Global Chapter 5 Looking into the future for agriculture and AKST

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Key Messages

1. Quantitative projections indicate a tightening of world food markets, with increasing resource scarcity, adversely affecting poor consumers. Real world prices of most cereals and meats are projected to increase in the coming decades, dramatically reversing trends from the past several decades. Price increases are driven by both demand and supply factors. Population growth and strengthening of economic growth in sub-Saharan Africa, together with already high growth in Asia and moderate growth in Latin America drive increased growth in demand for food. Rapid growth in meat and milk demand is projected to put pressure on prices for maize and other coarse grains and meals. Bioenergy demand is projected to compete with land and water resources. Growing scarcities of water and land are projected to increasingly constrain food production growth, causing adverse impacts on food security and human well-being goals. Higher prices can benefit surplus agricultural producers, but can reduce access to food by a larger number of poor consumers, including farmers who do not produce a net surplus for the market. As a result, progress in reducing malnutrition is projected to be slow.

2. Improved Agricultural Knowledge Science and Technology (AKST) helps to reduce the inevitable tradeoffs between agricultural growth and environmental sustainability at the global scale. AKST can help to maximize the socioeconomic benefits of extracting natural resources from a limited resource base, through increasing water productivity and intensifying crop, livestock and fish production. Without appropriate AKST development further production increases could lead to degradation of land, water and genetic resources in both intensive and extensive systems.

3. Growing pressure on food supply and natural resources require new investments and policies for AKST. Tightening food markets indicate that a business-as-usual approach to financing and implementing AKST cannot meet the development and sustainability goals of reduction of hunger and poverty, the improvement of rural livelihoods and human health and equitable, environmentally sustainable development. Innovative AKST policies are essential to build natural, human and physical capital for social and environmental sustainability. Such policies will also require more investment in AKST. Important investments supporting increased supply of and access to food include those in agricultural research and development, irrigation, rural roads, secondary education for girls, and access to safe drinking water.

4. Continuing structural changes in the livestock sector, driven mainly by rapid growth in demand for livestock products, bring about profound changes in livestock production systems. Structural changes in the livestock sector have significant implications for social equity, the environment and public health. Projected increases in livestock numbers to 2050 vary by region and species, but substantial growth opportunities exist for livestock producers in the developing world. The availability of animal feed will however affect both the rate and extent of this growth, since competition is growing between animal and aquaculture feeds that both use fishmeal and fish oil. Livestock feeds made with fish products contribute to superior growth and survival but are increasing prices and consumption of fishmeal and fish oil in the aquaculture sector and a corresponding decrease in the use of these products in the livestock sector, especially for pigs and poultry, can affect production and increase prices. Moreover, declining resource availability could lead to degradation of land, water, and animal genetic resources in both intensive and extensive livestock systems. In grassland-based systems, grazing intensity (number of animals per ha of grazing land) is projected to double globally, and possibly quadruple in sub-Saharan Africa. In addition to the potential environmental impacts of more intensive livestock production systems, the sector faces major challenges in ensuring that livestock growth opportunities do not marginalize smallholder producers and other poor people who depend on livestock for their livelihoods.

Other 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.

5. Growing water constraints are a major driver of the future of AKST. Agriculture continues to be the largest user of freshwater resources in 2050 for all regions, although its share is expected to decline relative to industrial and domestic uses. Sectoral competition and water scarcity related problems will intensify. Reliability of agricultural water supply is projected to decline without improved water management policies. There is substantial scope to improve water management in both rainfed and irrigated agriculture. AKST and supporting interventions geared towards water conserving and productivity enhancement in rainfed and irrigated agriculture are needed to offset impacts of water scarcity on the environment and risks to farmers.

6. There is significant scope for AKST and supporting policies to contribute to more sustainable fisheries, by reducing the overfishing that has contributed to growing scarcity of resources and declining supplies of fish in the world's oceans. To date, AKST and supporting policies have not contributed to halting overfishing of the world's oceans. There are some initiatives to rebuild depleted stocks, but recovery efforts are quite variable. A common and appropriate policy response is to take an ecosystem approach to fisheries management but many governments are still struggling to translate guidelines and policies into effective intervention actions. Other policy options have included eliminating perverse subsidies, establishing certification, improving monitoring, control and surveillance, reducing destructive fishing practices such as bottom trawling bans, expanding marine protected areas and changing fishing access agreements. There are also policy responses to reduce effort in industrial scale fishing in many areas, while also supporting small-scale fisheries through improved access to prices and market information and increasing awareness on appropriate fishing practices and post-harvest technologies.

Rapid growth in demand for aquaculture products will also be adversely affected by growing scarcity of coastal land and offshore areas and water scarcity in land-based operations. The most appropriate policy response to this problem is integrated coastal management that better utilizes these shared resources for wider benefit. Another policy option is promoting best management practices, which include looking into appropriate feeding strategies as fish oil, on which the production of high value species depends, becomes increasingly scarce.

7. Expected climate changes are likely to affect agriculture, requiring attention to harmonizing policies on climate mitigation and adaptation with others on agriculture and forest land for bioenergy and on forestry for carbon sequestration. Climate change is expected to 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 in specific regions. Elsewhere, however, with higher temperatures and more erratic precipitation, the impact on crop yield can be negative. Under higher climate sensitivity, climate impacts are very likely to be negative for all regions. Even with small climate change projections, impacts are projected to be negative for dryland areas in Africa, Asia and the Mediterranean area. These climate impacts can be mitigated by climate policies, but very low stabilization experiments (450 ppmv CO_2-equivalents) will likely require measures such as carbon sequestration and bioenergy plantations that compete for land. Therefore, climate mitigation policy options might require reprioritizing among alternative development and sustainability goals.

8. Food safety regulations can help improve the quality of life, but need to be designed to avoid adversely affecting poor farmers' access to markets. Demand for products with high quality and safety standards is expected to grow in industrialized countries. This market will only be accessible to those developing countries with sufficient AKST capacity and knowledge to meet the higher standards, especially in post-harvest handling. Better quality standards are only likely to emerge in developing countries if consumers are educated about the benefits of consumption of perishable products, if public health regulation and liability laws are established, and if better laboratory infrastructure is built. Challenges in coming decades include ensuring safer food for consumers and raising the quality of life without reducing food availability, access and use by the poor or by creating barriers to poor countries and smaller producers by excluding their exporting produce through multinational companies. Implementation of quality and food safety control programs with intensive internal and external supervision can improve productivity without increasing costs for consumers. Government actions toward product quality standardization should consider the effect on the distribution of costs and benefits between actors.

9. Rural communities have a greater say in the future of small-scale agriculture as their access to information via information communication and technology (ICT) and to financial capital via remittance investment plans increases. The attributes of ICTs are linked directly and indirectly with the sustainability and development goals. As internet access increases in rural areas, small-scale producers will benefit from more readily available information, both traditional and local knowledge and technological and market information, if private and public institutions take up the challenge of providing climate, weather, and price data. In addition cellular phone use among national and international migrants will enhance information flows and their participation in decisions. 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 ICTs and migrant remittances will impact the land management, food security and livelihood strategies of rural communities in new ways.

10. Society benefits from involving women in all levels of processes from education to decision making and work, increasing their access and contribution to AKST.
In the developing world it is expected that an increasing share of women workers would participate in rural farm activities and in agro-based industries and agro-based service sectors. Investments in health services, child care, and education are fundamental to achieving the development and sustainability goals that support women's participation in agriculture and AKST. AKST policies and investments in rural infrastructure, which improve women's status, enhance women's role, and reduce their burden through better water and energy supply, would help improve livelihoods while also supporting other AKST policies.

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

This chapter examines the potential future for agriculture and AKST using primarily quantitative methods combined with qualitative analyses of those issues that cannot easily be addressed in quantified models. For this approach a reference run is developed from 2000 to 2050, based on the assessment of drivers of agriculture and AKST explained in Chapter 4. It builds on changes in drivers used in previous assessments and uses a set of modeling tools to sketch out a plausible future based upon past trends. This reference run is used to indicate how the development and sustainability goals (see Chapter 1) might take shape out to 2050. In subchapter 5.3 the reference run is described and the results are shown. No important policy actions are assumed in the reference run to show more sharply the consequences of a non-interventionist reference case.

In a second step, in subchapter 5.4, a set of policy actions are simulated in order to assess the impact these could have on the attainment of development and sustainability goals. Here, policy experiments on investments in AKST, climate mitigation, extensive use of bioenergy, trade liberalization, changes in water productivity and in dietary changes, such as shifts to consumption of organic food or less meat, are implemented and analyzed. In this way, the quantified impact and tradeoffs of these specific policy actions can be made visible. Not all future developments, however, can be assessed with the various tools that are used in this subchapter. Subchapter 5.5 therefore describes a series of important, emerging issues related to AKST that can affect the reference world and alternative policy pathways. Subchapters 5.6 and 5.7, finally, examine synergies and tradeoffs and implications for AKST in the future, respectively.

