be used as tool in these countries to demonstrate that the food is safe to eat, however, in some cases labeling will become a mechanism by which consumers will associate quality and safeness of a product, weighting more perception and reputation that the actual quality characteristics. A more stringent label regulation, including description of origin of food's ingredients of processed agricultural products, could inevitable create an unnecessary obstacle to future trade agreements (Matten 2002).

One way small scale producers can meet increased food safety requirements is by pursuing the direction of fewer chemicals and more nature friendly products, which go parallel with the development of less persistent pesticides. However in the short term the cost of these new pesticides seem higher than former pesticides and in many cases aren't affordable to producers in the least developed world, where low-cost labor often compensate the multiple applications, needed with some of the old pesticides, which might be of low quality or adulterated (Carvalho 2006; Dinham 2003). Countries in the tropical belt are challenged by environmental conditions and by not enough AKST developed to overcome their intrinsic productivity limitations.

GM products are a potential way to enhance agricultural productivity for many producers having a difficult time in increasing yields without a heavy dependence on pesticides. GM products have been used for relatively long time, if taking into account that near 2000 crop varieties were created in the past through irradiation and mutation of DNA, however, there is a low level of acceptance of raw GM fruit and vegetables (Harlander 2002). In the future some GM foods might be more readily accepted by the consumers. Rice could be an example since currently and with the varieties available there are not sufficient natural resources or money to produce all the rice needed in the world (Cantrell 2002). In fact it has been suggested that GM rice could one day help in eliminating vitamin A deficiency/xerophthalmia (Egana 2003). However, a major obstacle to the increase of GM consumption would be created if GM foods are connected with a new toxin, anti-nutrient, allergen or bioactive substance that could have been inadvertently incorporated up- or down-regulated as a result of genetic manipulation (Konig et al. 2004). Also, another concern is the possibility of horizontal transfer, from plant to bacteria, of antibiotic-resistant gene usually introduced to the plant in the process of plant transformation (Thomson 2003). Moreover, it is unlikely that there have been enough testing of the impact of GM foods on health, but risk assessment can be expected to improve in the future, as AKST becomes better able to identify risks and hazards more precisely (Burkhardt 2000; Konig et al. 2004).

Some industries will need a especial approach to demonstrate safety standards, especially when social, economical and health issues align together in the production of food. Despite the fact that there is no evidence that organic product pose higher food safety risks than conventional products in neither developed (Bourn and Prescott 2002) nor developing countries (Nguz et al. 2005), under the assumption that the product have truly been farmed under certified conditions (Mukherjee et al. 2004), some intrinsic characteristics of the industry may be considered challenging. The production of organic livestock for instances may be a challenge since it is an industry/market characterized for certain values and practices that may compromise safeness of the product. The main concern in this regards is ensuring good animal welfare and giving animals good living conditions, but outdoor life (and not animal confinement) pose more risk for diseases and low quality of the animal products (Vaarst et al. 2005). AKST development for these types of emerging demanded industries may create an opportunity of specialization for some developing countries.

5.4.7.3 Involvement of private and public sectors: Two pathways for the next decades

The spurt in private standards has been partly driven by the events of food safety failures in the eighties and nineties (Dolan and Humphrey 1999, 2000; Freidberg 2003, 2004). With several standards in practice, there have been attempts to harmonize globally with the formation of Global Food Safety Initiative (GFSI). The major goal of GFSI was to “create a global set of voluntary but universally accepted standards of food safety, quality and security” (Freidberg 2005). In case of pesticide residue limits for example, the GFSI intended to eliminate situations where some countries demand compliance with Codex Alimentarius, while other impose their own limits.

As it is difficult for the supermarkets to identify which products have been produced under specific protocols, firms meeting guidelines will continue trying to distinguish themselves from those who do not. As consequence in developed countries, retail industry and private retailers will continue developing and improving private food safety protocols. Reardon et al. (2003) suggest the rise of private standards as 1) strategic tools by the supermarkets to differentiate themselves 2) instruments of supply chain coordination by standardizing product requirements across all suppliers, 3) substitutes for missing or inadequate standards in less developed regions, and 4) a strategic tool over the informal sector by claiming better food safety. Initiatives of produce growers and shippers to create industry agreements are part of on-going discussions (California Department of Food and Agriculture 2007) but could be fundamental in the future to assure industry quality standards across a particular region or country.

Supermarkets will likely continue rising very fast in developing countries (Reardon et al. 2001, 2003; Berdegué et al. 2005), and the preference of consumers to shop where perishable commodities quality is high will promote the link between wholesalers, retailers and food safety agencies. Major food retailers in Central America, for example have already implemented stringent food safety regulations, sampling more than 20 types of products daily, those associated with higher chance of having pathogens or pesticide residues such as leafy greens and tomatoes (Berdegué et al. 2005).

Clearly, even having the private industry in the lead of the establishment and monitoring of food safety regulations, the national health entities will be responsible for informing the general public about potential and actual health problems associated with consumption of food. However, in most countries, the surveillance infrastructure is inefficient or nonexistent. In fact, in many developing countries, laboratory resources and skills to identify pathogens are scarce, and etiology-specific surveillance is often no possible (Schlundt 2002). Recent changes in maximum permitted concentration of pesticides by some countries have challenged even the detection limits of current analytical methods which will limit the expansion of the private sector, especially if the local market is not of considerable large size to justify the investment (Carvalho 2006).

Implementation of quality and food safety control programs with intensive internal and external supervision can improve productivity rather than increasing costs for consumers. In some developing countries large produce suppliers with dedicated and specialized perishable wholesalers will be able to save significant amount of sale-related costs as a result of production cost reduction with technical assistance, quality assurance systems and selection of preferred growers, in a semi vertical-integrated business (Berdegué et al. 2005).

Upon hesitation of national entities to control food safety programs due to its effect on food security, private agencies will use it for their advantage by developing reputation that can be associated with high quality products. Trust for quality will be in fact one of the most important issues for consumers in the future, since conventional food borne outbreaks have similar psychological consequence as bioterrorism. This is because regardless of the source of contamination food represents security, comfort and the ability to provide basic needs to those who rely on others for protection and support (Bruemmer 2003). As mentioned, associations of growers themselves could be part of the food safety private initiatives as they will be the most interested in maintaining a sustainable business.

For some developing countries several constraints hamper the progress in implementing food safety regulations, including lack of human capacity, importance of food safety in the political agenda and inadequate post harvest and laboratory infrastructure and organization (Babu and Reidhead 2000). The private sector will need to implement an important effort toward developing better training in certain agricultural practices. A country like India, still with low overall use of pesticides, consistently show products with pesticides residues (Gupta 2004) denoting the need for more efficient agricultural education. Food safety issues and sense for locality could be a direct competitor to producers, and food safety agencies, from developing countries with some comparative advantage in production of agricultural products. In some developed countries 2/3 of consumers will likely spend more money if more local produce, livestock and fish products are available (Nabhan 2004).

5.4.7.4 Governments enforce policies

In the event of serious food safety crises, governments will react directly in several ways such as creating state food safety agencies, educating in, certifying and monitoring the implementation of standards and record keeping, increasing rigor of minimum quality standards and establishing new rules for product traceability, a situation that has happened already in European Union (Codron, Giraud-Heraud, and Soler 2005).

The free trade market movement and particularly the need to reduce internal hunger and augment chances to explore international markets will also result in more governments imposing their own rules or in mandating the established international regulations. For some countries this will certainly create a major challenge as there are concerns about the possibility of mishandled information to affect the perception of the international consumer. Food export could be rejected and/or the potential loss of tourism is a disincentive for many governments to release information on food borne disease and food borne contamination (Schlundt 2002). The most relevant point for this scenario to root in the future regards to the fact that the government action will be conditioned by how decisions will affect the distribution of costs and benefits over actors (Codron Giraud-Heraud, and Soler 2005). Clearly, the final product cost and potential restrictions of products are concerns.

The mechanism to monitor regulation enforcement as a nation will not be an easy task due to the diverse agents comprised by the food system. It is possible that a national initiative will stimulate what has already started in many regions of the world, the vertically integrated chain, with large distributors and national companies handling the food at every step of the chain. This however will also cause challenges for which we have seen examples in recent years. In France a national initiative aiming an integrated farming system which allows communication of GAPs to consumers gave rise to an issue, that much produce is imported and thus cannot be marketed with the "integrated farm management" label even if the product comes from a recognized private label certified (e.g. EUREPGAP) farm (Codron Giraud-Heraud, and Soler 2005).

In some developing countries the role of the government will still be amply intensive even in a private sector-leading scenario. This is because the infrastructure for examining water and product samples might not be economically feasible for private agencies, which in turn will force the government to provide the service (Berdegue et al. 2005). Moreover, in some developed and developing countries, with a leading private sector in the food safety area, governments will also play an important role through the establishment of job benefits. An important number of workers and produce handlers are willing to work when they are ill because they can't afford to stay at home without pay (Fonseca and Nolte, forthcoming).

The decision of governments to directly control the enforcement of policies may only be true in some agricultural industries such as fishery. The aquaculture industry is expanding rapidly in many developing countries, an activity observed as positive given the important source of protein fish is (Thorpe et al. 2006). However, quality of certain seafood products may be a concern as it is known that in some areas of the world consumption of seafood, in particular inexpensive mollusks, provides metals and other substances that accumulate in their tissues (Astorga-España, Rodríguez-Rodríguez and Díaz-Romero 2007).

Regulation of GM foods could be another area where governments will likely play a major role, in both developed and developing countries. Production of GM crops is a relatively simple technology and is clearly within the capabilities of national research institutes in many developing countries (e.g. Argentina, China, India, Mexico, Brazil). In addition, some other countries could be benefited by alliances that bring together researchers from many countries to work on a common effort (Chrispeels 2000). Some countries believe that a mandatory process-based label on genetically engineered food may be perceived by many consumers as a warning label that the product is unsafe, and therefore could be misleading and inappropriate as mandatory international guideline.

5.4.7.5 Final remarks

The main challenges for the next decades is first to assure safer food to consumers, and raise quality life without creating a barrier to poor countries/producers for opportunities of success. The concern is that food safety may only be "purchased" by some consumers, a situation that could be particularly notorious with products sourced from long-distance areas (Schillhorn van Veen 2005). Secondly, in our search for mechanisms to improve food security in the world we are challenged to develop a system that will not cause the emerging of currently unknown health problems.

The two future paths on food safety regulatory mechanisms described above (private sector providing education, auditing and analyses or government enforcement and monitoring) will be affected by the type of market to which products are directed. Moreover, even with national enforcements some countries might continue to have regulation that differs substantially from those required in the export market and other local markets. The pressure over natural resources will determine some "natural" differences among countries. While Australia might consider the use of reclaimed water, other countries will continue with firm position against it due to concerns with food safety-related issues (Hamilton, et al. 2005). Some countries with known overdependence on pesticides but with the potential capacity to develop a more systematic approach, such as India (Gupta 2004) will have the opportunity to improve internal standards and increase presence in the export market.

The more informed consumers are the more opportunities for producers will be developed. A system of seaweed production in great highly liquid tank culture may be unaffordable now but could be feasible in the future upon growing demand. Clearly, a subsequent development of AKST to maximize its production without compromising safeness of the process and security of other food industries will be needed (Nazrul-Islam 2004).

