GLOBAL IAASTD CHAPTER 4

OUTLOOK ON AGRICULTURAL CHANGE AND ITS DRIVERS

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Key Messages

1. Agriculture will need to respond to several key changes in driving forces in the next decades. Key drivers include an increasing global population, changes in dietary and in trade patterns, land competition, increases in agricultural labor productivity, climate change and demands for agriculture to provide ecosystem services. A driver is any natural or human-induced factor that directly or indirectly influences the future of agriculture. Categories of indirect drivers include changes in demographic, economic, sociopolitical, scientific and technological, cultural and religious and biogeophysical change. Important direct drivers include changes in food consumption patterns, natural resource management, land use change, climate change, energy and labor.

2. A range of recent global assessments provide information on plausible future developments regarding agricultural production systems and their driving forces; however, no assessment has explicitly focused on the future role of AKST. Global assessments provided by, among others, the Millennium Ecosystem Assessment, the UN Food and Agriculture Organization AT 2015/2030, and the Comprehensive Assessment of Water Management in Agriculture have explored plausible future developments in agriculture. These assessments have made use of different approaches to address future agricultural changes, and usually are based either on detailed projections or scenario analyses. These approaches do not aim to predict the future – rather they provide a framework to explore key interlinkages between different drivers and resulting changes. In that context, one should also realize that assessment is limited by the ranges of key scenario inputs that are considered. For instance, while crop prices have increased abruptly over the last few years (driven by among other an expansion of biofuel production and rapid increases in food demand) these have not been considered in most existing assessments yet.

3. Existing assessments expect increases in global population over the next 50 years (about 2-3 billion people), ongoing urbanization, and changing life patterns to lead to a strongly increasing demand for food and pressure on the agricultural system. Increasing income implies changes in diet (from carbohydrates to protein based, thus, the livestock revolution), and in the manner of food preparation. These changes are expected to affect food consumption patterns and increase demand for non-home based preparation of food. Demand for food is also very likely to be affected by the demographic changes, e.g., the ageing population of many developed countries. Urbanization is projected to continue and to lead to a decline in the percentage of the population depending on agriculture for income, changes in food systems and additional pressures on arable land.

4. Most existing assessments project that international trade in agricultural commodities will increase and often predict developing countries on aggregate will become net importers. There are many reasons for increasing agricultural trade, such as increasing demand for food, increasing interregional relationships and commodity specialization – possibly facilitated by trade liberalization. As a result, increases in agricultural trade are reported in the majority of existing scenarios, even while many assessments have used contrasting assumptions with respect to ongoing globalization for the scenarios that were developed. Globalization and liberalization will affect countries and groups within countries in different ways. While agricultural trade among developing countries is likely to increase, as a group they may become net importers of agricultural commodities with a possibility of further widening agricultural trade deficits. Conversely, industrialized countries tend to become net beneficiaries of trade arrangements as they are expected to face less pressure to reduce their support for agriculture.

5. Existing assessments highlight the importance of democratization, decentralization and other sociopolitical developments in shaping agricultural policy choices. While these factors are hard to quantify, assumptions underlying different scenarios are partly built around them (e.g. increasing international governance). Several scenarios expect participation of local farmer groups in agricultural policy formulation to increase. Most scenarios also assume that governance effectiveness is also expected to increase over time and this can reduce corruption, perceived to be prevalent in developing economies. But improving states' capacities in governance and effectiveness in policy implementation is a long term process, and impacts are still uncertain. Key options discussed in these assessments include building "soft" infrastructure, such as networks, organizations, cooperatives, in order to produce social capital that may reduce conflicts at all governance levels; facilitating common-pool agricultural resource management; and enhancing access of farmer groups to markets.

6. Existing assessments project a combination of intensification of agricultural production and expansion of cultivated land to meet increasing demands for food, feed, fiber and fuel. A major uncertainty in the scenarios presented in these assessments results from the degree of extensification versus intensification in agricultural production. Roughly 70-80% of the extra production is projected to stem from intensification. Major expansion of agricultural land is projected to take place in sub-Saharan Africa, Latin America and East Asia (excluding China). New developments in AKST are expected to focus on increases in efficiency in the entire food production chain.

7. Existing assessments indicate a major increase in bioenergy production; in the medium term this might lead to a tradeoff between energy security and food security, especially for the poor. Several scenarios, in particular those that emphasize climate policy and energy-security, indicate that agriculture may become an important producer of bioenergy. They, however, also highlight that bioenergy production can become a major use of land, possibly increasing, even in the long-term, food prices and decreasing biodiversity. Bioenergy production based on the conversion of cellulose to fuel ethanol or other hydrocarbons will impact food security and biodiversity less than 1st generation biofuels. Most assessments also expect higher energy prices. These higher prices (and possible changes in energy subsidies) are likely to encourage the use of more energy-efficient technologies in agricultural production as well as in processing and distributing food.

8. Existing assessments indicate that while agriculture is a major contributor to global environmental change - such as land degradation, nutrient pollution, biodiversity loss, decreasing surface and groundwater availability and climate change - it will also have to adapt to these changes. Assessments indicate an increased demand for water from the non-agricultural sectors, which could further exacerbate water limitations already felt by developing country farmers. Increasing rates of land degradation in many regions may limit the ability of agriculture systems to provide food security. Business-as-usual scenarios indicate a further increase in the already substantial negative contribution of agriculture in global environmental change. However, alternative scenarios highlight that there are also many opportunities for enhancing the positive role of agriculture in providing ecosystem services and minimizing its environmental impacts.