5.2 Rationale and Description of Selected Tools

The inclusion of various tools in the assessment process enables the examination of the various relationships that transpire determined by major drivers. Also synergies and tradeoffs between specific policy interventions can be made visible through the use of modeling tools. Modeling results can be used to support policy analysis in this assessment. Clearly, models cannot provide answers for all issues. In that case, qualitative translations of the modeling results are used in this Chapter to assess the most crucial policy options that have been identified in Chapter 4.

5.2.1 Rationale for model selection

In this assessment, with its focus on agriculture and the role of AKST, the partial equilibrium agricultural sector model International Model for Policy Analysis of Agricultural Commodities and Trade, or IMPACT (Rosegrant et al., 2002), plays a pivotal role. Partial equilibrium agricultural sector models are capable of providing insights in long-term changes in food demand and supply at a regional level, taking into account changes in trade patterns using macro-economic assumptions as an exogenous input. To be able to assess the environmental consequences of changes in the agricultural sector, a range of environmental models is used as well. The integrated assessment model IMAGE 2.4 (Eickhout et al., 2006) is central in this environmental assessment, while specific models like EcoOcean and GLOBIO3 (Alkemade et al., 2006) are used to provide consequences for specific issues, marine and terrestrial biodiversity, respectively. The livestock spatial location-allocation model, SLAM, (Thornton et al., 2002, 2006) and the water model WATERSIM (de Fraiture et al., 2006) are used to give specific insights in crucial sectors for agriculture and AKST. The computable general equilibrium (CGE) model GTEM (Ahammad and Mi, 2005) is used to validate the GDP and population input data to achieve cross-sectoral consistency for the reference run. And finally, the regional models, GEN-CGE,for India, (Sinha et al., 2003) and the Chinese Agricultural Policy Simulation Model (CAPSiM) (Huang and Li, 2003) are used to add local flavors to the global analyses that have been performed by the other tools. India and China were chosen since future policy change in these two countries will affect global food supply, demand, prices, and food security. Moreover, China- and India-specific modeling tools are used to provide deeper insights about specific development goals such as the distributional aspects of equity and poverty which cannot be addressed by global models.

The tools used in this assessment for the reference run out to 2050 are summarized in Table 5.1. A selection of the models is also used for the policy experiments in subchapter 5.4, as indicated in Table 5.1. Short descriptions of model types are provided below and longer descriptions, including an assessment of major uncertainties are introduced in the appendix to this chapter. Linkages among models are presented in subchapter 5.2.2.

INSERT TABLE 5.1

5.2.1.1 Partial equilibrium agricultural sector models

Partial equilibrium models (PE) treat international markets for a selected set of traded goods, e.g. agricultural goods in the case of partial equilibrium agricultural sector models. These models consider the agricultural system as a closed system without linkages with the rest of the economy, apart from exogenous assumptions on the rest of the domestic and world economy. The strength of these partial equilibrium models is their great detail of the agricultural sector. The “food” side of these models generally 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. Biophysical information on a regional level (e.g., on land or water availability), is constraining the supply side of the model.

Food projections' models that simulate aggregations of components—regions, commodities and larger countries—tend to be more reliable (McCalla and Revoredo, 2001). PE 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 policy makers and citizens to major issues that need attention to avoid adverse food security outcomes. A test for the usefulness of these models may therefore 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, since, 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, the 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.

5.2.1.2 Integrated assessment models

Integrated Assessment models (IAMs) are 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 can support policy discussions in this area.

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

Processes that change ecosystems and their services mostly occur at highly disaggregated levels. Models therefore require regional specificity. A tendency to increase the level of explicit geographic information in models, for instance by using a detailed grid, can be seen in the 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 decision-making. 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, uncertainty analysis is typically included only partially or not at all.

5.2.1.3 CGE models

CGE models are widely used as an analytical framework to study economic issues of national, regional and global dimension. CGE models provide a representation of national economies, next to a specification of trade relations between economies. CGE models are specifically concerned with resource allocation issues, that is, where the allocation of production factors over alternative uses is affected by certain policies or exogenous developments. International trade is typically an area where such induced effects are important consequences of policy choices. 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, 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 is fundamental (e.g., among agriculture, energy, processing and manufacturing as well as services), trade (domestic and international), and existing policies. Given their economy-wide coverage, some variant of this type of models has become a part of the Integrated Assessment models (e.g., IMAGE; Eickhout et al., 2006).

A strength of CGE models is their ability to analyze 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. However, CGEs are poor in addressing distributional issues within the regions: only average adjustments in the regional economies are simulated. Moreover, CGE models should be handled with care for long-term projections since fundamental changes in the economic structure of a region cannot be simulated by a CGE model. Therefore, CGE models are only used in this assessment for assessing the economic consequences globally of trade liberalization.

5.2.1.4 Marine biomass balance models

Fisheries models, such as EcoOcean, allow managers to explore how marine systems, especially fisheries, might respond to policy changes at the scale of the ocean basin or region not addressed by most other fisheries models. 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 variation 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 and an indication of how the diversity of the fisheries will change over time.

The models have some weaknesses. The functional groups used in EcoOcean are broad groupings of marine organisms, which limits their ability to describe 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 or 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 seven 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 that 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.

5.2.2 Interactions of models in this assessment

The focus of the analyses in this Chapter is on the issues summarized in Figure 5.1. This figure illustrates which models address which issue.

INSERT FIGURE 5.1

5.2.2.1 Relations between the models

The most important inputs—population and GDP growth—are used exogenously in all modeling tools to enhance consistency of the analyses. The global CGE model is used to provide consistency among population, economic growth, and agricultural sector growth. Climate is used as an input in many of the modeling tools. Future climate change is simulated by the IMAGE 2.4 model and is then used by other models as well.

In the chain of models, IMPACT simulates food supply and demand and prices for agricultural commodities for a set of 115 countries/sub-regions for 32 crop and livestock commodities, including all cereals, soybeans, roots and tubers, meats, milk, eggs, oils, oilcakes and meals, sugar and sweeteners, and fruits and vegetables. The 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 of IMPACT.

The SLAM model is using the livestock supply and demand from IMPACT. In the SLAM model, land is allocated to four categories: landless systems, livestock only/rangeland-based systems (areas with minimal cropping), mixed rainfed systems (mostly rainfed cropping combined with livestock) and mixed irrigated systems (a significant proportion of cropping uses irrigation and is interspersed with livestock). The allocation is carried out on the basis of agroclimatology, land cover, and human population density (Kruska et al., 2003; Kruska, 2006). The second component of the model then allocates aggregated livestock numbers to the different systems, allowing disaggregated livestock population and density data to be derived by livestock-based system. The structure of the classification is based on thresholds associated with human population density and length of growing period, and also on land-cover information. The primary role of SLAM in this assessment is to convert the livestock outputs of the IMPACT model (number of livestock slaughtered per year per FPU) to live-animal equivalents by system, so that changes in grazing intensity by system can then be estimated. These estimates of grazing intensity are subsequently used as input data to the IMAGE model to assess the land-use change.

The crop and livestock supply and demand from IMPACT and the grazing intensity from SLAM are used as input by IMAGE 2.4, a model designed to cover the most important environmental issues. For land-use changes, the input from IMPACT and SLAM is used. For changes in the energy sector, the IMAGE energy model TIMER (van Vuuren et. al., 2007) is used. Because of the focus of the IMAGE model on land and energy, it is most suitable to also address bioenergy. The potential for bioenergy is determined by the land-use model of IMAGE 2.4 and, through price mechanisms of price supply curves, the amount of bioenergy in the total energy mix is determined by the TIMER model (Hoogwijk et al., 2005). All socioeconomic drivers are simulated for 24 regions (26 regions in the TIMER model); the land-use consequences on grid scale of 0.5 x 0.5 degrees. Through linkages of the terrestrial system to carbon and nitrogen cycle models, the atmospheric concentrations of greenhouse gases and tropospheric ozone are simulated as well. A simple climate model combined with a geographical pattern scaling procedure (Eickhout et al., 2004) translates these concentrations to local changes in temperature and precipitation.

The terrestrial changes as simulated by IMAGE are used as input by the terrestrial biodiversity model GLOBIO3 (Alkemade et al., 2006). GLOBIO3 is using dose-response relationships for each region and ecosystem type to translate environmental pressures (like climate change, nitrogen deposition, land-use change and infrastructure) to average quality values of these ecosystem types. For this analysis all ecosystems are represented by a set of representative species. The quality of the ecosystem types are therefore an approximation of the mean species abundance (MSA) present in each ecosystem type. Note that each MSA value is by definition between 0 and 1.

The fisheries EcoOcean model is used to assess the future catch, value and mean trophic index of marine systems in different oceanic parts of the world. The FAO statistical areas provide a manageable spatial resolution for dividing the world into a reasonable number of spatial units. Similarly 43 trophic groups represent the different functional groups that are found in most areas of the world's oceans. For each of the 19 regions, information from the "*Sea Around Us"* catch database is used for each year from 1950 to present to fit the catches. Once the model has been tuned and is deemed to perform satisfactorily, a series of future-oriented evaluations is performed. The EcoOcean model is not linked to any of the other models and is only used to add insights about the future quality of the marine systems.