Food safety regulation will be more difficult for developing countries, and should be accompanied with a strong support toward development of AKST and maximum diversification permissible by the local conditions. Bangladesh, once extremely dependent on food imports, has transformed its devastated agricultural sector into one of the most productive farm economies in the region through partnership with foreign aid agencies, international research institutions, and indigenous organizations. Greater crop diversification and food safety regulation will help further food security in Bangladesh (Nazrul-Islam 2004).

It is clear then that demand for product with high standards of overall quality and safety will continue to grow in developed countries, a market that will only be accessible to those developing countries with sufficient AKST capacity. On the other hand, in developing countries, better quality standards, perhaps set by supermarkets, will only occur if consumers are educated toward the benefits of consumption of perishable products, if public health regulation and liability laws are established, and if better laboratory infrastructure is built. This situation will probably be accessible in countries with relatively significant middle economical class and with true potential for government enforcements (Berdegué et al. 2005).

Consumer pressure for safer food will increase, while economic globalization will dramatically raise the risks and costs of food-borne diseases, as it has lately been witnessed in some of the developed countries. It will become particularly difficult to control factors that compromise outbreak risks without collaborative international effort (Burlingame and Pineiro 2007). A new approach will be necessary, one that incorporates food safety issues into the development of trade negotiations. Enhancing communication among policymakers from countries with common interests will allow transfer of success schemes to those with those in more need. It is likely that organizations of poor actors and collaboration of NGOs with governments will remain important positive supports (Babu 2004).

5.4.8 Biotechnology and biodiversity

Agricultural biotechnology encompasses a range of scientific tools used to understand and manipulate the genetic structure and function of organisms for practical use in agriculture. Genetic engineering is the most controversial tool within the biotechnology toolkit. A number of challenges – scientific, regulatory, social and economic – will fundamentally influence the degree to which genetic engineering is used in crop and livestock improvement research over the coming decades. Greater or lesser use of genetic engineering will, in turn, shape the evolution of the agricultural sector and biodiversity. This subchapter examines alternative policy development pathways that could determine whether genetic engineering becomes a mainstream, routine part of agricultural crop and livestock research portfolio or whether it is abandoned in favor of more conventional approaches. The implications for the evolution of the agricultural sector and biodiversity – natural and agricultural – are explored.

5.4.8.1 Genetic engineering vs. conventional breeding

Agricultural output has doubled since the 1960s and will need to increase by a further 85% by 2050 to meet projected demand for food, fiber and fuel. Yield improvement, based on conventional breeding, has been responsible for 90% of the growth in agricultural output since the 1960s, but yield growth is slowing down. Without significant improvements in yields, millions of hectares of land will have to be converted from pasture and forest to cropping.

Genetic engineering is both a more precise extension of breeding techniques that have been used for centuries and a radical departure from previous experience. Unlike conventional breeding, which produces new genetic combinations through cross-breeding, and mutation breeding, which introduces thousands of unknown genetic changes through the application of chemical agents or radiation, genetic engineering involves the transfer of one or more precisely selected genes into the genome of the host organism. The ability of genetic engineering to transfer genes across the species barrier or indeed across kingdoms is precisely what gives the tool such power and what attracts such controversy.

Conventional breeding and genetic engineering are complements – not substitutes – so a development pathway that posits one against the other is inherently unrealistic. Because transgenic traits must be incorporated in suitable, locally adapted cultivars before they can be of use to farmers, strong traditional plant breeding capacity is required. Similarly, some breeding challenges are intractable with conventional tools because desirable traits may not exist within the genome of the target species. Transgenic approaches could be the only way to overcome such intractable challenges.

Genetic engineering can also be used within a single species to speed up the breeding process by inserting a specific gene into an otherwise desirable genetic background without requiring multiple generations of backcrossing to eliminate unwanted changes, as is necessary with conventional breeding. Genetic engineering can thus supplement conventional breeding approaches, broadening the range of useful genetic variation or speeding up the crop improvement process, but it cannot replace conventional breeding.

Thus far, transgenic approaches have focused on overcoming specific production constraints, rather than on overall yield improvement. Yield improvements associated with some transgenic crops have come indirectly through better pest, disease and weed control rather than through improvements in agronomic yield potential. It is likely that a combination of transgenic and conventional breeding approaches will be necessary to meet the crop improvement requirements of the next 50 years.

5.4.8.2 Factors influencing the adoption of transgenic crops

Farm level profitability ultimately determines whether farmers will adopt and retain a new technology, but this depends on much more than the technical performance of the innovation. Institutional factors such as national agricultural research capacity, environmental and food safety regulations, intellectual property rights protection, and the existence of efficient agricultural input and output markets matter at least as much as the technology itself in determining the level and distribution of economic benefits.

A certain level of national research capacity is a prerequisite for the adoption of transgenic innovations. Genetic engineering is a relatively difficult and expensive research method compared with conventional breeding. Despite a few early successes, the development of beneficial transgenic applications has proven to be more difficult than many early predictions suggested. Only a few developing countries have the research capacity necessary to develop autonomous transgenic constructs and many lack the basic plant breeding capacity required to adapt imported transgenic innovations into locally adapted cultivars.

Concerns over the proprietary nature of most transgenic innovations and the potential for monopoly exploitation have created an additional layer of resistance to the technology. Most of the transgenic crops now available commercially were developed in the private sector and the innovations are held under strict intellectual property rights rules. Countries must ensure a minimal level of IPR protection in order to attract private investment in transgenic innovations suitable for their local conditions. On the other hand, countries must also ensure the equitable sharing of the economic benefits derived from transgenic innovations.

Transgenic crops and animals face a wide range of rapidly changing biosafety and food safety regulations around the world. Completing the necessary laboratory and field-level safety tests and compiling the supporting documentation for approval of a new transgenic crop event have been estimated to cost about US$10 million in the United States, roughly equal to the costs incurred in the research stage. In many countries where regulatory procedures are less transparent and less predictable, costs associated with foregone commercial opportunities due to unexpected delays may be even higher than the direct costs of regulatory compliance.

Excessive regulatory costs are likely to fall more heavily on small local firms and public research institutions than on large multinational companies since the former may lack the financial capital and experience required to manage the regulatory process. Ironically, this regulatory burden may decrease prospects for the development of transgenic crops and traits suitable for small-scale farmers in tropical and sub-tropical regions.

Regulatory systems also influence the impacts of transgenic crops on natural and agricultural biotechnology. Some countries require each new cultivar containing an approved transgenic trait to undergo a separate biosafety testing procedure. This can significantly retard the incorporation of the trait into locally adapted cultivars, narrowing the range of genetic diversity within a crop. More broadly, if regulatory procedures unnecessarily delay the adoption of yield-improving innovations, they can foster area expansion, potentially bringing uncultivated land into production, with negative implications for natural biodiversity.

Given the many factors that influence the development and deployment of transgenic approaches, it is clearly possible to envisage a future in which the technology would be used relatively little. For example, transgenic approaches to plant and livestock improvement could be abandoned if any serious harmful effects on human health or the environment were discovered, especially if the problems were found to be inherent to the technology. On the other hand, further positive experiences with the current generation of transgenic crops and the development of new transgenic innovations having clear consumer or environmental benefits could lead to greater acceptance and use of the technology.

5.4.8.3 The status quo

Despite the existing barriers to the development and deployment of transgenic innovations, transgenic crops have been adopted rapidly in many countries, and now covered more than 100 million hectares after only ten years of commercialization (James 2007). While transgenic crops are being adopted rapidly at the global level, relatively few developing countries are growing them in significant quantities and the countries of the European Union currently have only one transgenic crop approved for cultivation. Ten years after the first transgenic crop was commercially grown, four crops and two traits continue to account for 98% of global transgenic crop area.

The economic evidence thus far shows that on average farmers who adopt transgenic crops benefit in terms of lower production costs, lower crop losses, greater convenience and higher net returns. The economic evidence available to date suggests that transgenic crops may be pro-poor (Ruttan 2004) and that the benefits are broadly shared by consumers, technology suppliers and adopting farmers, although non-adopting farmers are penalized as their competitors achieve efficiency gains they are denied (Anderson and Jackson 2005). Furthermore, evidence is mounting that some transgenic innovations are beneficial for the environment by reducing pesticide use (Pray et al. 2002) and facilitating the adoption of conservation tillage (Qaim and Traxler 2005).

Despite the positive evidence so far, the pace of transgenic crop approvals has been slow in many countries and new crops and traits have not emerged as quickly as many observers expected. With a few small exceptions such as Bt white maize in South Africa, Bt rice in Iran, and virus-resistant papaya in the United States, the transgenic crops currently being produced commercially are primarily for non-food uses. No major transgenic food crop has been introduced on a large scale anywhere in the world.

This suggests that the status quo pathway will involve continued rapid adoption of insect resistant and herbicide tolerant maize, soybean, cotton and canola varieties in the developing countries where they are already approved. More developing countries are likely to approve these crops – especially Bt *(Bacillus thuringiensis*) cotton and yellow maize – under status quo conditions. Adoption of Bt maize in Europe will continue to expand slowly due to consumer resistance, despite growing tension between consumers and farmers (who see their competitiveness eroding in the face of competition from countries where adoption is proceeding).

5.4.8.4 Policy development pathways: more biotechnology

The continued safe introduction and use of the current generation of genetically engineered crops and the emergence of transgenic innovations of direct benefit to consumers or the environment could lead to greater public acceptance of transgenic approaches and ultimately to a rationalization of regulatory regimes across countries, traits and crops. This in turn could mean that the costs (monetary and temporal) of transgenic research, development and deployment could fall significantly, leading to the rapid growth in the number of transgenic events and their pace of adoption.

Several transgenic crops engineered to provide direct consumer benefits are in the research and regulatory pipeline, such as oilseeds with improved lipid profiles and staple grains with vitamin and mineral fortification. Three major transgenic food crops are on the brink of approval: Bt rice, herbicide tolerant wheat and nutrient reinforced rice. Traits for the remediation of polluted or degraded land or adaptation to heat and drought could assist in dealing with current agro-environmental challenges and in the adaptation to rapid climate change. Any of these developments could lead to a more rapid expansion of genetic engineering in crop and livestock improvement.

5.4.8.5 Implications for the agricultural sector

Such developments would likely lead to productivity gains in agriculture, potentially with important benefits for small farmers in the developing world. Since most of the world's poorest people live in rural areas of developing countries and depend on agriculture for their livelihoods, improving agricultural productivity remains the key to poverty reduction. Recent research shows that agriculture-led growth reduces poverty more strongly than growth in other sectors (Bresciani and Valdes 2007).

Transgenic crops differ in the extent to which they are pro-poor, depending on the cultivation practices associated with them, the IPR and biosafety regimes that apply and the extent to which smallholders have the necessary resources (human, physical, financial and social capital) to enable them to adopt new technology. Insect resistance traits have been shown to be strongly pro-poor, in China, India and elsewhere, because the technology is embodied in the seed, the most scale-neutral form of "technology" imaginable. Nutritionally enhanced seeds could also be strongly pro-poor for similar reasons. Herbicide tolerant crops have generally been adopted by large commercial farmers so far, although herbicide tolerant soybeans have been successfully adopted by relatively small (by Argentine standards) farmers (Qaim and Traxler 2005).

On the other hand, economic impacts tend to be more pro-poor where significant market competition exists in the supply of transgenic seed. For example, the insect-resistant cotton varieties developed independently by the Chinese Government have introduced enough competition in the Chinese seed market to keep market prices low, allowing small farmers to reap the majority of the economic value created by the crops (Pray et al., 2002). In contrast, the Argentine Bt cotton market is not competitive, and the seed supplier charges such high prices that the crop is not profitable for farmers and hence has not been widely adopted (Qaim and de Janvry 2003).

Where access to productivity-enhancing technology is denied to small-holders, they would be disadvantaged relative to other farmers. Farmers in countries where the technology is discouraged would fall behind their international competitors who have access to transgenic innovation, unless they can find and fill a market niche for GM-free products.

Within a country where transgenic crops are available, smallholders could be disadvantaged if they are excluded from the process of technology adoption, either as a result of explicit policies targeting larger commercial farms for technology improvement, or through a lack of knowledge or resources needed to facilitate technology adoption. This could foster a consolidation of farms as larger farmers become more competitive and expand their operations.

5.4.8.6 Implications for biodiversity

The impacts of a rapid expansion of transgenic crops on natural and agricultural biodiversity could be significant and will depend in part on how regulatory regimes evolve. Natural biodiversity could be affected through crop yields and their implications for land use, potential out-crossing of transgenic material to related crop and wild species, and direct and indirect effects on non-target species. Agricultural biodiversity could be affected indirectly, much as it was by the spread of modern green revolution varieties, as well as directly through the use of the technology.

The most direct way transgenic crops could affect natural biodiversity is through their effect on crop yields and associated pressures influencing land use. To the extent that transgenic innovations support yield growth (or reduce crop losses to pests and diseases), they could alleviate pressure to expand crop production into currently uncultivated areas, protecting the natural biodiversity that exists there.

The potential of transgenic material to spread to related wild or agricultural species has been the subject of intense scrutiny and debate. The potential for out-crossing to wild or agricultural relatives varies by crop. Transgenic varieties of crops that have a high propensity to outcross typically have not been approved for cultivation in areas where wild relatives are endemic. Most crop species, whether transgenic or not, are unlikely to be able to reproduce and persist in the wild, and management strategies can be used to minimize the risk (FAO 2004).

The potential for transgenic crop varieties to cross with conventional varieties clearly exists, although transgenic traits that do not confer a competitive advantage are unlikely to persist in farmers' fields unless they are specifically selected for. Out-crossing to wild or cultivated relatives could be prevented by the use of genetic use restriction technologies, but this approach is controversial and has not been developed commercially. Whether the existence of an otherwise benign transgenic trait in an agricultural crop constitutes a meaningful loss of biodiversity is a matter of debate, particularly if it is a trait farmers have selected for (Raney and Pingali 2005).

The pattern of crop genetic diversity in the developing world has changed over the past two centuries with the modernization of agriculture, and accelerated with the green revolution. The germplasm that dominates the major cereal crops has shifted from the locally adapted populations that farmers historically selected from the see they saved – often called “landraces” – to the more widely adapted seed types produced by scientific plant-breeding programs – called “modern varieties”. To the extent transgenic crops foster the adoption of modern varieties they will perpetuate this trend.

Whether modern variety adoption necessarily reduces agricultural biodiversity is a matter of debate. Agricultural biodiversity is important because it influences the resilience of crop ecosystems and maintains a “library” of genetic resources for current and future breeding activities. The domestication of wild plants into landraces narrowed the genetic base for these crops as farmers selected among the full range of plant types for those that produced more desirable results (Smale, 1997). Although more genetically uniform than their early relatives, landraces are characterized by a high degree of genetic diversity within a particular field. Modern varieties, on the other hand, tend to exhibit little diversity within a particular field, but each plant contains genetic material from a wide variety of progenitors and is adapted to perform well across a wide range of agro-climatic conditions. A simple count of the varieties in a particular area or measures of genetic distance among varieties thus may not tell us much about the resilience of crop ecosystems or the availability of crop genetic resources for breeding programs (Raney and Pingali 2005).

Transgenic techniques can directly affect agricultural genetic diversity. Transgenesis permits the introduction of genetic materials from sexually incompatible organisms, greatly expanding the range of genetic variation that can be used in breeding programs. Transgenesis allows the targeted transfer of the genes responsible for a particular trait, without otherwise changing the genetic makeup of the host plant. This means that a single transgenic event can be incorporated into many varieties of a crop, including perhaps even landraces. Compared with conventional breeding in which an innovation comes bundled within a new variety that typically displaces older varieties, transgenesis could allow an innovation to be disseminated through many varieties, preserving desirable qualities from existing varieties and maintaining or potentially increasing crop genetic diversity (Raney and Pingali 2005).

On the other hand, the widespread incorporation of a single innovation, such as the Bt genes, into may crops and varieties may constitute a kind of genetic narrowing for that particular trait. Furthermore, transgenic crops that confer a distinct advantage over landraces may accelerate the pace at which these traditional crops are abandoned or augmented with the transgenic trait (Raney and Pingali 2005).

Regulatory regimes are concerned with the potentially harmful consequences of gene flow from transgenic crops to conventional varieties or landraces. In this context, it is important to recognize that gene flow from conventional varieties to landraces frequently occurs (especially for open-pollinated crops such as maize) and is often consciously exploited by farmers. It is likely that, in the same way, farmers would consciously select for transgenic traits that confer an advantage (de Groote et al. 2004).

Finally, regulatory decisions influence the implications of transgenic approaches for biodiversity, often in unexpected ways. For example, when biosafety procedures require the separate approval of each plant variety containing a transgenic event, it slows the development of new varieties and narrows the range of genetic diversity available to farmers. Similarly, when new transgenic approaches to address a given production constraint (such as herbicide tolerance) are delayed, the approved technology may be overused with negative consequences for biodiversity and other environmental indicators.

5.4.8.7 Policy development pathways: less biotechnology

If society determines that the risks associated with transgenesis in agriculture exceed the benefits, the tool could be abandoned. Agricultural improvement research would continue, however, as it must to meet current and future challenges. Other research tools would be used more intensively, including conventional and mutagenic breeding. Non-transgenic molecular tools would also be used, such as marker assisted breeding. It is likely that a wider range of genetic variation would be sought within crops and wild relatives, and molecular tools would facilitate this search.

In developed countries, more than half of all agricultural research expenditures are currently made by the private sector. Much of that research is aimed at developing patentable genetic constructs for use in crop and livestock improvement through transgenesis. The overall level of agricultural research expenditures could be reduced substantially if transgenic tools were abandoned, unless firms could assert binding intellectual property rights over discovered traits. At the same time, the costs associated with the regulation of transgenic crops would also be avoided. Overall, it is likely that the elimination of a powerful tool like transgenesis would slow the pace of agricultural research and improvement and further increase food prices and food insecurity relative to the reference run.

5.4.9 Information and communication technologies and local knowledge[5]

5.4.9.1 Setting the context – reference conditions

Not only have Universal Access policies failed to reach the most marginal, they have in fact given the elite groups a renewed relative advantage. This skewed impact is reminiscent of the initially uneven benefits from the Green Revolution. Under the reference conditions a divide remains regarding access to Information and Communication Technologies (ICT) between very poor and richer farmers. Hence, a

[5] This chapter builds on an earlier paper by Ramirez and Lee (2005).

more strategic targeting of policies, investment and incentive plans, and methodological innovation is necessary. There is an emerging understanding in (ICT) circles that no single approach to service delivery will satisfy the needs of all users (Ramírez and Lee 2005). As we are here concerned with natural resource users, the challenge turns to the unresolved barriers of providing access to connectivity across rural and remote areas with weak demand, uneven market access and competing public investment requirements.

Natural resource management will not become a significant driver for ICT demand. However, ICT is increasing in importance for agriculture in those cases where there is access to markets. It is also increasing in importance and attracts investment when natural resource management links to the outside world (e.g. remittance workers sending funds that are invested in farm inputs) or across sectors (e.g. municipalities aggregating their health, education and local government needs for bandwidth). The investment, however, is not simply about infrastructure. The valuation of the benefits of ICTs goes beyond the essential "access perspective", to one of "effective use". Effective use brings together several prerequisites: reliable access to infrastructure and user equipment, relevant content, cost-saving or meaning-making services, capacity development and financial sustainability. The last few items underline the importance of the organizational context within which ICTs evolve: private cybercafe's will continue to thrive while publicly or donor-funded telecenters struggle to respond the market changes or collapse (Parkinson, 2003, 2005; Robinson, 2006).

To date, the poverty alleviation impact of ICTs has been confirmed for radio and telephony, whereas the evidence for the Internet is less consistent (Kenny 2002). Among the major barriers are uneven access, human resource development and local content (Torero and von Braun 2006). Uneven access is most dramatic between urban and rural areas, and unfortunately most ICT indicators –when available- are nation-wide and therefore mask these fundamental differences. The type of macro level evidence includes the following:

- There is a positive link between telecommunications infrastructure and GDP, suggesting that a 1% increase in telecommunications infrastructure penetration might lead to a 0.03% increase in GDP (Torero and von Braun 2006).
- The welfare effect of rural households is most closely associated with rural telephony which brings about immediate savings to the users (Torero and von Braun, 2006; Kenny, 2002) which is referred to as consumer surplus (Kayani and Dymond 1997) and has been reported to represent a savings ranging from 4-9 times the costs of a single phone call (Bayes et al. 1999; Richardson, Ramírez, and Haq 2000).
- The attributes of ICTs are linked directly and indirectly with the MDG, especially those that relate to health and education (Torero and von Braun 2006).

There is evidence that, while those with higher income and levels of education derive most benefits from ICTs, the poorest of the poor do derive benefits especially from telephony. The poor spend between and 3.7% of their monthly income on telecommunications services (Kayani and Dymond 1997; Song and Bertolini 2002). In a comparison between users and non-users, Song and Bertolini (2002) found that the top three information needs of non-users was personal well-being, agricultural inputs, with employment and agricultural outputs tied for third; for users the top needs were government and administration, personal well-being and the third was business input.

5.4.9.2 Projecting user categories and service delivery systems

For the purpose of this analysis we group natural resources users into three broad categories:

- farm families with access to markets,
- rural communities with diversified livelihoods that include on-farm income, and
- communities that access common property resources –pastures, watershed, forests- as part of their livelihoods.

The first category spans small, diversified farm units all the way to industrial monoculture production systems, as long as they are well linked to markets. The second includes the large number of subsistence productions systems that export labor and increasingly rely on remittance incomes (see next section). The third includes those households that are natural resource users but practice little or now sedentary agriculture or fish farming.

Whether in industrialized or in developing countries, we expect to see an increasing division between privatized extension or advisory systems that serve farmers who can link to markets, and public extension systems for those who cannot. Where there are public-funded systems that are privately delivered, they will inevitably lean towards the first category as commodity-oriented advice is more rewarding. The second category of users will require advice across sectors, which will face the challenge of cross-ministry coordination. Under the baseline, a third type of service will emerge that addresses environmental stewardship and collaborative resource management, possibly with other ministries and donors involved. The first will address farm challenges; the second community challenges including health, education and labor; and the third watershed/ecosystem challenges, (including payment for environmental goods services as is already the case in OECD settings). There will be farmers and farmer groups that do not exactly fit into a particular category or who shift from one to another.