IMPACT provides broad insights into socioeconomic consequences. The regional GEN-CGE and CAPSiM models provide added insights into distributional consequences and gender for China and India, respectively. The WATERSIM model is used to provide more insights into the water balance. Water demand for irrigation, domestic purposes, industrial sectors, livestock and the environment are estimated on a basin scale. Water supply for each basin is expressed as a function of climate, hydrology and infrastructure. The model iterates between basin, region and globe until the conditions of economic equilibrium and hydrologic water balance are met.

5.2.2.2 Policy experiments

IMPACT is the core modeling tool used to assess agriculture and AKST for the IAASTD. It is therefore represented in most of the policy experiments. Investments requirements in AKST and changes in diets (both organic and non-meat) are simulated in IMPACT. Climate mitigation and bioenergy policies are implemented first in IMAGE. Trade liberalization is performed by GTEM, simulating changes in the economic structure. IMPACT then picks up changes in the economic structure and simulates the consequences for food supply and demand. The regional consequences are examined through the regional GEN-CGE and CAPSiM models for India and China. Finally, changes in the water productivity are assessed by WATERSIM.

5.3 Description of Reference World, Including Quantification

5.3.1 Rationale of reference world

The reference case 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. Current policy pathways are expected to continue out to 2050. This continuation of the "real world" is plausible. In subchapter 5.4 some of the major questions affecting the future of agriculture and AKST are simulated and results are compared to the reference world.

5.3.2 Inputs into the reference world

5.3.2.1 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 (Table 5.2). Population growth continues to slow in high-income countries. Population growth drives changes in food demand and is an indirect driver for AKST. The data for population changes are taken from the medium variant projections of the UN (UN, 2005), based on an assessment of previous studies (see also Chapter 4).

INSERT TABLE 5.2

5.3.2.2 Overall economic growth

Economic growth assumptions are loosely based on the TechnoGarden scenario of the Millennium Ecosystem Assessment (MA, 2005). Incomes are expressed as MER-based values. The economic growth assumptions of the TechnoGarden scenario are near the mid-range growth scenarios in the 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.

INSERT TABLE 5.3

5.3.2.3 Agricultural productivity

Agricultural productivity values are based on the Millennium Ecosystem Assessment (MA) (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.

5.3.2.4 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 are projected to 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 5-6% 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.

5.3.2.5 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 reference run 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 variants, 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.

5.3.2.6 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.

5.3.2.7 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 et al., 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 et al., 2002).

5.3.2.7 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 policy variant 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.

5.3.2.8 Climate change

Climate change is both driving different outcomes of key variables of the reference run (like crop productivity and water availability) and is an outcome of the agricultural projections of the reference run, through land-use changes and agricultural emissions, mainly from the livestock sector (FAO, 2006b). Given the medium energy outcomes in the reference run (see subchapter 5.3.3.3), results from the B2 scenario are directly used in most of the modeling tools. From the available B2 scenario, the ensemble mean of the results of the HadCM3 model for B2 scenario was used. The pattern scaling method applied was that of the Climate Research Unit, University of East Anglia. The “SRES B2 HadCM3” climate scenario is a transient scenario depicting gradually evolving global climate from 2000 through 2100. In the IMAGE model, climate change is an output of the model. The IMAGE model uses a global climate model (MAGICC) to calculate global mean temperature change – and uses downscaling techniques to downscale this data to a 0.5 x 0.5 grid. Through this approach, different GCM results can be used to assess the consequences of the uncertainty in local climate change. For the reference run, the pattern of Hadley Centre’s HadCM2 is used for the downscaling approach, which is consistent with the pattern used in the other modeling tools. 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. According to IPCC the climate sensitivity is likely to be in the range of 2 to 4.5°C with a best estimate of about 3°C, and is very unlikely to be less than 1.5°C (IPCC, 2007). Climate sensitivity is not a projection but is defined as the global average surface warming following a doubling of carbon dioxide concentrations (IPCC, 2007). The uncertainties in the climate sensitivity are not assessed in the reference world. Specific sensitivity analyses will show the importance of the uncertainties in values of the climate sensitivity.

5.3.3 Description of reference world outcomes

5.3.3.1 Food sector

Food supply and demand. In the reference run, global food production increases 1.2% per year during 2000-2050. This growth is a result of rapid economic growth, slowing population growth, and increased diversification of diets. Growth of demand for cereals slows during 2000-2025 and again from 2025-2050, from 1.4% per year to 0.7% per year. Demand for meat products (beef, sheep and goat, pork, and poultry) grows more rapidly, but also slows somewhat after 2025, from 1.8% per year to 0.9% annually.

Changes in cereal and meat consumption per capita vary significantly among IAASTD region. Results are presented in Figures 5.2 and 5.3. Over the projections period, per capita demand of cereals as food declines by 3 kg in the LAC region and by 10 kg in the ESAP region. On the other hand, demand is projected to considerably increase in the sub-Saharan Africa region, at 39 kg, and still by 7 kg in the NAE and CWANA regions, respectively. Recovery and strengthening of economic growth in sub-Saharan Africa will drive relatively fast growth in regional demand for food. In developing countries and particularly 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 the SSA region, growing incomes are expected to lead to a shift from roots and tubers to rice and wheat. Per capita food demand for roots and tubers in SSA is projected to decline from 171 kg to 137 kg between 2000 and 2050, while rice and wheat demand are expected to grow from 18-20 kg to 30-33 kg (Table 5.4). Under the reference run, the composition of food demand growth across commodities is expected to change considerably. Total cereal demand is projected to grow by 1,305 million Mg (Megagrams), or by 70%; 50% of the increase is expected for maize; 23% for wheat; 10% for rice; and the reminder, for sorghum and other coarse grains.

INSERT FIGURES 5.2, 5.3, AND TABLE 5.4

Demand for meat products continues to grow rapidly across all six IAASTD regions, by 6-23 kilograms per person. The increase is fastest in the LAC and ESAP regions and slowest in the SSA and NAE 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 553 million Mg during 2000-2050, a staggering 42% of total cereal demand increase (Figure 5.4).

Tables 5.5, 5.6, 5.7 and 5.8 present results for changes in livestock numbers for beef, sheep and goats, pigs, and poultry, respectively, for the IAASTD regions. The global population of bovines is projected to increase from some 1.5 billion animals in 2000 to 2.6 billion in 2050 in the reference run. Substantial increases are projected to occur in all regions except NAE: the number of bovines is projected to double in CWANA and ESAP, and to increase by 50% in SSA, for example. Cattle numbers are projected to peak in SSA in about 2045. Bovine populations are relatively stable in NAE to 2050 in the reference run.

Similar patterns are seen for changes in sheep and goat populations. The global population is expected to increase from 1.7 billion in 2000 to 2.7 billion in 2050, again with substantial increases in all regions except NAE. In ESAP, sheep and goat numbers are increasing to 2050 still, but the rate of increase is declining markedly. In all other regions, numbers reach a peak sometime around 2040, and then start to decline.

INSERT FIGURE 5.4, TABLE 5.5 and TABLE 5.6

Globally, pig numbers are expected to peak around 2030 and then start to decline, and numbers in no region are projected to increase between 2040 and 2050. Poultry numbers are projected to more than double by 2050. Peak numbers are reached around 2045 in NAE, with small declines thereafter, while numbers are continuing to increase somewhat in CWANA and SSA and still rapidly in LAC and ESAP. Growth in cereal and meat consumption will be much slower in developed countries. These trends are expected to lead to an extraordinary increase in the importance of developing countries in global food markets.

INSERT TABLE 5.7 and TABLE 5.8

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 is expected to slow.

For the crops sector, water scarcity is expected to increasingly constrain production with virtually no increase in water available for agriculture due to little increase in supply and rapid shifts 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. Once plants are weakened from abiotic stresses, biotic stresses tend to set in and the incidence of pest and diseases tends to increase.

With declining availability of water and land that can be profitably brought under cultivation, expansion in area is not expected to contribute significantly to future production growth. In the reference run, cereal harvested area expands from 651 million ha in 2000 to 699 million ha in 2025 before contracting to 660 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 1.02% per year in 2000-2050; in the NAE region, average crop yield growth will decline to 1.02% per year; in CWANA to 1.26% per year, and in ESAP to 0.84% annually, while cereal yield is expected to grow at a higher 1.61% and 1.68% per year in LAC and SSA, respectively.

As can be seen in Figure 5.5, area expansion is significant to projected food production growth only in sub-Saharan Africa (28%) and in the LAC region (21%) in the reference run.

Table 5.9 presents regional estimates of grazing intensity in the reference world. These were calculated as the number of Tropical Livestock Units (TLU) (bovines, sheep and goats, where one bovine is equivalent to one TLU and a sheep and goat 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 are expected to increase by about 70%, from 0.19 in 2000 to 0.32 TLU per ha for the reference run. Most of these increases will be due to higher inputs in the grazing systems in the humid and subhumid savannas. The increases are less in CWANA and SSA, and for the latter, grazing intensities are fairly stable after 2030 -- cattle numbers have peaked by 2040 and there are fewer in 2050 than in 2030 (see Table 5.5), small ruminant numbers by 2050 are only somewhat above those for 2030, while at the same time the model indicates some loss of grazing land in SSA to necessarily marginal mixed rainfed systems. Grazing intensities change relatively little in NAE. Again, given typical stocking rates of 10-15 ha per animal in the arid and semiarid grazing systems, these results of the reference run imply considerable intensification of livestock production in the humid and subhumid grazing systems of the world, but particularly in LAC.