Each group has very distinct needs, and inevitably privatized systems will continue to leave out those that are least able to link to markets (Chapman and Tripp, 2003; Davidson and Ahmad, 2002; Farrington, et al., 2002). The private ICT sector will work along a demand-driven and contractual approach focusing on servicing the first group with information and advice in production, processing and marketing. They will cherry-pick clients from this well-endowed first group. The public system will need to work more along a more integrated approach seeking to support existing multiple survival strategies, not just production oriented ones. The third will embrace collaborative management approaches.

The agroecology will also dictate the extent to which each category of users is able to thrive and the extent to which investments in know-how, organic matter, labor or diversification may yield results. As has been shown in farming systems research and extension, there are different livelihood strategies for the major agroecosystems. Those where soils are exhausted of organic matter and where production is reliant on rainfed cropping systems may require support to *exit strategies* that in the past were unheard of (Dixon et al., 2001; Pretty and Hine, 2001) but which are already prevalent (e.g. remittance economies). Under the baseline, crop intensification will increase, requiring a concentration of agricultural inputs, including fertilizers and irrigation on crop areas. At the same time, increased climate variability and climate change will contribute to the marginalization of additional lands, and the frequency of floods and droughts will increase. Each agroecology will respond differently to these pressures, and a livelihoods approach as proposed by Pretty and Hine (2001) provides a holistic checklist to review how each type of asset will respond.

Indigenous knowledge (IK) will be a necessary contributor at several levels: IK depends on methods, media and networking patterns for information exchange. The appropriation of media, however, is a prerequisite for the holders of the knowledge to keep control over its utilization (Srinivasan, 2006). The social practices, gendered division of labor, and cultural heritage are the incubators of this knowledge. The means by which the information is shared and the social means through which it becomes socialized as knowledge may or may not be combined with modern ICTs; who decides to do this and in what terms will be critically important. Secondly, IK provides content that is locally adapted and reflects years of adaptation. The integration of IK and western scientific knowledge will need an interface that allows each to express its wisdom and forms, without sacrificing its cultural relevance. Under the baseline, increased globalization and integration of markets presents both an opportunity and a threat to IK. While knowledge will be transferred more easily across regions and countries, IK might well disappear if adequate support systems are not put in place.

Beyond ICTs, tacit knowledge will be a central component in natural resource management. Be it a traditional forest user or a modern forester, their management practices are learned in apprenticeship. The integration of two knowledge systems will also require that practitioners are involved in the development of applications; once again the emphasis is on demand-based approaches. The first two groups that are involved in farming will benefit from spatial applications that allow for the integration of soil, water, economic, social and biological information to restore or maintain production systems (see Chapter 5.5. for further details). Once again, ICTs can only be but a part of the process. Challenges in terms of power and control will increase under the baseline: the consortia that own and operate ICT infrastructure work under a market logic that has little currency for respecting local, indigenous knowledge. The importance of mediating organizations thus becomes evident if we are to minimize the potential abuse that such power differentials create. Moreover, mediating organizations would be necessary to coordinate the coming together of all interested parties involved (see Chapter 5.4.9 for an example integrating remittance flows).

All of the services delivery systems projected will depend on supportive national agricultural, rural development, environmental, research and economic policy. Moreover, they will be affected by national and international resource competition and policy. The growing water crisis will be central to this challenge, affecting all categories of users. Global agricultural subsidy policies and trade agreements will influence the first group most immediately in that their behavior will be more closely linked to commodity prices.

5.4.9.3 Options for harnessing ICTs and information demands

The following is a possible policy path comprising three demand-driven types of service delivery systems catered for each natural resource user group.

Some systems will attempt to work with both farmers that can link to markets while also catering to the needs of other groups. However, overall each type of service and natural resource user will display unique information needs and communication requirements. Each service will harness ICTs differently due to the specific accessibility and e-readiness levels of each group. The second system may benefit from the lessons from some telecenter experiences as mediators of information across different sectors, although such access may be limited or non-existent in remote areas. Moreover, lessons from existing telecenter experiences merit attention, especially if we are to minimize the challenges of socioeconomic polarization and lack of relevant content already documented (Robinson, 2004). In most rural contexts, infrastructural upgrades will first be required to increase the access of potential users (wireless technology's potential will be tested). The recognition of rural ICTs as an infrastructure portfolio will allow for policy and public investment decisions. This may be possible as politicians acknowledge how liberalization and privatization of the industry have proven to be insufficient mechanisms to attract investment in rural areas. Table 5.4.8-1 summarizes the types of services and content that each NR user group will receive, as well as the level of analysis and action, and the type of information demands.

Under the baseline therefore, beyond financial viability, we need to account for outcomes, of which increased human and organizational capacity are both of primary

"...The emphasis is on the importance of organizational contexts in shaping learning outcomes associated with the design and use of information and communication systems. These organizational contexts influence social perceptions of barriers to the use of information systems, the social values that become embedded in technological systems such as the Internet, and whether social actors can acquire the necessary range of capabilities for the production of advanced information and

importance. Hence, a more strategic targeting of policies, investment and incentive plans, and methodological innovation is necessary under the baseline outlook. As we are here concerned with natural resource users, the challenge turns to the unresolved barriers of providing access to connectivity across rural and remote areas with weak demand, uneven market access and competing public investment requirements.

- Understanding the place of ICTs in developing country agriculture depends on four key concepts: **knowledge is an increasingly significant factor of production**;
- All actors in the agricultural sector are part of **an evolving Agricultural Knowledge System** (AKS);
- ICTs accelerate agricultural development by **facilitating knowledge management** for AKS members; and that
- ICTs are essential **coordinating mechanisms in global trade**.

Expanding the use of ICTs in developing country agriculture will demand a more active and empowered role for rural intermediate organizations. These organizations will increasingly act as local knowledge brokers: they will identify client needs and suitable knowledge management methods, and provide feedback on the quality of existing agricultural knowledge services as well as identify new ones (Ritter, 2003).

5.4.9.4 Conclusion

There is a growing trend of unpredictability when it comes to technology and development. There are several challenges associated with our projections: In many developing countries, universal access policies have been directed by industry and power elites. The result is a commercial, supply-side orientation. Fundamental changes in these approaches require political will and a visionary approach to ICTs as basic tools for democratization and engagement.

Innovation in funding and cross subsidization will be required. If and when ICTs become a basic infrastructure portfolio, there will be a political space to renew the experimentation with incentive mechanisms to make rural ICTs sustainable by harnessing rural entrepreneurship. The state will redefine its role as designer of incentive mechanisms, not in the delivery of services. USAID provides the following recommendations for project design in agriculture and ICTs":

- "*Empower agricultural and rural intermediary organizations* such as extension agents, local NGOs, and producer associations through ICTs in order to increase their effectiveness at understanding and servicing their clients' needs.
- *Improve rural access to ICTs* through support of multi-use telecenters and piloting of emerging alternate technologies that foster inexpensive, low-power alternatives to PCs.

- *Develop and adapt relevant agricultural content for digital dissemination*, using local intermediate organizations to evaluate the relevance and technical accessibility of information from institutionalized sources or created by intermediaries themselves.
- *Ensure that women and girls can participate effectively* and equitably in emerging knowledge networks by ensuring women's access to ICTs, availability of women-oriented content (e.g., subsistence as well as cash crop information), and selection of intermediaries with women in meaningful positions as key partners.
- *Use ICTs to strengthen community feedback mechanisms* for democratic governance, research and extension feedback, and project impact assessment" (Ritter 2003).

These recommendations require adjustment for different users groups, though they do suggest an emphasis on the second group, with weak market access. The emphasis on supporting intermediary organizations is noted and endorsed as not only are they able to reach those least connected to markets, but they may be the best positioned to seek and generate locally relevant content.

Planning approaches based on conventional telecommunication approaches have proven unable to deal with the complexity and context-specificity of ICTs in development, even in urban contexts (Andrew and Petkov 2003; Firmino 2005). New systemic mind-sets are needed, along with more demand-based approaches where users are closely involved in the design of services and applications. A demand-based approach is a common plea in ICT for development literature (Mansell and Wehn 1998). Technology, especially wireless and mobile telephony will provide new opportunities; technology on its own is not a magic bullet.

Lastly, measuring the impact of ICTs on NRM will remain a challenge in that we do not expect to be able to demonstrate a direct causality, but rather a contribution. Policymaking will need to evolve to allow for this type of outcome mapping. Innovation in monitoring and evaluation in this area is evolving and will need further action-research investment (Earl, Carden, and Smutylo 2003; Ramirez 2007).

5.4.10 Urbanization and migration

One of the best documented examples of rural-urban migration is that between rural Europe and the Urban United States at the beginning of the 20th Century stimulated by economical crisis, famine and war among other things. Over the past fifty years, the number of people living away from their home countries has doubled, to 191 million in 2005 (UNFPA 2006; UN 2006). Although migration has taken place throughout history, it is a vital component of today's globalized economy and the contribution it can make to agricultural development and poverty reduction will depend on the policy paths are chosen over the next 50 years.

The systematic study of rural-urban migration dates to the mid 1950's when the urban population in Europe and North America began to outstrip the rural. As international migration became more prevalent during the 1970's studies documented the movement of rural populations of Asia, Africa and Latin America to industrializing urban areas and from these to the developed countries, mainly North America, Europe and Japan. A shift in this trend began in the 1990's when migrants from the rural less developed countries began to move directly to rural and urban areas in the developed ones (Timur 2000). In 2005, Europe had received 34% of migrants, North America 28% and Asia 28% while only 15% of migrants were taken up by Oceania, African, Latin American and Caribbean countries (Fig. 5.4.10-1) (UN 2006). At the present rate of 3% annually, the migrant population worldwide will double in the next 25 years (WB 2006b). The demand for migrant labor in receiving countries comes from a number of sectors, the most important being domestic service, construction, agriculture and seasonal labor (UNPFA 2006). While data and projections are scant and subjective, rainfed farming regions are expected to export many more migrants than irrigated cultivation zones.

Remittances have become the mainstay of many poorer urban and rural families. In Andean rural communities, for example, part of the remittances are invested in small-scale agriculture, part used for living expenses, part for construction and remodeling of homes looking toward the development of agro-tourism activities (Tamagno 2003). Migrant remittances fuel many national economies, as well as rural households whose consumption patterns generate a significant multiplier effect throughout many regions where self-sufficient non-irrigated agriculture remains the norm. Although estimates vary on the rate of growth and continuity of current emigration flows, remittance transfer amounts via the global banking system was in the order of US$67 billion in 2005 (WB 2006b). While remittance transfer costs have diminished, access to money transfer operators has boomed as central banks and international financial authorities have improved transaction tracking. The volume of remittances to rural areas in the South will likely continue to increase given the crisis in small-scale agriculture and the sustained economic growth in the North.

Many international migrants form Hometown Associations (HTAs) in their new living and work environments. These de facto non governmental organizations (NGOs) have, over time, come to represent the interests of their membership as they adapt to new circumstances far from home and family. HTAs represent transnational communities made up of second and even third generation migrants (Bressere, 2004). Evidence is emerging that HTAs send collective remittances, to fund select small-scale infrastructure projects in their homelands. Increasingly, national, provincial and municipal governments in Latin America are providing matching funds for hybrid public-private-civil society collaboration for local development programs including agricultural infrastructure. HTA initiatives are honing negotiating skills

> Skype-Paypal-eBay reports that Paypal is now operating in 109 countries using 15 currencies and that they are targeting remittances as a major application.
>
> http://conferences.oreilly.com/etel

and demand transparency in their alliances, and as a consequence are transforming local and regional politics in their home jurisdictions (Orozco and Rouse 2007).