INSERT FIGURE 5.5 and TABLE 5.9

It should be noted that the rate of conversion of rangeland to mixed systems will be under-estimated in this analysis. The impact of infrastructural development is not taken into account, so the projected changes in grazing intensities are likely to be under-estimated 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 semiarid and arid rangelands, particularly in SSA, and the uncertainties concerning technological change and the institutional landscape that will affect these livestock systems in the future (Freeman et al., 2006), the shifts in production to the wetter and mixed systems that are implied are likely to have considerable potential environmental impacts in the reference run.

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 21-61% in the reference world, prices for beef and pork by 40% and 30%, respectively, and for poultry and sheep and goat by 17% and 12%, respectively (Table 5.10). 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.

INSERT TABLE 5.10

World trade in food will continue to increase, with trade in cereals projected to increase from 257 million Mg annually in 2000 to 657 million Mg in 2050, and trade in meat products rising from 15 million Mg to 62 million Mg. 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 200%, 170%, and 330%, respectively (Figure 5.6). 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 5.6 and 5.7). 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 102 million Mg, and to grow to 38 million Mg in Argentina and 10-11 million Mg in Brazil and Mexico. Wheat exports are projected to grow to 60 million Mg in the United States, and to 37 million Mg in Russia, 34 million Mg in Australia, and 31 million Mg in Argentina, respectively. Soybean exports are projected at 20 million Mg in Argentina and 15 million Mg in Brazil. Net meat exports are expected to increase sharply in the United States and Argentina. Europe is expected to also increase exports, mainly because of slow or no growth in demand with stable population. For rice, Myanmar is expected to join Thailand and Vietnam as particularly significant exporters.

INSERT FIGURE 5.6 and FIGURE 5.7

INSERT BOX 1

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 2,738 kilocalories by 2050, compared to 3,000 or more calories available, on average, in all other regions. Only the South Asia sub-region has similar low gains in calorie availability – at 2,746 calories per capita per day by 2050. Calorie availability is expected to grow fastest in the ESAP region at 630 kilocalories over the 2000-2050 period (Figure 5.8).

In the reference run, childhood malnutrition (children of up to 60 months) will continue to decline, but cannot be eradicated by 2050 (Figure 5.9). Childhood malnutrition is projected to decline from 149 million children in 2000 to 130 million children by 2025 and 99 million children by 2050. The decline will be fastest in Latin America at 51%, followed by the CWANA and ESAP regions at 46% and 44%, respectively. Progress is slowest in sub-Saharan Africa—despite significant income growth and rapid area and yield gains 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, an increase of 11% is expected to 33 million children in the region.

INSERT FIGURE 5.8 and FIGURE 5.9

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 5.10). The 2% value is based on recent FAO reports on the growth of aquaculture (FAO/WHO, 2006; see also Table 5.11).

Atlantic Ocean. Under the reference run there is an overall decline in landings (5.4%) between 2003 and 2048 but under the 2% increase in small pelagic effort variant there is a 7% increase in landings (Figure 5.11). In both alternatives 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 reference run 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 variant 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 5.12 and declines in large demersal and large bentho-pelagic fish (e.g., cod, haddock)

INSERT TABLE 5.11 and TABLE 5.12 HERE

INSERT FIGURE 5.10, FIGURE 5.11, FIGURE 5.12 HERE

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 variant (Figure 5.11). Six FAO areas are included in the Pacific and much of the change in landings in the reference run 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 variant 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 5.13).

Indian Ocean. In the reference run 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 5.11). Landings increase in the 2% effort variant. 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 5.14).

Mediterranean. Landings in the reference run increase by 7% with a corresponding decline in trophic level of 3%. In the 2% small pelagic effort variant, landings increase by 50% then level off while the trophic level declines steadily and by 3% from 2003 (Figure 5.11). 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 5.15).

INSERT FIGURE 5.13, FIGURE 5.14 and FIGURE 5.15

5.3.3.2 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 et al., 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 5.12, 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 5.13 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 14%. Regionally, by 2050, SSA is projected to more than double water consumption, LAC is expected to increase water consumption by 50%, and ESAP by 13%, while in the NAE region the increase is modest, at 6%. 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 3.2% to 2.5% (Table 5.12). Combined with the increase of population share from 10% to 13% CWANA is expected to face the largest challenge in meeting demands exerted by socioeconomic development and conservation demands to sustain ecological systems.

INSERT TABLE 5.13

Irrigation is expected to continue to be the largest water user in 2050 for all regions (Table 5.14). However, it is estimated that the share of irrigation consumption in total water depletion will decrease by about 8% from 2000 to 2050, largely due to the more rapid growth of non-irrigation water demands that compete for water with irrigation (Table 5.15), and also because of projected declines in irrigated areas in some parts of the world. 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. On the other hand, significant increases are expected in the LAC and SSA regions at 45% and 77% respectively.

INSERT TABLE 5.14 AND TABLE 5.15

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, irrigation water supply reliability (IWSR) is expected to decline in all regions. Globally, the IWSR decreases from 70% to 58% 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 433 million ha in 2000 to 478 million ha in 2025 and to then slightly decline to 473 million ha by 2050. Cereals account for more than half of all irrigated harvested area over the reference run period. Over the projections horizon, irrigated area is projected to more than double in SSA. However, by 2050, SSA is expected to still account for less than 2% of global harvested irrigated area. Increases in LAC and ESAP are projected at 41% and 12%, respectively, whereas almost no changes are projected for the CWANA and NAE regions (Figure 5.16).

Table 5.15 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 almost double by 2050, approaching 651 km^3 per year. Notably, non-irrigation consumption in developing countries is estimated to reach 482 km^3, more than doubling from 2000. In comparison, total non-irrigation water consumption in developed countries only increases moderately. The most significant increase in the group of developing countries is domestic water consumption, which grows rapidly from 93 km^3 to 256 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.

INSERT FIGURE 5.16

5.3.3.3 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 more than 700 EJ in 2050 (see also Figure 5.17). 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 developed 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 bioenergy represents a fast growing alternative to oil – but remains 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 run 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.

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.

INSERT FIGURE 5.17

5.3.3.4 Climate

Under the IAASTD reference run, the atmospheric concentration of greenhouse gas rises driven mainly by increasing emission of greenhouse gases from the energy sector (see Figure 5.18 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. This trend is not stabilizing in 2050, so higher concentrations will occur on the longer term.

The effect of more greenhouse gases 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 5.19. These values are well in line with IPCC, where best estimate values at the end of the twenty-first century range between 1.8 and 4.0 degrees Celsius. This range is even larger when the uncertainties in the climate sensitivity are taken into account as well (see subchapter 5.3.3.4). Including this range of uncertainty, the IPCC gives a temperature range between 1.1 and 6.4 degrees Celsius by the end of the twenty-first century. Taking uncertainties in the climate sensitivity into account in the reference run, global-mean temperature increase will be around 1.0 and 2.5 degrees Celsius in 2050.

The calculations show that in the first few decades of the twenty-first 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, mainly in Asia, 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, augmenting the climatic impacts and increasing the need for adaptation (Leemans and Eickhout, 2004), especially in nature and agriculture.

Changes in global mean temperature cannot reflect the regional effects 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 the extent of the regional effect is still very uncertain. Although the global mean temperature change is around 1.4°C between 1990 and 2050 (see Figure 5.19), regionally this can imply changes of more than 2.5-3°C (Figure 5.20). The IPCC concluded that many of the developing countries are most vulnerable to climate change, mainly because of there dependency on sectors, which are relying on climatic circumstances, and their low ability to adapt (IPCC, 2007). For example, agricultural production, including access to food, is projected to be severely compromised by climate variability and change in many African countries and regions (IPCC, 2007). The area suitable for agriculture, the length of growing seasons and yield potential, particularly along the margins of semiarid and arid areas, are expected to decrease.

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, although this effect is not larger than 20% (IPCC, 2007). However, as recently concluded by IPCC (IPCC 2007) at higher temperature increases the impacts on crop yield will be dominated by negative impacts. In total, the impact in 2050 is still relatively small, apart from some crucial regions like South Asia (Figure 5.21). Results can become even more negative when changes in climate variability are included as well, which is not included in this analysis. These conclusions are in line with IPCC, where it was concluded that, globally, the potential for food production is projected to increase with increases in local average temperature over a range of 1-3°C, but above this it is projected to decrease (IPCC, 2007). Moreover, increases in the frequency of droughts and floods due to changes in climate variability are projected to affect local production negatively, especially in subsistence sectors at low latitudes (IPCC, 2007).

INSERT FIGURE 5.18, FIGURE 5.19, FIGURE 5.20 and FIGURE 5.21

5.3.3.5 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 5.3.3), total land use for humans is still increasing until 2050 with an expansion of 4 million km^2. The increasing demand for bioenergy is one of the important reasons for this development (Figure 5.22). In Figure 5.23, the regional split-up is given for bioenergy areas being used for energy purposes. Although Latin America is currently one of the most important energy crop growing regions, in the future regions where land abandonment will occur increasingly (like in 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 5.3.3.3). Moreover, in this approach most of the bioenergy is grown on land that is abandoned or on land that is low productive (see Appendix for the methodology; Hoogwijk et al., 2005).

These changes in land use also impact air quality and the atmospheric composition of greenhouse gases. Figure 5.24 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.

INSERT FIGURE 5.22, FIGURE 5.23, AND FIGURE 5.24

5.3.3.6 Environmental consequences—Forests and terrestrial biodiversity

Forests represent valuable natural ecosystems, with high potential to provide a variety of services to mankind and rich in biodiversity measured by the number of species. Although forest can re-grow with time after clear-cutting for timber production, and after abandonment of agricultural production, these areas will revert only slowly to a more natural state, if ever. As a somewhat arbitrary definition, only forests that were established before 1970 are included in the count presented here. Therefore, re-growth forests after 1970 are excluded from the areas shown in Figure 5.25. The only new areas included are those that change from other natural biomes to forest as a consequence of climate change and without human intervention. The figure illustrates that the natural forest areas decline in all regions, but most clearly developing regions like LAC and ESAP.

Biodiversity is expressed in terms of the indicator mean species abundance (see Appendix on GloBio3). The MSA value is affected by a range of human induced stress factors. For terrestrial biodiversity these include loss of habitat, climate change, excess nitrogen deposition, infrastructure and fragmentation. These stress factors are the direct drivers of biodiversity loss and are derived from indirect drivers like population, GDP, energy use, etc.

Loss of the biodiversity quality in the natural biomes started already many centuries ago, as can be seen in the historical graph from 1700 to 2000; see Figure 5.26. The strongest declines occur in the temperate en tropical grasslands and forests. The remaining biodiversity is found more and more in biomes that are less suitable for human development and thus less likely to be affected, such as deserts and polar biomes. This trend continues with an anticipated and accelerating further loss of biodiversity.

At the global level, there is a substantial biodiversity loss in the reference run: the remaining MSA level drops another 10% after 2000. The rate of decrease for the period 2000-2050 is even higher than in the period 1970 to 2000; see Figure 5.27. The role of agricultural land-use change remains the largest of all pressure factors, which is clearly related to the strong increase in crop areas (see subchapter 5.3.3.5). The major contributors to the additional biodiversity loss from 2000 to 2050 are: expanding infrastructure, agriculture and climate change. The influence of nitrogen deposition and fragmentation does not increase, even though these factors share similar indirect divers as the other factors. In fact, through expanding agriculture, less natural biomes are left where these stresses can exert their influence.

INSERT FIGURE 5.25, FIGURE 5.26, and FIGURE 5.27

5.4 Assessment of Selected, Major Policy Issues

5.4.1 Climate change policies and agriculture

In the previous subchapters, 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^{o}C 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^{o}C, 1.5-4^{o}C, and 2-5^{o}C. The Stern review recently concluded that given all evidence, limiting temperature increase to about 2^{o}C would be an economically attractive goal (Stern, 2006). 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 temporary overshoot. This is also supported by the model analysis carried out for IAASTD. Figure 5.28 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. Carbon capture and storage 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%.

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 bioenergy. The 450 ppm stabilization 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 variant has important benefits in reducing climate change – although some of these may only materialize in the long-term as shown in Figure 5.29. 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 run (see subchapter 5.3.3.4). 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.

INSERT FIGURE 5.28 and FIGURE 5.29

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 industrialized 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 variants leading to a diverse set of policies and application of a range of different models.

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 variants 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 5.30 shows the overall impacts of trade liberalization under variant 1 in terms of changes in gross regional product (a regional equivalent to 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. 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 5.31). 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 5.32).

INSERT FIGURE 5.30, FIGURE 5.31, and FIGURE 5.32

Figure 5.33 shows that there is an increase, globally, in overall trade volume under liberalization, with a noticeably larger effect, relative to the reference case, in 2025 (soon after the liberalization is complete), compared with 2050. Figure 5.34 presents changes in cereal production as a result of the trade liberalization variant. The removal of protection for important cereals in North Africa leads to a decline in production in the CWANA region, as well as in the NAE region. On the other hand, production in ESAP, SSA, and LAC increases. Trade liberalization leads to increased prices for cereals and meats in 2025 (Figure 5.35) but prices decline again somewhat in the later period.

While estimates of the benefits of removal of global agricultural subsidies and trade restrictions vary, other analyses have found similarly positive outcomes 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). Another study indicated that European Union 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 US$22 billion (Asideu, 2004).

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 5.36). Again, CWANA and SSA regions are projected to be affected the most, declining by about 1.5% relative to the reference case at 2025.

INSERT FIGURE 5.33, FIGURE 5.34, FIGURE 5.35, and FIGURE 5.36

INSERT BOX 2

5.4.3 Investment in AKST

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 5.16 and 5.17.

INSERT TABLE 5.16 AND TABLE 5.17

Results of the four alternative variations are presented in Figures 5.37 to 5.45 and Table 5.18 and 5.19. The AKST high variant, which presumes increased investment in AKST, results in higher food production growth and reduced food prices and makes food more affordable for the poor when compared to the reference world. As a result, demand for cereals is projected to increase both as food and as feed, by 339 million Mg or 13% (Figure 5.37 and Table 5.17). 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, 633 million Mg or 24%. On the other hand, 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 5.38

and 5.39). However, under AKST_low, area expansion would contribute 38% to production growth in SSA and LAC, and 25% in CWANA, compared to 27, 21, and 7% 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 137% and 75%, respectively (Figure 5.40 and 5.41). Under AKST_high, ESAP would also increase its net import position for meats and cereals, while NAE would strengthen its net export position for these commodities. Under AKST_low_neg, on the other hand, high food prices lead to depressed global food markets and reduced global trade in agricultural commodities.

INSERT FIGURE 5.37, FIGURE 5.38, FIGURE 5.39, FIGURE 5.40 and FIGURE 5.41

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 therefore drops sharply (Table 5.19).

Sharp increases in international food prices as a result of the AKST_low and combined variants as shown in Table 5.18 depress demand for food and reduce availability of calories as shown in Figure 5.42. In the most adverse, AKST_low_neg variant, average daily kilocalorie availability per capita declines by 1,100 calories in sub-Saharan Africa, pushing the region below the generally accepted minimum level of 2,000 calories and thus also below the levels of the base year 2000. Calorie availability together with changes in complementary service sectors can help explain changes in childhood malnutrition levels (see also Rosegrant et al., 2002). Under the AKST_high and AKST_high_pos variants, the share of malnourished children in developing countries is expected to decline to 14% and 8%, respectively, from 18% in the reference world and 27% in 2000 (Figure 5.43). This translates into absolute declines of 25 million children and 55 million children, respectively under the more aggressive AKST and supporting service variations (Figure 5.44). On the other hand, if investments slow down more rapidly, and supporting services degrade rapidly then absolute childhood malnutrition levels could return or surpass 2000 malnutrition levels at 189 million children in 2050 under the AKST_low_neg variation and still to 126 million children under the AKST_low variation.

What are the implications for investment under these alternative policy variants? Investment needs for the group of developing countries for the alternative AKST variants have been calculated following the methodology described in Rosegrant et al. (2001) and are shown in Figure 5.45. Investment requirements for the reference run for key investment sectors, including public agricultural research, irrigation, rural roads, education and access to clean water are calculated at US$1,310 billion (see also Tables 5.16 and 5.17 for changes in parameters used). As the figure shows, the much better outcomes in developing-country food security achieved under the AKST_high and AKST_High_pos variants do not require large additional investments. Instead they can be achieved at estimated investment increases in the five key investment sectors of US$263 billion and US$636 billion, respectively.

INSERT FIGURE 5.42, FIGURE 5.43, FIGURE 5.44, and FIGURE 5.45

INSERT TABLE 5.18 AND TABLE 5.19

5.4.4 Focus on bioenergy

Among the renewable sources, bioenergy deserves special attention (energy from crops, lingo-cellulosic products and timber by-products). Currently, bioenergy is the only alternative to fossil fuels that is available for the transport sector. Studies into the 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. Large-scale application of biomass as energy carrier will mean that in the short term bioenergy will primarily be derived from specific crops that are cultivated for energy production (sugar cane, maize, oil crops). The eventual contribution from biomass greatly depends on the expectations of extracting energy from lingo-cellulosic products (both woody and non-woody products, like poplar and grass). 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 Chapters 3, 4 and 6 the discussion on the advantages and disadvantages of bioenergy is summarized. 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. Results for bioenergy can become more positive when the second generation bioenergy (the lingo-cellulosic bioenergy sources) becomes available, since these sources offer more CO_2 reductions and use less land per unit of energy. However, this second generation bioenergy is not expected to become available within the coming 10 to 15 years (UN-Energy, 2007).