In addition to the flow of remittances, information flows between countries of origin and receiving countries has increased exponentially as cybercafés and telecenters spring up in small towns and villages almost everywhere in the world. These provide a locally-owned human and technical resource that provides services and training for neighbors and customers many of whom communicate cheaply and frequently with kin abroad. Cell phones are at least, if not more important in the exchange of information among rural and urban centers at the national level and internationally as the networks expand and user costs diminish.

Research suggests that 10% of funds received from remittances could be saved or invested, if trustworthy options were available in appropriate information circuits that prevail in subsistence economies (WB 2006b). Furthermore, evidence suggests that only a fraction of the amounts sent home is diverted from consumption and invested in sustainable productive endeavors. At present, distrust of official programs, unfulfilled promises and the lack of opportunities in rural areas make it difficult to configure development options that rural communities are willing to take on (Tamagno 2003). Recently, international finance and development institutions have become aware of the power of migrants' remittances. However, leveraging this private capital for development would most likely require incentives as well as negotiation with organizations on both sides of the migration chain.

While migrant organizations are beginning to exert political power at home and abroad via HTAs, the untutored and undocumented status of many limits their capacity for participating openly in transnational development programs. But, at home, returning migrants compete for local offices and their experience and funds influence decision making and political priorities in rural jurisdictions (UN 2006; Tamagno 2003; Orozco and Rouse 2007). Looking toward 2050 several possible futures emerge if we project the current migration – remittance – rural social change patterns for rainfed smallholders.

5.4.10.1 Policy path one: sustainable migrants and AKST alliance

Given proper incentives – cultural, political, and economic, migrant HTAs could partner with the agricultural knowledge communities housed in the extant global network of research and technology institutions (e.g. CGIAR). Through a focused collective remittance program, where the scientific community contributes baseline spatially-anchored data, HTAs could work with the increasingly available high resolution digital cartography of the ecosystems suitable for intensifying or opening cultivation in their home rainfed jurisdictions. Improved water, soil and agronomic techniques can also be directed at irrigated cultivation. This collaboration, led by young members of migrants' families trained in the new, digital tools and employing local cybercafés and telecenters for fine tuning decision support tools focused on local ecosystems, can develop a menu of viable investment options for HTAs willing to commit resources via collective remittances to agricultural infrastructure back home.

These menus would contain, among other items, hydrological, soil and potential cropping plus market data along with links to appropriate technologies, training organizations and microbanks to enhance, for example, the productivity of dryland farming. In this fashion, each HTA, working within its own farming traditions in the homeland space together with an AKST partner, may have a decision support tool to accompany their collective and family remittance options based on a geographic information system platform. This tool may be available online for authorized and trained users, at home and where migrants live and work. This option may evolve where HTAs are strong, representative of their transnational communities and astute in political negotiations with State agencies, including extension services.

5.4.10.2 Policy path two: corporate leasing of viable smallholdings

Where HTAs fail to reach a level of organizational stability and maturity required to sustain a pattern of collective remittances focused on improving agricultural productivity at home, and where tenure, water, soil, cropping options and market proximity permit, corporate leasing of smallholders' land may occur. In regions with extensive out-migration this is a probability. External capital and entrepreneurship may transform the technology mix to intensify production on suitable marginal lands, but the downside could be the sacrifice of traditional farming methods under less than optimal growing conditions as well as still more out migration. Available labor supplies may be problematic as well, especially in regions where the best and brightest already moved away, leaving older folks and young children to tend subsistence plots and meager grazing areas. Where corporate farming of nearby irrigated lands is today a pattern, it is not farfetched to contemplate an expansion of this form of farming if economic incentives, energy costs and the political weakness of Diaspora home communities and regions allow these changes to occur. This scenario is foreseeable where market forces and agri-consortia are powerful and migrant organizations are weak, distant and uncommitted to sustaining traditional livelihoods in their home territories.

5.4.10.3 Policy path three: continuity and stagnation

Where migrants and their organizations are unable to channel funds and political leadership back home, and in regions with sparse population on marginal, often degraded lands far from major markets, rudimentary technology and scarce or no access to credit, the probability of an intensification of today's syndrome of old folks and children in "ghost villages" guarding unproductive agricultural resources is high.

Francisco Meré, author of an overview on Mexican emigration and former director of a government agricultural and agribusiness financial agency, FIRA, is not optimistic: "Remittances from rural to urban and rural to international migration (predominantly to the United States) and becoming a relevant part of household income, particularly for those who hold a smaller plot of land, where remittance may represent as much as 30% of the household's income."[6]

In deforested, over-grazed and mono-crop regions with increasingly unpredictable moisture patterns, the risks inherent in water management and cash crops may preclude any sustainable food security policy for local families mired in the "old ways". Continued migration or assuming a caretaker syndrome with remittance-supported livelihoods may have a low opportunity cost, both for those with kin already in the North (or the developing South) and Agricultural Ministries as well. Subsistence farming may be the only option for these extensive regions where the State has either downsized or eliminated public agricultural extension services, curtailed investments in hydro-infrastructure and made export-oriented crops who receive the brunt of official supports untenable in these marginal territories. Some regions in Mexico (Zacatecas, the Mixtecas) where rural out-migration began years ago have already achieved this condition.

5.4.10.4. Concluding remarks

Massive out-migration from rural areas, the attenuation of effective national agricultural extension services plus the growing polarization between profitable irrigated, export oriented crops and subsistence rain-fed farming subject to inefficient "market forces", provides a grim profile for future scenarios of food security, farm productivity and infrastructure development in regions dominated by dry land small holders. Rural out-migration from small towns and villages is now a consolidated, multi-generation tradition linked to transnational communities and their organizations with women increasingly assuming more decisive roles. These communities' actions and future partnerships will determine the destiny of their homelands. Families still working marginal lands today often supplement their meager incomes with remittance receipts from kin either abroad or working in the cities. Options for increasing the productivity of these rain-fed regions could consider partnerships among HTAs, agronomic technology providers, microbanks, and NGOs, employing Internet connectivity together with focused information sources and decision support tools and with local and national agencies.

5.4.11 Interface of human, animal, and plant health

5.4.11.1 Baseline

Under the baseline, the global population is projected to grow from 6.1 billion in 2000 to 8.2 billion by 2030 approximately 60% of the population will live in urban areas, with growth concentrated in DC. Human, animal, and plant diseases are associated with AKST will negatively affect these larger and more urbanized populations. Two trends will be of particular importance -- continued emergence and re-emergence of infectious diseases and the growing human health burdens of non-communicable diseases.[7]

[6] http://www.usda.gov/oce/forum/2007%20Speeches/PDF%20speeches/PalafoxF.pdf Pg. 6

7 Diseases and disabilities can be categorized into communicable diseases, maternal, and perinatal conditions, and nutritional deficiencies; non-communicable diseases (primarily chronic diseases); and injuries.

The geographic range and incidence of many human, animal, and plant diseases are influenced by the drivers of AKST. Communicable diseases are the primary cause for variations in life expectancy across countries (Pitcher et al., in press). Factors driving disease emergence include intensification of crop and livestock systems, economic factors (e.g. expansion of international trade), social factors (changing diets and lifestyles) demographic factors (e.g. population growth), environmental factors (e.g. land use change and global climate change), and microbial evolution. Diseases will continue to emerge and re-emerge; even as control activities successfully control one disease, another will appear. Most of the factors that contributed to disease emergence will continue, if not intensify, in the 21st century (IOM, 1992). The increase in disease emergence will impact both high- and low-income countries.

Currently, 204 infectious diseases are considered to be emerging; 29 in livestock and 175 in humans (Taylor, Latham, and Woolhouse 2001). Of these, 75% are zoonotic (diseases transmitted between animals and humans). The number of emerging plant, animal, and human diseases will increase in the future, with pathogens that infect more than one host species more likely to emerge than single-host species (Taylor, Latham, and Woolhouse 2001). This will be facilitated by increasing movement of plants and animals through trade. Under the baseline, trade in meat products is expected to grow from 15 million metric tons in 2000 to 30 million metric tons by 2025 and 55 million metric tons by 2050, an almost quadrupling. The volume of trade in fruits and vegetables is projected to grow by 278% to reach 250 million metric tons by 2050.

Serious socioeconomic impacts are expected to occur when diseases spread widely within human or animal populations, or when they spill over from animal reservoirs to human hosts (Cleaveland, Laurenson, and Taylor 2001). AKST is important for three broad categories of infectious diseases: diseases whose incidence is affected by agricultural systems and practices (e.g. malaria and bovine spongiform encephalopathy), food borne zoonotic diseases, and epidemic zoonotic disease (e.g. avian influenza). For example, the expansion of harvested irrigated area under the baseline—as a result of the need to further intensify food production and to better control water supplies under increased climate variability and change—is expected to contribute to an increased incidence of malaria in some areas. Another example is the rapidly increasing demand for livestock products under the baseline could increase the likelihood of BSE to spread more widely.

Emerging infectious diseases of crop plants pose a significant threat to agricultural productivity and, in cases of globally important staple crops, food security. The emergence of new plant diseases has largely resulted from the accidental introduction of pathogens in infected seed and in contaminated machinery and globally traded agricultural products. Furthermore, increased intensification of agricultural systems both facilitates the establishment and spread of these new pathogens, and imposes selection pressure for greater pathogen virulence (Anderson et al. 2004). Climate also plays an important role in disease emergence: winds disperse fungal and bacterial spores, nematodes and insect vectors of plant viruses; crop-canopy microclimatic conditions influence pathogen colonization of leaf surfaces; and seasonal climatic extremes mediate the extent of yield loss from plant diseases. The negative impact that increased climate variability and change will exert on host-pathogen dynamics could accelerate the process of pathogen migration into new agroecosystems, and provide conditions that elevate disease organisms from minor to major status (Coakley et al. 1999).

A second trend of importance to AKST over the coming decades is that non-communicable diseases, such as heart disease, diabetes, stroke and cancer, account for nearly half of the global burden of disease (at all ages) and the burden is growing fastest in low- and middle-income countries (Mascie-Taylor and Karim 2003). Chronic diseases are expected to rapidly increase as a result of more sedentary, urbanized lifestyles. In addition, the overall large increase in calorie availability in developing countries is expected to lead to rapidly raising levels in obesity and associated non-communicable diseases -- the average number of calories available per person in the group of developing countries is projected to increase from 2,677 calories to 3,267 calories, and per capita meat demand in the reference world is also increasing considerably across IAASTD regions (Figure 5.3.2.1-2). Weight gain, hypertension, high blood cholesterol, and a lack of vegetable and fruit intake result in significant health burdens in both high and low-income countries (Ezzati et al. 2002). The greater supply of and demand for energy-dense, nutrient-poor foods is leading to obesity and related diseases in countries that have yet to overcome childhood undernutrition (Hawkes and Ruel 2006).