To explore the bioenergy potential under the IAASTD reference case, the procedure of De Vries et al. (2007) is followed in which the potential for bioenergy is defined as the amount of bioenergy that could be produced from 1) abandoned agricultural land and 2) 40% of the natural grass areas (see also Appendix). Under these assumptions, the technical 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, a potential supply of 80 EJ is assumed. Until 2050, the overall impact of bioenergy on biodiversity is negative, given the direct loss of land for nature versus the long-term gain of avoided climate change (SCBD/MNP, 2007).

5.4.5 The scope of improving water productivity

The reference run foresees a substantial increase in water consumption in agriculture, and particularly in non-agricultural sectors. This may be reason for concern. First, already more than a billion people live in river basins characterized by physical water scarcity (Comprehensive Assessment of Water Management in Agriculture (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. 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; MA, 2005; Pimentel et al., 2004) with often severe consequences for the poor who depend heavily on ecosystems for their livelihoods (Falkenmark et al., 2007). Lastly, climate change may acerbate water problems particularly in semiarid areas in Africa were the absolute amount of rain is expected to decline, while seasonal and inter-annual variation increases (Alcamo et al., 2005; Kurukulasuriya et al., 2006; Barnett, Adam and Lettenmaier, 2005; Rees and Collins, 2004; Wescoat, 1991).

Fortunately, there is ample scope to improve water productivity and basin efficiency, to minimize additional water needs (Molden et al., 2007). 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 5.20).

INSERT TABLE 5.20

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 (Röckstrom, 2003, 2007). But, low adoption rates of water harvesting techniques indicate that upscaling local successes pose major challenges for AKST.

5.4.5.2 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 variant all additional water and land for food can be met by improving land and water productivity in irrigated areas (de Fraiture et al., 2007). The scope for productivity improvement in rainfed is equally promising. In the high yield variant all additional land and water for food can be met by improving water productivity (de Fraiture et al., 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.

5.4.5.3 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.

Table 5.21 shows the outcomes of a variant in which all high potential options are successfully implemented. The results from the WATERSIM model show that a major part of additional water use to meet future food demand can be met by increasing the 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%. When multiple uses of water are encouraged and fisheries and livestock production are integrated, the output per unit of water in value terms may even be higher. 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.

In the realization of an optimistic water productivity variant AKST plays an essential role. Challenges for AKST are listed in Table 5.22.

INSERT TABLE 5.21 and TABLE 5.22

5.4.6 Changing preferences for meat and certified organic products

Consumer preferences are evolving for both meat-focused diets and foods that are produced using integrated nutrient management. These two trends could (both individually and collectively) 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 products that are certified in their use of better nutrient management practices (Knudsen et al., 2006, Steinfeld et al., 2006). As a result of the slow-down in meat demand, 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 products that come from integrated nutrient management, which includes both meat and non-meat commodities, will be the shift in production toward certified practices that would impact productivity. The impact on productivity depends on the region in which it is practiced, however. In industrial country regions, which already practice high-input intensity, conventional agriculture, the adoption of integrated nutrient management techniques would likely lower productivity and cause higher unit costs of production, while still providing greater satisfaction to those consumers who value such products. In regions like sub-Saharan Africa, on the other hand – where fairly low-intensity agriculture is still widely practiced – the adoption of integrated nutrient management techniques will likely cause on increase in yields, over-and-above the reference levels.

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 less meat-intensive diet has the potential to be a global phenomenon, introduction of production techniques that practice integrated nutrient management is more practical in industrial country regions due to infrastructure and institutional requirements that are more readily available and applicable (see Halberg et al., 2006 for further discussion).

5.4.6.1 Specification of the low growth in meat demand policy issue

The global slow down in the growth of meat demand 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 a differentiated set of multipliers for developed versus developing regions, and assumes that the slowdown in meat demand is stronger in the industrialized regions, compared to that in developing regions. Regional average income demand elasticities for meat and non-meat foods for IAASTD regions are presented in Table 5.23. The effect, in general, is that the meat income demand elasticities in industrialized country regions decline half again as fast while those for non-meat 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 non-meat commodities, respectively. In developing regions, the rates of decline are taken to be 110% and 90% of the baseline rates, for the meat and non-meat commodities, respectively.

INSERT TABLE 5.23

5.4.6.2 Specification of the adoption of integrated nutrient management.

The rise of industrialized country agricultural practices that use integrated nutrient management follows on the specification of the organic agriculture scenario in Halberg et al. (2006). This variant is specified purely as a supply-side adjustment in the industrialized world to yields of crops and livestock most easily converted to integrated nutrient management production techniques. Crops include maize, wheat, soybeans, other grains, and potatoes. Beef, dairy, and sheep/goat are the focus for livestock. The variant 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 5.24 and 5.25. The principal change from Halberg et al. (2006) in this implementation of widespread adoption of integrated nutrient management in 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.

INSERT TABLE 5.24 and TABLE 5.25

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 non-meat foods than in the reference case. Prices will directly follow the changes in income demand elasticities with meat prices falling and non-meat food prices increasing. Figure 5.46 shows the resulting differences from the reference case for the two types of foods: a 13% decrease in meat prices and a 10% increase in the price of non-meat foods. As the rise of integrated nutrient management in agriculture results in a decline in average yields, commodity prices increase between 11-13% for major meat commodities and 3-21% for major crops like maize and soybean (Figures 5.47 and 5.48).

Per capita food consumption also shifts in these alternatives to the reference baseline. With the rise in prices in the case of increasing use of integrated nutrient management in agriculture, per capita consumption of all foods leads to decreases of up to 17%, but varies across regions, according to dietary patterns. On the other hand, the slowdown in meat demand growth shifts food preferences away from meat and toward non-meat foods, which is commensurate with the price shifts discussed earlier, and the consumption shifts shown in Table 5.26, with a few exceptions. In sub-Saharan Africa the countervailing force of the price shifts actually lead to increased consumption of meat in addition to non-meat 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.

INSERT FIGURE 5.46, FIGURE 5.47, FIGURE 5.48 and TABLE 5.26

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 a decrease in meat demand would lead to a decline in malnourishment. Figure 5.51 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 0.5% decline in malnourished children while a certified organic world would see a 3% increase.

The potential evolution of consumer preferences for more use of integrated nutrient management practices in agriculture and non-meat foods is uncertain. While the reference case presented previous actually already includes a certain amount of these shifting preferences, the purpose of this analysis is to highlight the potential impacts if these trends strengthen in the future. If meat demand were to decrease 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 non-meat foods will be the main challenge for agricultural production. Meanwhile, an increase in the use of integrated nutrient management practices in 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. Emerging Issues that Influence the Future

5.5.1 Interface of human, animal, and plant health

5.5.1.1 Future trends

Human, animal, and plant diseases associated with AKST will continue to be of importance to future populations, including more urbanized populations in low-income countries. 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.[1]

Currently, 204 infectious diseases are considered to be emerging; 29 in livestock and 175 in humans (Taylor et al., 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 et al., 2001). 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 twenty-first century (Institute of Medicine, 1992). The increase in disease emergence will impact both high- and low-income countries, with serious socioeconomic impacts 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).

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

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

pathogen migration into new agroecosystems, and provide conditions that elevate disease organisms from minor to major status (Coakley, Sherm and Chakraborty, 1999).

A second trend of importance 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. 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 et al., 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). Micronutrient deficiencies increase morbidity and mortality, decrease worker productivity, and cause permanent impairment of cognitive development in infants and children.

5.5.1.2 Impacts of development

Development is expected to reduce some of the risks of current human, plant, and animal diseases, with new communicable diseases arising to in their place. Communicable diseases are the primary cause for variations in life expectancy across countries, so reducing the burden of communicable diseases will increase life expectancy in low-income countries. Significant challenges will continue for several decades in building capacity to reduce emerging infectious diseases in low-income countries. Developing countries need laboratories and research centers (and the human and financial resources to staff and maintain them), along with resources in primary health care systems to identify, control, and treat disease outbreaks. High-income countries need to commit to additional resources for research and development on communicable diseases. Although progress is being made for some diseases, history suggests that diseases will continue to emerge faster than they are identified and controlled -- infectious disease control is an ongoing process with long-term improvement, but without possibility of achievement of eradication of all infectious diseases.

While agricultural and income growth are contributing to rapid reductions in the overall number of underweight children, the global decline masks differences across regions that will continue to adversely affect development over the coming decades. Unless more attention is paid to the problems of micronutrient deficiencies, the human health consequences will reduce the ability of nations to achieve development and sustainability goals (Welch and Graham, 2005).

Key forces that will affect development 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.

A trend expected to continue is the highly inequitable distribution of health workers (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. Africa 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.

5.5.1.3 Policies to Facilitate Achievement of AKST Goals

Reducing the threat of emerging infectious diseases requires enhancing disease surveillance and control programs through (1) strengthening existing research and monitoring facilities and establishing new laboratories and research centers for disease identification and control, (2) improving primary health care systems, and disease surveillance and control at local and global levels, and (3) developing the capacity to understand the interactions of factors that drive disease emergence. Developing these programs requires additional resources. Multidisciplinary collaboration, particularly across health and agricultural sectors, will facilitate identification of policies and measures to reduce the burden of communicable and non-communicable diseases. One approach for reducing the burden of human and animal epidemics is the development of national networks for emergency response, with the human and financial resources to interpret forecasts, detect signs of emerging plant, animal, or human diseases, and environmental crises, and develop and implement effective responses.