Further approximately 840 million people do not receive enough energy from their diets (Kennedy, Nantel and Shetty 2003) and over three billion people are micronutrient deficient, most of them women, infants, and children in resource-poor families in low-income countries (Welch and Graham 2005). Under the baseline, the number of malnourished (underweight) children is expected to decline from 146 million children in 2000 to 80 million children by 2050. While agricultural and income growth are contributing to rapid reductions in the overall number of underweight children, the global decline masks differences across regions. Living healthy and productive lives requires that agriculture provide more than 50 essential nutrients (e.g. vitamins, minerals, trace elements, amino acids, essential fatty acids) in quantities needed to meet metabolic demands; deficiencies exist even where the food supply is adequate to meet energy requirements. Micronutrient deficiencies increase morbidity and mortality, decrease worker productivity, and cause permanent impairment of cognitive development in infants and children; together, these reduce the ability of nations to achieve development and sustainability goals (Welch and Graham 2005).

A trend expected to continue is the highly inequitable distribution of health workers, as shown in Figure 5.4.11-1 by level of health expenditure and burden of disease for the WHO regions (WHO 2006). The level of health expenditure is an indication of the resources for public health. Regions with the lowest relative need have the highest numbers of health workers, while those with the greatest health burden have a much smaller health workforce. The African Region suffers more than 24% of the global disease burden but has access to only 3% of health workers and less than 1% of the world's financial resources, even when loans and grants are included. The Americas (Canada and the U.S.) experience 10% of the global disease burden, has 37% of the world's health workers, and spends more than 50% of the world's financial health resources.

5.4.11.2 Trends and responses

The challenges of human, animal, and plant diseases are largely separate from food security and chronic diseases. Two plausible trends are presented for each type of challenge. For both, one is a continuation of current trends (business as usual), with emerging human, animal, and plant diseases and food insecurity continuing to constrain development under the business-as-usual scenario, with progress unevenly distributed and a variety of factors limiting achievement of development and sustainability goals. For emerging diseases, a second trend is a more global focus on preventing disease emergence. For food security, a second trend includes increased global cooperation on developing and deploying technologies to increase crop yields and reduce micronutrient deficiencies, and increased regional and local emphasis on local production of high-quality food.

For all trends, key driving forces over the coming decades include demographic change; rate and degree of increase in climate variability; trends in ecosystem services; impact of climate change on freshwater resources, agricultural systems, livestock, wildlife, forests, and marine systems; economic growth and its distribution; rate of technology development; trends in governance; degree of investment in public health and other infrastructure.

Emerging human, animal, and plant diseases continue to constrain development. Regions and countries focus more on their immediate interests and concerns, so there is limited public health investment in improving infrastructure related to emerging diseases in low- and middle-income countries. With insufficient increases in investment and knowledge transfer by high-income countries and limited funding for research, and technology development, public health and agricultural agencies struggle to identify and control diseases as they emerge. This is compounded by trends in drivers of infectious diseases that favor the geographic spread of vectors and pathogens, and the intensity of disease transmission. Increasing climate variability and change, land-use changes, desertification, and other large-scale environmental changes create opportunities for pathogens and vectors to enlarge their geographic range. The cost associated with controlling emerging and reemerging diseases negatively affect development in low- and middle-income countries, such that progress on disease control is slower than hoped and at a higher cost.

Policies and measures will primarily be reactive to disease emergence. Occasional large outbreaks with significant economic and health consequences will lead to changes in surveillance policies and programs. Quarantine policies will likely be enforced occasionally to prevent diseases moving across borders. Although effective, as illustrated by the ongoing issues with control of BSE, quarantine policies can be disruptive to livelihoods and economic development. Because funding for research and technology development will focus on regional and national concerns, few new AKST options will be developed to improve disease surveillance and control. Limited funding will constrain coordination and collaboration across agencies and institutions.

Human, animal, and plant diseases are kept in check, but at a significant cost. UN agencies, institutions, businesses, and NGOs work together with countries to implement policies and measures to control human, animal, and plant diseases. Recognition that the world is inter-related translates into significant funding for research and development on emerging diseases of concern in low- and middle-income countries, including reestablishing well-funded laboratories and research centers in all world regions to help with disease identification and control. Investments are made in research and technology development to identify, diagnose, treat, and control emerging infectious diseases, including the role of AKST in disease control. These activities, along with increasing education of women, facilitate disease control activities in low- and middle-income countries.

Despite these achievements, significant weather changes result in increasing climate-related health risks in all countries. Trends in other drivers of disease emergence, including land-use change, desertification, other large scale environmental changes, and increased travel and trade, favor the introduction and geographic spread of vectors and pathogens and the intensity of disease transmission. Investments in surveillance and control activities by countries, businesses, and other donors can prevent large disease outbreaks. Increased research and technology development will facilitate identification of AKST options to prevent and control disease emergence. Increasing coordination and collaboration across agencies and institutions will facilitate implementation of these options, increasing disease control, but at a significant cost.

5.4.11.3 Food security and chronic diseases

Food insecurity and increasing rates of chronic diseases constrain development. Although health transitions will continue in middle- and low-income countries, burdens of infectious diseases, malnutrition, and chronic diseases will lower productivity and reduce health and life expectancy. Over-consumption of nutrition-poor foods will continue to increase the rates of obesity, diabetes, and related chronic diseases in all countries. In high-income countries, the large disease burdens begin to decrease life expectancies. Increasing wealth in some sectors of middle- and low-income countries will lead to increased adoption of "western" lifestyles and patterns of food consumption, which will further increase rates of chronic disease and increase opportunities for the emergence and spread of human, animal, and plant diseases.

Concurrent with increasing burdens of chronic diseases, micronutrient deficiencies will increase because of limited funding of AKST to increase output of farming systems by enhancing micronutrient production and bioavailability, and reducing losses of micronutrients (Ruel 2001; Welch 2001). These deficiencies will continue to increase disease susceptibility and lower productivity, thus making it more difficult to achieve sustainability and development goals. Because the world is more regionally focused, policies to mitigate some of these trends will focus on local solutions, with some spill-over effects in middle- and low-income countries from investment in AKST. However, there will not be sufficient funding for public health research, development, and technology transfer to other countries. The high burden of ill health means that more funds are spent on treatment than on finding sustainable solutions.

5.4.11.4 Achieving food insecurity and chronic disease rates goals

Increased global cooperation on developing and deploying technologies to increase crop yields and reduce micronutrient deficiencies, and increased regional and local emphasis on local production of high-quality food, facilitate achievement of food security and decrease rates of chronic diseases. Food insecurity, micronutrient deficiencies, and chronic diseases will continue to adversely affect human health and well-being, but for decreasing numbers of people. Urban agriculture is supported with appropriate controls to prevent the emergence of infectious diseases. Strong investments are made in human and financial resources to better understand and control undernutrition (including micronutrient deficiencies) and food security, both within and across countries. Spill-over effects include reduced morbidity due to HIV/AIDS and other diseases the undernutrition can exacerbate.

5.4.12 Changing preferences for meat and certified organic products

5.4.12.1 Introduction

Consumer preferences are evolving for both meat-focused diets and certified organic products. This could lead to several important differences from the reference case presented here. Rising interest in the health and environmental impacts, among other concerns, of conventional agriculture has pointed many consumers towards changing dietary habits away from meat and focusing on certified organic products (Knudsen et al. 2006, Steinfeld et al. 2006). As a result of the rise of vegetarianism, there is the potential for a shift in consumer preferences that would decrease the share of meat products in the typical person's diet and emphasize non-meat foods. The main consequence of growing consumer demand for certified organic products, which includes both meat and non-meat commodities, will be the shift in production toward certified practices that will impact productivity.

5.4.12.2 Implementation in IMPACT

The IMPACT modeling framework, which was described earlier, was used to simulate these trends for comparing and contrasting with the reference case. Though the shift toward a more vegetarian diet has the potential to be a global phenomenon, certified organic production is more practical in developed regions due to infrastructure and institutional requirements that are more readily available and applicable (see Halberg et al 2006 for further discussion).

Specification of the rise of vegetarianism. The rise of global vegetarianism ("VEGGIE") is implemented via adjustments to the income demand elasticities for meat and vegetarian foods. Income demand elasticities for meat products (beef, pork, poultry, and sheep/goat) decline at a faster pace than in the reference case. At the same time income demand elasticities decline at a slower pace for vegetarian foods (fruits and vegetables, legumes, roots and tubers, and cereal grains). Elasticities for animal products such as dairy and eggs are left the same as in the reference case. This happens globally using the same multipliers across all regions. Regional average income demand elasticities for meat and vegetarian foods for IAASTD regions are presented in Table 5.4.12.2-1. The effect, in general, is that the meat income demand elasticities decline half again as fast while those for vegetarian foods decline only half as fast as in the baseline; i.e., the rates of decline are 150% and 50% of the baseline rates for meat and vegetarian commodities, respectively.

Specification of the rise of certified organic products. The rise of developed-country certified organic agriculture follows on the specification of the organic agriculture scenario in Halberg et al. (2006). This scenario is specified purely as a supply-side adjustment in the developed world to yields of crops and livestock most easily converted to certified organic production. Crops include maize, wheat, soybeans, other grains, and potatoes. Beef, dairy, and sheep/goat are the focus for livestock. The scenario adjusts the yield growth rates from 2005 to 2015 such that the agronomic yields for the specified commodities achieve the differences from baseline specified in Halberg et al (2006) as laid out in Tables 5.4.12.2-2 and -3. The principal change from Halberg et al (2006) in this implementation of widespread adoption of organic agriculture is that the apex of the spread is achieved in 2015, which would cover roughly half of the area harvested or managed animal herds. This year marks a turn-around in the decline of average yields for these crops and baseline yield growths from 2015 to 2050 are achievable due to technology investments and farming system adaptations. This specification is meant to be illustrative of the potential impacts of such developments but it is an optimistic representation of such a large-scale shift to organic production.

5.4.12.3. Potential outcomes

The commodity price impacts of these two alternative outcomes compared to the reference case is fairly straightforward. In a future of increased vegetarianism, the income demand elasticities are much lower for meats and much higher for vegetarian foods than in the reference case. Prices will directly follow the changes in income demand elasticities with meat prices falling and vegetarian food prices increasing. Figure 5.4.12.3-1 shows the resulting differences from the reference case for the two types of foods: a 20% decrease in meat prices and a 30% increase in the price of vegetarian foods. As the rise of certified organic agriculture results in a decline in average yields, commodity prices increase between 3-6% for meat and dairy products and 10-20% for the other crops (Figures 5.4.12.3-2 and -3).

Per capita food consumption also shifts in these alternatives to the reference baseline. With the rise in prices in the case of increasing organic agriculture, per capita consumption of all foods decreases between 1-3%. On the other hand, the increase in vegetarianism shifts food preferences away from meat and toward vegetarian foods, which is commensurate with the price shifts (Table 5.4.12.3-1), with a couple exceptions. In sub-Saharan Africa the countervailing force of the price shifts actually lead to increased consumption of meat in addition to vegetarian foods. The price shifts in North America/Europe actually lead a slight inversion of the expected outcome, but this is due to the changes being implemented on the already low elasticities in this region not having as much effect as in other regions.

The calculation of the malnutrition indicators in the IMPACT framework (malnourished children by weight under five years old) has per capita kilocalorie consumption as an important factor and this follows the food consumption changes noted above. Non-meat foods are denser in calories on a per kilogram basis, so an increase in vegetarianism would lead to a decline in malnourishment. Figure 5.4.12.3-4 shows the impact on this malnutrition indicator aggregated to the developing world. Ultimately, a reduction in the growth of meat consumption with relatively more consumption of non-meat foods sees a 4% decline in malnourished children while a certified organic world would see a 2% increase.

5.4.12.4. Challenges for AKST

The potential evolution of consumer preferences for more certified organic agriculture and vegetarian foods is uncertain. While the reference case presented previous actually already includes a certain amount of these shifting preferences, the purpose of this section is to highlight the potential impacts if these trends strengthen in the future. If vegetarianism increases at a global level, the primary challenge will be to augment productivity investments on the crops that will maintain a balanced diet for consumers, particularly for crops that will constitute balanced proteins to replace meats. Increasing demands and prices for vegetarian foods will be the main challenge for agricultural production. Meanwhile, an increase in certified organic agriculture would raise different set challenges. In particular, maintaining productivity levels and controlling costs will be the most important issues to address. Alternative organic inputs for large-scale production that will maintain soil nutrients and improve labor efficiencies will be rather important.

5.5 Implications of Policy Simulations: Synergies and Trade-offs

5.5.1 Poverty and equity

Although economic growth is a critical driver for poverty reduction and explains a significant share of the historical decline in poverty in most regions of the world, policies and investments in the fields of education, health, and infrastructure are also essential for sustained poverty reduction. Lipton and Sinha (1998) argue that, while globalization is changing the outlook for the rural poor by raising average incomes, it also tends to increase income variability both across regions (leaving some regions and countries behind) and across time, thus increasing the vulnerability of those who can least afford it. Moreover, macroeconomic and trade policy is being transformed by liberalization and globalization, producing large gains for many in both rural and urban areas, but relatively little for poor farmers and landless laborers, who often lack the skills, health, information, or assets needed to seize the new opportunities. The poor may thus increasingly concentrated in regions ill-equipped to gain from globalization/liberalization- e.g., in remote rural area.

Under these circumstances, growth alone will not solve the poverty problem. Policies must also reach out directly to the poor. Particularly important are investments in the human capital of the poor. Investments in health, nutrition and education not only directly address the worst consequences of poverty, but also attack some of the its most important causes. Even with rapid economic growth and active investment in social services, however, some of the poor will be reached slowly if at all. And even among those who do benefit to some extent, many will remain vulnerable to adverse events. These groups should be reached through income transfers, or through safety nets that help them through short-term stresses or disasters.

Despite that poverty together with the assumption of equitable distribution of food and basic services, has been the main agenda of governments and private institutions (e.g. financial agencies, donors) in developing countries for several decades now, improvement on the lives of the rural poor seems to be slow. A re-focus on investments and the sectors where these should be granted both by the national governments and the granting institutions have to be reconsidered. In fact, studies of Fan, Zhang and Zhang (2002) have shown that government expenditures on production-enhancing ventures resulted to enhanced agricultural productivity, reduced regional inequality and lessens rural poverty in rural China. These investments consist of agricultural research and development, irrigation, rural education, and infrastructure including roads, electricity and telecommunications.

At the macro level, irrigation investment has significant effects in increasing crop production and reducing poverty, but the impact of irrigation is lower than rural roads and agricultural research (Fan, Zhang, and

Zhang 2002; Fan and Hazell 2000; Fan, Hazell, and Thorat 1999). Other research showed considerably higher impacts of irrigation on growth, both absolutely and relative to other investments. In India, a different scenario was observed where investment in road systems, research and development (R&D), and education ranked highest in terms of reducing the number of poor. Fan, Hazell, and Thorat (1999) calculated the marginal rate of return for some expenditure variables by the Indian government. High investment in roads enhances productivity by promoting non-agricultural employment opportunities, leading to higher wages and lessening rural poverty. With every 1 million Rupee (Rs) increase in road investment (at 1993 constant prices), 165 poor people will be raised above the poverty line. On the other hand, government investment in irrigation ranked fifth in reducing the number of poor, and has an important effect on total factor productivity. For every 1 million Rs invested in irrigation seven poor people will be lifted out of poverty, while an additional 100 billion Rs would raise TFP growth at a rate of 0.56%, opening an opportunity for private investment.

5.5.2 Hunger, health and food security

Under the reference run, a substantial increase in food prices will cause relatively slow growth in calorie consumption, with both direct price impacts and reductions in real incomes for poor consumers who spend a large share of their income on food. This in turn contributes to slow improvement in food security for the poor in many regions. Progress is slowest in sub-Saharan Africa—despite rapid income growth and significant area and yield growth as well as substantial progress in supporting services that influence well-being outcomes, such as female secondary education, and access to clean drinking water—by 2050, there will be a reduction by only 19% in the number of malnourished children in sub-Saharan Africa. As a result, net food imports will increase considerably in sub-Saharan Africa. Significant improvements in food security can be made with higher investments and improved policies for AKST. Alternative policy experiments show that with higher investments in AKST the share of malnourished children in the group of developing countries are projected to decline to only 64 million from the baseline of 80 million. If these higher investments in AKST are combined with improvements in complementary service sectors, such as health and education, then a further reduction to 47 million is projected.

5.5.3 Natural resources and environmental sustainability

Water demand is projected to grow rapidly, particularly in developing countries. Irrigation remains the single largest water user over the 50-year projection period, but the increase in demand is much faster for domestic and industrial uses than for agriculture. Given significantly faster growth in water demand in all sectors and declining water availability resulting from climate change in this baseline, developing countries are substantially more negatively affected by declining water supply reliability for irrigation and other uses than developed countries. This is especially so for developing countries with arid climates, poor infrastructure development, and rapidly increasing populations. Overall, to satisfy future water demand and security food supply, investments, new technology adoption, and policy reform in water and irrigation management are all necessary to maintain water supply reliability and to reduce water supply vulnerability for irrigation, especially in developing countries. Besides water supply augmentation, demand management is also of high importance in balancing future water demand and supply. Other research indicates that more investment in basin efficiency improvement would potentially bring similar effects in securing irrigation water supply as more investment in water infrastructures. Likewise, water saving technology and conservation measures in the industrial and domestic sector would result in more reliable water supply in non-irrigation sectors and relieve the increasingly intensified intersectoral water competition.

On the fisheries side, although small pelagic species are robust, the behavior of the small pelagic fish towards the end of the modeled period (2048) indicate that such a policy of mining small pelagic fisheries to support a growing aquaculture industry may not be that sustainable in the long-term except in a few areas of the world's oceans. This needs to be also interpreted with caution since small pelagic fish are extremely sensitive to oceanographic changes and if the predictions for changes in sea temperature are realized, this biomass and possibly the dynamics of species within this group will change significantly and have a reverberating affect up through the higher trophic levels since most animals especially marine mammals and seabirds rely on this group of fish for much of their food. Therefore a policy of increasing landings needs to be carefully considered in the light of climate change.

On land resources the scarcity of land becomes a more prominent challenge for policy makers. Growth of population combined with changes towards high land-demanding meat diets is resulting in additional demands for land. Although crop productivity is expected to increase further, which is accounted for in the reference run, the uncertainty to which extent this productivity increase will actually be met is also increasing. Moreover, the increase in livestock needs to be compensated by intensified livestock production systems or an increasing carrying capacity in all rangeland systems. This increase in carrying capacity is not expected, certainly not in vulnerable drylands, as identified before in the Millennium Ecosystem Assessment. But not only changes in population and diet are causing an increase in land demand. Also new land demanding factors like biofuels (stimulated because of concerns for climate change or energy self-sufficiency) are very likely to grow exponentially the coming decades. This will not only impact the food prices additionally (Section 5.5.2), but will also lead to more competition for land. The combination of all these land demanding factors will lead to rather grim conclusions on biodiversity. Where the Convention on Biological Diversity (CBD) has set the target to reduce the rate of loss of biodiversity significantly by 2010, this target seems impossible to reach on the longer term, let alone in 2010. Since nature is not valued at all in the current economic markets, human development will only encounter problems with biodiversity after specific thresholds are already passed. On the short-term no policy options seem to be available to help in reaching the CBD target (see also the Global Biodiversity Outlook of CBD). Even worse: some policy options to reduce the pressures on the natural system (e.g.

climate mitigation strategies as described in Section 5.4.1) will worsen the direct impact on biodiversity through additional land-use changes required for using biofuels. Concluding, the competition for land will be one of the major concerns for policy makers and this concern is not easily solved, especially not when other environmental problems are partly solved with the implementation of more land demanding factors like biofuels.

5.6 Implications for AKST in the Future

5.6.1 Introduction

As the reference world in 2050 and the various policy discussions show, agriculture will have to face a number of new and difficult challenges in the future. Food security is likely to still be a problem 50 years from now (though to a lesser extent). Agricultural production is likely to be constrained by competition for land and water and climate change issues. Strategies for adapting to new regulations for food safety, and the development of biotechnology and bioenergy pose significant challenges and opportunities. Food prices could rise as a result of these challenges and constraints. In addition, income growth, urbanization and growing global inter-connectedness are leading to diet diversification and homogenization. Scientific advances and stronger protection of intellectual property rights have greatly increased the ability of agricultural researchers to recoup their investments in crop improvement research. These and other factors have altered the commercial incentives for agricultural research in ways that have transformed the system through which agricultural technologies are developed and disseminated, with profound implications for farmers in developing countries. Trade liberalization and greater integration of global food markets are leading to more reliable food supplies and have for the moment lowered food prices in real terms, but as the reference world shows this might not continue in the future. However, alternative policy experiments show that with higher investments in AKST, significant improvements can be made in food security.

Appropriate AKST investments and policies will require an appropriate mix of strategies, depending on the potential and constraints in different regions while addressing the broader changes taking place in global and national food systems. In particular the priorities for research and development ought to focus on:

- yield-enhancing, resource-conserving technologies for favorable as well as unfavorable environments for crops and livestock production;
- diversification and commercialization of agricultural systems;
- ecosystem services production in addition to food or timber, including biodiversity conservation;

5.6.2. Yield-enhancing, resource-conserving technologies

Given growing populations and income induced demand for increased cereal consumption (for populations at low income levels) there continues to be a strong need to seek higher productivity levels for the staple cereals. The need for increasing the productivity of cereals is higher the greater the diversion of high potential irrigated lands to non-cereal pursuits.

Both substantial crop-specific research and system level research effort will be required to enhance productivity while conserving the natural resource base. Crop-specific research includes increases in yield potential, shorter duration cultivars, improved quality characteristics and greater tolerance to pest stresses. Modern biotechnology can play an important role in shifting the yield frontier as well as reducing yield variability due to biotic and abiotic stresses.

Resource management research would include land management and tillage systems that allow for shifts of cropping patterns and animal husbandry in response to changing incentives and farm level water management systems that can accommodate a variety of crops within a season. Also important at the system level is research on the carry over effect of inputs and management practices across crops, for instance, high insecticide and herbicide applications, or the effects of intensification in terms of prolonged water saturation, the build up and carryover across crops of pest populations, rapid depletion in soil micronutrients and changes in soil organic matter could lead to reduced productivity of monoculture systems over the long term.