Reducing undernutrition requires greater attention to food security, not just to crop yields. Although there is promising research arising on modifying crops and soil fertility to improve micronutrient content, considerable additional research is needed on new cultivars and approaches to improve the lives of billions of people worldwide. Additional resources are needed to be able to effectively deploy current and emerging technologies and cultivars. An issue likely to continue to be important is how low-income countries can afford the costs of new seeds and inputs. Development of effective policy options (including enforcement) can reduce current food safety issues.

5.5.1.4 Regional differences

As noted previously, there are large regional differences in the burden of infectious diseases and undernutrition, with the largest burdens in Africa and South and South-East Asia. The burden of chronic diseases is now similar across most countries.

5.5.2 Information and Communication Technology and traditional and local knowledge

5.5.2.1 The promise of ICTs

ICT is increasing in importance for agriculture particularly for those producers who have access to markets. It is possible to attract investments when natural resource management activities are linked 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). It follows then that the broad promise of ICTs tends to be described at the macro level:

- 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, von Braun, and Akhter, 1999; Richardson et al., 2000).
- The promise of ICTs is most directly with those MDG that relate to health and education (Torero and von Braun, 2006).

5.5.2.2 The barriers associated with ICTs

Among the major barriers associated with ICT we include: 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. Other barriers include:

- The macroeconomic models referred to above work best for middle and high income countries; and for lower income countries economic development impact from ICTs is expected to be modest (Torero and von Braun, 2006).
- The investments required are 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 human and organizational development aspects of ICTs have in the past been eclipsed by a fascination on the technological dimension. Capacity development refers to the training of individuals across the wide range of technologies, services, applications and content areas, and to the capacities by small and medium size enterprises to make use of ICTs.
- There is evidence that, while those with higher income and levels of education derive most benefits from ICTs, the poor spend between and 3.7% of their monthly income on telecommunications services (Kayani and Dymond, 1997; Song and Bertolini, 2002). 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). In other words, the poor benefit from communication services significantly more than from information services.

5.5.2.3 ICTs and traditional and local knowledge

The development and spread of traditional and local knowledge can benefit directly from ICTs when holders of this knowledge have access to it and control over its utilization (Srinivasan, 2006). The integration of traditional and local knowledge and western scientific knowledge will need an interface that allows each to express its wisdom and forms, without sacrificing its cultural relevance. However, increased globalization and integration of markets presents both an opportunity and a threat to traditional and local knowledge. While knowledge will be transferred more easily across regions and countries, traditional and local knowledge might well disappear if adequate support systems are not put in place.

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 and traditional 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. 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.

5.5.2.4 Policy implications

At present, Universal Access policies have 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 continues to grow regarding access to ICT between very poor and richer farmers. Hence, a more strategic targeting of policies, investment and incentive plans, and methodological innovation is necessary; the following are possible policy scenarios:

- 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). Increasing access to ICTs cannot be carried out by market forces alone. The liberalization and privatization of telecommunications created effective competition only in high density markets (in industrialized and in developing economies). Government participation in subsidizing capital infrastructure –often though competitive grants to the private sector- remains a central policy instrument, yet it needs to be adapted to the conditions of each country.
- Access is not enough. The notion of *effective use* calls for attention in tandem to a wide range of *readiness requirements*; training requirements, service development, local content development, to name but three.
- Local or “mediating” organizations that work as mediators between community needs, technology, markets and government programs can be strategic in this aspect. Mediating organizations can aggregate demand from health, education, and the business community to help attract infrastructure and service investments.
- For local content and traditional knowledge to be respected and harnessed, attention is first needed on issues of power and control over the infrastructure. The importance of policies that nurture local organizations is once again of paramount importance in the content area.

The era of seeing ICTs as magic bullets is past. ICTs are not a panacea for the poor in terms of the agriculture or natural resource management options; in contrast they do give an edge to the better off who already link with markets. Indeed for the poor the short term promise of ICTs is more evident in enhancing health and education services and especially in reducing their transaction costs (communication). On the other hand its information potential is only achievable if it is integrated with a comprehensive rural community development strategy.

5.5.3 Food safety and food security

5.5.3.1 The reference case

Trust in agricultural product quality has become one of the most important issues for consumers, since food represents security, comfort and the ability to provide basic needs to those who rely on others for protection and support (Bruemmer, 2003). Food safety will continue receiving attention in both industrialized and in less developed countries (Unnevehr, 2003) because: 1) 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; 2) As technology improves, it is easier to measure contaminants in food and document their impact on human health; 3) Trade liberalization has increased opportunities for agricultural exports, and food safety regulations have become the binding constraint on food trade in many cases; 4) International food scares, such as BSE and avian flu, have made consumers, producers, and legislators more aware of the risks associated with agricultural food safety problems (Unnevehr, 2003; Narrod et al., 2005).

Appropriate food safety regulation is considered fundamental to expand products from least developing countries into developed and other developing countries (Babu and Reidhead, 2000; Pinstrup-Andersen, 2000). However, the increased food safety standards are particularly worrisome in terms of food security and the livelihood of the poor as multinational retail companies that dominate the market often exclude small growers that find it difficult to meet foreign as well as domestic standards (Narrod et al., 2005). Labeling will be likely used to demonstrate that the food is safe to eat, however, a highly 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).

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; 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). 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 postharvest and laboratory infrastructure and organization (Babu and Reidhead, 2000).

The continuous increase urban development imbedded within agricultural production areas raises concerns since it may affect both the quality of living and the safeness of final crop products. The risks posed by agricultural production systems in urban areas to health and environment may be associated with inappropriate use of agricultural chemicals (pesticides, nitrogen, phosphorus) which may contaminate drinking water sources; air pollution (carbon dioxide and methane from organic matter, ammonia, nitrous oxide and nitrogen oxide from nitrates); and odor nuisance (Carvalho, 2006). Further, close proximity of great number of people and domestic animals to production areas, accompanied with high population of wild life creates an ideal scenario where potential disease sources (e.g. warm blood animals, humans) and vectors (e.g., animals, insects) increase the risk for contamination of irrigation water and crop plants. Optimal management of urban resources and well established good agricultural practices are needed for sustainable agricultural production (Fonseca, 2006).

5.5.3.2 Identified routes

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) especially because no intervention mechanism, other than irradiation, is currently available to completely decontaminate agricultural commodities eaten raw (Fonseca, 2006). The demand for products with high standards of overall quality and safety will continue to grow in industrialized countries. Meanwhile in developing countries, better quality standards 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 surveillance and analysis capacity is built (Berdegué et al., 2005). The development of a national food safety “culture” in the future will be influenced by who will be the regulatory/audit agents and to what extend the different actors will be involved (Carvalho, 2006; Codron et al., 2005; Reardon et al., 2003; Schlundt, 2002)

In one scenario, private rather than public standards will continue to be the predominant drivers of the agri-food systems (Henson and Reardon, 2005). In developing countries where institutional capacity often limits the enforcement of mandatory public standards, firms will continue relying on private standards (Loader and Hobbs, 1999). The private sector will need to implement an important effort toward developing better training in certain agricultural practices. 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).

In a second scenario, governmental policies will have great influence on food safety issues. In the event of food safety crises, governments will continue reacting by 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 (Codron et al., 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 amount 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, 2007).

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 postharvest and laboratory infrastructure and organization (Babu and Reidhead, 2000). One way small scale producers could meet increased food safety requirements in the future is by pursuing the direction of fewer and less persistent pesticides. However in the short term the cost of these new environmentally friendly 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, while complying with acceptable food safety guidelines.

5.5.3.3 Challenges as affected by policies

The main challenges for the next decades will be first to ensure safer food to consumers and raise the quality of life without creating a barrier to poor countries/producers for opportunities of success. Food security is a concern as 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 emergence of currently unknown health problems. The free trade market movement and the need to reduce internal hunger will likely result in more governments imposing their own rules or mandating the established international regulations. 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 (Schlundt, 2002). Thus, governments will act influenced by how the actions will affect the distribution of benefits across the entire population (Codron et al., 2005).

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 policy makers from countries with common interests will allow transfer of success schemes to those with those in more need (Babu, 2004). 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 (Hamilton, 2005). Some countries with known overdependence on pesticides but with the potential capacity to develop a more systematic approach will have the opportunity to improve internal standards and increase presence in the export market (Gupta, 2004). In this regards, 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 AKST to produce for the export market.

5.5.4 Biotechnology and biodiversity

5.5.4.1 The reference case

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. Conventional breeding and genetic engineering are complements; thus the reference case development pathway includes a combination of a strong traditional plant breeding capacity together with the use of transgenic traits when useful, cost-efficient, pro-poor, and environmentally sustainable. A wide range of new traits are at various stages of development, some of which are likely to lead to varieties that are drought-resistant, exhibit improved nutritional content of feed and feedstuffs, and offer enhanced shelf-life (Graff et al., 2005). 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. Factors shaping future adoption of new technologies include improved profits, decreased risk, increased health and well-being, and reduced effort, compared to earlier technologies used. They also include institutional and physical constraints affecting farming, like availability and terms of credit, information and product support provided by extension and technology providers, tenure conditions, and land ownership. Furthermore, the availability and quality of technology are dependent on policy and institutional variables, 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 (Raney, 2006). Potential constraints include property rights constraints, as well as evolving biosafety and food safety regulations around the world. Based on the literature assessing both constraints and benefits of crop technologies, 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 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).

5.5.4.2 Alternative pathways – more biotechnology

In spite of the limited growth in the development of transgenics, it is possible that these technologies will re-emerge as a major contributor to agricultural growth and productivity. 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. New biotechnological discoveries and their successful application in a country like China, where experimentation and investment in crop biotechnology continue, may lead other countries to follow suit. Finally, the concern about climate change and increasing energy prices could lead to significant investment in the development of biofuels, which, in turn, would increase rapidly growing resource scarcity and possibly higher food prices. Higher food scarcity, in turn, would increase the value of improved agricultural productivity and may lead countries to reassess the regulations restricting the growth of biotechnology. Furthermore, the development of biofuel crops may also rely on transgenic varieties and lead to enhancement of agricultural biotechnology and increase their acceptance.

Under such an alternative pathway, oilseeds with improved lipid profiles and staple grains with vitamin and mineral fortification could be introduced, and three major transgenic food crops that are already on the brink of approval (Bt rice, herbicide tolerant wheat and nutrient reinforced rice) could expand in developing countries and industrial countries alike. Furthermore, such a pathway could see traits for the remediation of polluted or degraded land or adaptation to heat and drought, which could assist in dealing with current agroenvironmental challenges and in the adaptation to rapid climate change.

5.5.4.3 Alternative pathways – less biotechnology

If society determines that the risks associated with transgenesis in agriculture exceed the benefits, the tool might be abandoned over the next several decades. 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. Under this alternative pathway, 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 industrial 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 in industrial countries 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 but not stop the pace of agricultural research and improvement. As a result, humanity would likely be more vulnerable to climatic and other shocks and to increased natural resource scarcity under this alternative pathway.

5.5.4.4 Implications for the agricultural sector

For new technologies to be pro-poor, they need to relate to crops consumed by subsistence and small-scale farmers, allow for small-scale cultivation practices, and they need to be adapted to the human, physical, financial and social capital of the rural poor. Economic impacts tend to be more pro-poor where significant market competition exists in the supply of new technologies. The increased supply, as well as enhanced quality of improved technologies could contribute to reduced food prices, providing extra benefits to the urban poor. Improved food productivity can also be an important force to counter increased energy prices that are likely to contribute to increased food prices, which have a disproportionate negative effect on the poor.

5.5.4.5 Implications for biodiversity

The impacts of a rapid expansion of transgenic crops on natural and agricultural biodiversity over the next 50 years 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 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).

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 agroclimatic 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., 2005).

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.

Finally, genetic engineering allows scientists to take advantage of biodiversity. Increased documentation of genomes and understanding of functional genomics provides information that is needed to develop new traits and new varieties that are of high value. Thus, the availability of tools for biotechnology and their development enhance the value of biodiversity, and to some extent, biotechnology and biodiversity are complementary. Furthermore, biotechnology provides tools to restore local varieties after slight modification allowing them to withstand disease or other pressures. The development of precision farming technologies that allow for the modification of application of inputs, including seeds, in response to changes in ecological conditions will provide impetus to increase crop diversity to take advantage of these new possibilities.

5.6 Implications of Policy Simulations and Emerging Policy Issues: Synergies and Tradeoffs

5.6.1 Poverty and equity

Chapter 5 examined projected changes in agriculture and AKST out to 2050 based on existing assessments and methodologies. At this point there are no established methodologies to adequately describe changes in poverty and equity out to 2050. This can only be inferred based on the state of literature and the analyses presented here. Increased agricultural productivity has been a key driver for economic and income growth in most countries at some stage of economic development and will continue to be key to growth in many agriculture-dependent developing countries out to 2050. However, although agricultural and economic growth are critical drivers for poverty reduction and explain 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, while changes in macroeconomic and trade policy tend to produce large gains for both rural and urban areas, poor farmers and (landless) agricultural laborers, who often lack the skills, health, information, or assets needed to seize new opportunities, tend to be left out of the general economic growth process, as they may be concentrated in remote rural areas or geographic regions ill-equipped to gain from globalization/liberalization.

To redress potentially adverse impacts on equity, investments in human capital are crucial for the poor. Moreover, given emerging health and food safety issues investments in health and nutrition are similarly important. Even with rapid economic growth and active investment in social services, 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 will need to be reached through income transfers, or through safety nets that help them through short-term stresses or disasters.

5.6.2 Hunger, health and food security

The *reference* run has shown that 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 and in food sovereignty for 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 7% in the number of malnourished children in sub-Saharan Africa.

Alternative policy experiments show that with higher investments in AKST, the share of malnourished children in the group of developing countries is projected to decline from a baseline of 99 million by 2050 to only 74 million. If these higher investments in AKST are combined with improvements in complementary service sectors, such as health and education, the projections show that an even greater reduction, to 43 million, could be achieved. By contrast, either flat-lined or slowed rates of investments into AKST will negatively affect regional food security and exacerbate childhood malnutrition, with levels that could easily surpass current malnutrition levels.

Moreover, uncertainties regarding a whole range of emerging issues, ranging from public health and food safety to policies in the areas of climate change and bioenergy could worsen (or improve) projected quantitatively modeled outcomes.

5.6.3 Natural resources and environmental sustainability

Regarding resources, scarcity is expected to become a prominent challenge for policy makers. In particular, growing water and land scarcity are projected to increasingly constrain food production growth; with adverse impacts on food security and human well-being goals. Growth of population combined with shifts towards high land/fodder-intensive meat diets is resulting in additional demands for land. Although crop productivity is expected to increase (as described in the reference run) the uncertainty as to whether this productivity increase can actually be met is also increasing. 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. In addition, new demands on land for products such as biofuels (stimulated by concerns about climate change and energy self-sufficiency) are very likely to grow exponentially in the coming decades. This will not only impact food prices but will also lead to greater competition for land. The combination of demand factors will lead to rather grim impacts on biodiversity. The target of the Convention on Biological Diversity (CBD) to reduce the rate of loss of biodiversity significantly by 2010 seems impossible to reach. Moreover, some policy options to reduce pressures on the natural system (e.g. climate mitigation strategies as described in this chapter) have a negative impact on biodiversity through additional land-use change required for biofuels.

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 secure food supply, investments in maintenance, new technology 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 is made in water infrastructures. Likewise, water saving technology and conservation measures in the industrial, rural and urban domestic sector would result in more reliable water supply in non-irrigation sectors and relieve the increasingly intensified intersectoral competition for water.

On the fisheries front, although small pelagic species are robust, the behavior of the small pelagic fish towards the end of the modeled period (2048) indicate that policies of mining small pelagic fisheries to support a growing aquaculture industry may not be sustainable in the long-term except in a limited part of the world's oceans. Caution needs to be taken even with this interpretation since small pelagic fish are extremely sensitive to oceanographic changes and if the predictions for changes in sea temperature come about, the species dynamics within this group will change significantly with potential reverberating affects up through 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 would need to be carefully considered in the light of climate change.

The tradeoffs between increased income for small farmers via crop production for food and fuel, livestock production, conservation and marketing of native varieties and species, and soil and water management for sustainability, will require a balancing act over the next 50 years. However, synergies do exist; biofuel crops, biotechnology, ICT, food safety standards, and globalization and trade liberalization can offer new opportunities to smallholders—if supporting policies and investments are implemented—and large agricultural producers alike making an ever more diverse range of products available to consumers.

5.7 Implications for AKST in the Future

As the reference world in 2050 and the various policy discussions show, agriculture will have to face a number of new and difficult challenges. Food security and food sovereignty are likely to still be problems 50 years from now. Agricultural production is likely to be increasingly constrained by competition for land and water and by climate change. Strategies for adapting to new regulations for food safety, and the development of biotechnology and bioenergy pose significant challenges and opportunities.

Food prices will most likely rise as a result of these opportunities and constraints. In addition, regional and national income growth, urbanization and growing global inter-connectedness are expected to increase diet diversification and homogenization. Trade liberalization and greater integration of global food markets can support more reliable food supplies and lowered food prices in real terms. But as the reference run shows this is unlikely to be achieved in the coming decades.

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. The key to improving yields under increasingly constrained conditions lies in technology to improve agricultural productivity in order to regenerate productivity growth. Biotechnology could play an important role here. To adapt to and mitigate the various effects from climate change requires the development of new cultivars. Likewise, CO_2 emissions can be reduced through new crop management practices supported by appropriate technologies. To achieve such breakthroughs, existing global and regional research-for-development networks for agricultural production technologies and knowledge need to work closely together so that technology and knowledge can flow to allow farmers to face the risks associated with future harvests. Information and communication technologies and traditional and local knowledge could play key roles in the regeneration of future productivity growth. As the alternative policy experiments in this chapter have shown higher, judiciously placed, investments in technology development can significantly improve outcomes for food availability and food security.