To what extent should the research system be concerned with technological developments in marginal or unfavorable environments? In large countries, such as India and China, with high domestic demand for cereals, the answer is relatively clear: investments in marginal environments are absolutely essentially for ensuring food security, even if the countries are integrated into the global economy. Cost-effective research investments would be in areas where the spill-over benefits from the favorable environments are high. Identification of strategies for diversifying the income and livelihood base of the farm households in these environments should also be an important area for research and policy.

5.6.3. High value agricultural crops and crop diversification

The challenges faced by farmers should be seen in the context of the general trends that will influence the structure of agricultural production, including the transformation of diets and rising import competition that will contribute to the increasing commercialization of the farm sector. Governments ought to help create an enabling environment for smallholder commercialization through infrastructure investments and institutional reform. “Retooling” smallholders with appropriate technology and knowledge that makes them able to face the requirements of the changing market conditions will be a formidable challenge for research and extension systems. Rural infrastructure investments play a crucial role in inducing farmers to move toward a commercial agricultural system. The emphasis for public investments should be on improving general transport, communications, and market infrastructure, while allowing the private sector to invest in commodity-specific processing, storage, and marketing facilities.

The primary objective of the research system during the process of commercialization and diversification remains to generate new technologies that improve productivity and farmer income. Governments have a difficult task to perform: on one hand, continued food security needs to be assured for populations that are growing in absolute terms; on the other hand, research and infrastructural investments need to be made for diversification out of the primary staples. In responding to diversification trends, the research should not abruptly shift from an exclusive focus on one set of commodities to another set of commodities. In addition to the productivity objective, the focus of research should be to provide farmers the flexibility to make crop choice decisions and to move relatively freely between crops. Gearing farmers to meet more exacting safety and quality standards ought to be essential part of the strategy.

5.6.4. Ecosystem services production

Ecosystem services are defined as all benefits that humans receive from ecosystems (Daily 1997; Costanza et al.1997; MEA 2003)). The Millennium Ecosystem Assessment distinguishes four different categories of services (MA, 2003): a) provisioning services, which include food production, b) regulating services (e.g. climate regulation, nutrient cycling), c) supporting services (e.g. biodiversity) and d) cultural services (e.g. amenity values). An eco-system perspective, as opposed to a conventional agricultural development perspective, recognizes that land management can produce more than just food or fibre and distinguishes between services that sustain agricultural production and those that are public goods in their own right.

Provisioning services in the form of agricultural production are one of the most important ecosystem services in terms of a clearly defined economic value, as compared with other ecosystem services. Supporting and regulating services, such as soil fertility and water flow management, while important complementary services to agriculture production, tend to be undervalued. In cases where the provision of environmental services involves a tradeoff with agricultural production; e.g. conserving biodiversity by maintaining forest areas, poor societies have generally chosen in favor of production.

In land abundant areas, including areas where rising off-farm employment opportunities have drawn populations out of rural areas, the potential for setting aside land for non-agricultural uses has been relatively high. Conversion of agricultural lands to forests contributes to carbon sequestration, watershed protection and biodiversity conservation. However, growing demands for production of feedstocks for bioenergy and growing constraints on water and land may be increasingly limiting these set-asides. On the other hand, in land scarce environments the trade-off between agricultural and non-agricultural services is high. In such environments, eco-system services would have to be complementary to, rather than a substitute for, food and fiber production. This requires the adoption of agricultural production systems that generate environmental services. Conservation tillage, agro-forestry systems, and silvo-pastoral systems, are some of the many examples of agricultural production systems that can generate external environmental benefits in the form of carbon sequestration, biodiversity conservation and watershed protection. (See Dutilly-Diane et al. 2004 for a discussion of rangelands management programs that can generate environmental services in drylands areas). The service is generated by the land user but the benefit is realized off site. The beneficiaries may include local residents, consumers in global markets or even future generations. These types of environmental services are generally in the form of public goods, with low rivalry in consumption and high exclusion costs.

In addressing the research agenda for the future, AKST systems are likely to face a new set of challenges:

- increased privatization of research and proprietary control of technology, especially for biotechnology products
- an uncertain future for public good research
- continued lack of technology access for the poor and marginal groups

5.6.5. Increased privatization of research

Over the past decade the locus of agricultural research and development has shifted dramatically from the public to the private multinational sector. Three interrelated forces are transforming the system for supplying improved agricultural technologies to the world's farmers. The first is the strengthened and evolving environment for protecting intellectual property in plant innovations. The second is the rapid pace of discovery and growth in importance of molecular biology and genetic engineering. Finally, agricultural input and output trade is becoming more open in nearly all countries. These developments have created a powerful new set of incentives for private research investment, altering the structure of the public/private agricultural research endeavor, particularly with respect to crop improvement.

To understand the magnitude of private sector investment in agricultural research today, one need only look at its annual research budget relative to public research targeted to the developing country agriculture. The world's top 10 multinational bioscience corporations' collective annual expenditure on agricultural research and development is nearly three billion US dollars. In comparison the CGIAR, which is the largest international public sector supplier of agricultural technologies, spends less than 300 million US dollars annually on plant improvement research and development. The largest public sector agricultural research programs in the developing world, those of Brazil, China, and India, have annual budgets of less than half a billion dollars each (Pingali 2007).

While there is more plant research being conducted today than at any time in history, the increased effort has not been evenly distributed geographically, or across crops. Pingali and Traxler (2002) identify three types of gaps in private research incentives—geographic, crop coverage, and disciplinary.

Geographic and ecological gaps: The size potential of domestic market and the ability to introduce existing commercial products from similar agro-ecological environments will be prime determinants of private sector investment. The multinational firms have been intensely interested in entry into the "giant" markets of Brazil, India and China, but have also interest in some smaller markets such as, South Africa and Mexico. Large areas of the developing world, however, remain outside the orbit of private sector interest most of sub-Saharan Africa and Central America are cases in point. Private sector interest in such tropical agricultural systems with small market potential will continue to be limited. For instance Eicher et al. (2006) argue that most GM crops are at least 10-15 years or longer from reaching smallholder farmers in Africa.

The private sector is also unlikely to invest in research for difficult growing environments, such as drought prone or high temperature environments for several reasons. These environments tend to have poorer infrastructure and are farmed less intensively, raising unitary marketing and distribution costs. Also, the expected rate of yield gain is a key determinant of farmer demand for seed and breeding progress in stressed environments is generally slow. Therefore orphan crops in marginal (stress prone) environments are unlikely to be of interest to the private sector now or in the future.

Crop gaps: The world commercial seed market is dominated by relatively few crops, most importantly maize, soybean, cotton and vegetable sales. Hybrid seed enjoy some protection from counterfeiting through the loss of hybrid vigor in second generation seeds. Private sector biotechnology investment, first in temperate agriculture and more recently in tropical systems, has concentrated on the above hybrid crops allowing them to appropriate the returns from their investments. On the other hand, the world's two most important food crops, rice and wheat, have received minimal attention from the private sector. Rice and wheat are self-pollinating crops and therefore not amenable to appropriating the returns from research investments. While hybridization is technically feasible for crops such as wheat and rice, they have achieved commercial viability only in small areas of India and China. Private sector investment in coarse grains, such as sorghum and millet, or tropical root and tuber crops, such as cassava, is miniscule.

Research area gaps: Even as we consider the rapid increase in private sector investments in agricultural research, particularly for commercial production systems in the developing world, we ought to be cognizant of significant gaps in private sector research focus and in disciplinary strengths. Private sector investment in biotechnology related activities is high relative to its other research activities and we anticipate it will continue to increase, particularly as the focus shifts to tropical agricultural systems. However, private sector investment and expertise in conventional areas of plant breeding is relatively weak, private companies have relied on the public sector for genetic resources, pre-breeding materials, and germplasm adapted to particular agro-ecological niches. Without the complimentary expertise in conventional breeding the ability of the global bioscience companies to move their genes from temperate crops into tropical germplasm will be limited.

In addition to conventional breeding and plant improvement, private sector is weaker, relative to the public sector research systems, in the areas of agronomy and crop and resource management research. Machinery development, fertilizer and chemical input use were areas that the multi-national corporations have traditionally been strong, but if we get beyond that to production systems research, private sector capacity is weak. For example, very little work is done in the private sector on the long-term consequences of intensive production systems and management options for sustaining the productivity of these systems. Even where such work is done by the private sector, the ability to transfer knowledge and technologies across trans-national and ecological boundaries is limited. Transnational germplasm transfer and adaptation that the private sector managed effectively through the purchase of local companies by the multi-nationals, does not work as well in the case of crop and resource management technologies. High location specificity of agronomic and crop management knowledge and technologies limits the scale economies in research and technology transfer. Moreover, there are limited proprietary benefits to be had from the development of improved crop management practices.

5.6.6. Public sector research

For both favorable as well as the unfavorable production environments, the public sector could concentrate on plant improvement research targeted towards self-pollinated crops such as wheat and rice. Private sector investments in these crops are small, yet enhancing their productivity and nutritional content is crucial to improve the food security and welfare of the poor subsistence producers as well as poor consumers.

Poor household in unfavorable environments depend on coarse grains such as: maize, sorghum and millet, as well as a variety of root and tuber crops. These low productivity environments characterized by drought and high temperature conditions have traditionally been ignored by private sector investments. Advances in genomics could boost the prospects for developing improved germplasm for these environments. The public sector needs to identify mechanisms for accessing private sector knowledge and technology that could be used for improving crops in marginal environments.

The public sector needs to also continue to work in developing improved crop and resource management technologies that enhance the profitability and sustainability of intensive production systems that use the improved germplasm produced by the private as well as the public sectors. Particular attention ought to also be paid to developing systems that will allow for the safe use of transgenic crops over the long term in small farm production systems.

Managing national and global genetic resources, establishing and maintaining scientific networks that act as a conduit of information and technology flow, developing and maintaining pre-breeding materials, are all areas that the public sector has traditionally been strong and will continue to be the leading player. Falcon and Fowler (2002) provide a detailed discussion on the future options for public sector management of global genetic resources. The private sector's research costs are substantially reduced by the provision of the above public goods by the national as well as the international research systems. The public sector has also been and will continue to be the leading player in developing scientific capacity through formal as well as informal training activities. Private research systems' ability to meet its human resource needs depends crucially on the public sector's sustained capacity as a supplier of training and capacity building.

5.6.7. Access of farmers to new technologies

The changing locus of agricultural innovation from the public to the private sector has increased the costs faced by developing countries and small farmers in accessing new technology. Access problems are particularly severe for poorer countries with small markets and weak institutions, traditional targets of public sector research on "public goods." This is a major policy challenge for international development community and national and local decision makers. A key area of improvement in technology adoption would be agricultural extension and advisory services, with an evolution away from the top-down extension approach that has usually dominated. In general, decentralized, demand-driven and participatory programs tend to be more democratic in design and more successful in implementation. Involving producer organizations in extension activities helps to engage producers in programs that coincide with their own goals. However, decentralizing extension services has met with a number of hurdles reducing effectiveness, including inadequate preparation by the central government, both in its own right and in managing the transition with local governments. Extension policies and strategies need to define effective division of labor between public extension and other providers, and identify over-all objectives for public-sector involvement in extension. A pluralistic agricultural extension system that allows for complementarity and appropriate targeting of extension advice to farmers by NGOs, private companies, producer groups, public agencies holds considerable promise for improving delivery of technology.