9. Existing assessments expect agriculture to increasingly be affected by global warming and changes in climate variability. For agriculture, changes in seasonal variability and extreme events are even more important than changes in mean temperature and precipitation. Recent studies, such as presented in IPCC's Fourth Assessment Report, indicate that negative impacts on agriculture tend to concentrate in low income regions. In temperate regions impacts could result in net positive yields. Developments in AKST will determine the capacity of food systems to respond to the likely climate changes. Agriculture is also a source of greenhouse gas emissions and therefore agriculture can play a significant role in mitigation policies. In order to play this role, new AKST options for reducing net emissions of carbon dioxide, methane and nitrous oxide need to be developed.

10. Trends observed over the last decade, as described in existing assessments, show that the share of employment in agriculture is declining and this emerging trend is

expected to continue. The expected increase in urbanization and international labor migration as well as better working conditions in other sectors will catalyse a labor shift away from agriculture to other sectors. Agricultural labor productivity is expected to increase as a result of improved mechanisation and developments in AKST that are responsive to emerging agricultural and food systems.

11. There is a trend in many regions to reduce investment in traditional agricultural disciplines in favor of emerging research areas such as plant and microbial molecular biology, information technology and nanotechnology. Investment in AKST is increasingly less driven by the needs of agriculture per se, but is a spin off of other research priorities such as human health and security. These investments mainly occur in industrialized countries and advanced developing countries and the products may not be easily accessible and applicable to least developing countries. To effectively apply advances in the emerging research areas to diverse agriculture systems requires knowledge generated in the traditional agricultural disciplines. The effect of the shift in investments on AKST is not fully explored.

4.1 Driving Forces of Agricultural Change

Changes in agriculture are a result of the developments of a range of underlying driving forces – both direct and indirect – and their many interactions. Previous chapters have described past agricultural changes in general, and change in agricultural knowledge, science and technology (AKST) in particular, in their political, economic, social, cultural, environmental contexts (Global Chapters 1-3). This assessment presents a conceptual framework to structure the analysis of agriculture and development towards reaching sustainability goals. This framework highlights, that agriculture, although a central focus of this assessment, needs to be seen as part of a larger societal context and is dynamically linked to many other human activities. Changes in these activities can both directly and indirectly drive change in agriculture (Fig. 4.1).

Driving forces or *drivers* are those factors that directly or indirectly induce changes in the agricultural system. A *direct* driver unequivocally influences agricultural production and services and can therefore be identified and measured with differing degrees of accuracy. An *indirect* driver operates more diffusely, often by altering one or more direct drivers, and its influence is established by understanding its effect on a direct driver. When assessing past developments and the prospects for future changes in agricultural systems and the role of AKST, it is crucial to understand the current trends in the driving forces that shape the agricultural system.

This chapter gives an overview of current literature on how agriculture and its drivers may change in the future – thus setting the context for looking specifically at how future agricultural development can be influenced by AKST (Global chapters 5-9). By identifying plausible assumptions on future changes of drivers of agricultural systems also an idea of the most prominent challenges that agriculture might face over the next 50 years emerges, and based on this understanding key uncertainties can be distilled. Published outlooks, projections and scenario studies are presented here to give an overview of how some of the most important indirect drivers of agricultural changes are expected to unfold, based on current literature and recent international assessments - the main indirect drivers discussed in this chapter are:

1. *Demographic developments*, including changes in population size, age and gender structure, and spatial distribution (4.3.1);
2. *Economic and international trade developments*, including changes in national and per capita income, macroeconomic policies, international trade, and capital flows (4.3.2);
3. *Sociopolitical developments*, including changes in democratization and international dispute mechanisms (4.3.3);
4. *Scientific and technological developments*, including changes in rates of investments in research and development and the rates of adoption of new technologies, including biotechnologies and information technologies (4.3.4);

5. *Education, cultural and religious developments*, including changes in choices individuals make about what and how much to consume and what they value (4.3.5);
6. *Global environmental change*, including nutrient cycling, water availability, biodiversity and soil quality – all of which are affected by global environmental change (4.3.6).

In addition, a number of direct drivers relevant to agricultural systems are discussed in this chapter and outlooks on how they might unfold over the coming decades presented, again based on published literature - the main direct drivers presented in this chapter are:

1. *Changes in food consumption patterns*, i.e. consumptions levels of crops and meat products (4.4.1);
2. *Land use change*, i.e. land availability as a constraint to agriculture (4.4.2);
3. *Natural resource management*, i.e. the impact of agriculture on natural resources and the constraints of natural resource availability and management on agriculture (4.4.3);
4. *Climate change*, i.e. the impacts of climate change on agriculture (4.4.4);
5. *Energy*, i.e. the relationship between energy and agriculture and the impact of large-scale bioenergy production (4.4.5);
6. *Labor*, i.e. the relationship between agriculture and the demand and supply of labor force (4.4.6).

Looking across the expected developments of the different individual driving forces presented in this chapter gives a first idea of how agricultural systems and their role in providing agricultural products and services might unfold over the coming decades (4.5). The future role of and options for AKST in agricultural development are explored in detail in the remainder of this report. To inform this discussion, this chapter concludes by highlighting some of the key uncertainties for future agricultural changes as well as for AKST as identified in current literature and recent international assessments (4.6).

4.2 Recent International Assessments

Recent international assessments provide a wealth of information about expected or plausible future developments – either by directly providing an outlook on expected developments in agriculture or by discussing possible developments of key driving forces and pressures that shape the future of agricultural systems. None of the existing global assessments, however, has addressed the role of and future prospects for agricultural science, technology and knowledge (AKST) in much detail. Nevertheless, these assessments still provide important sources of information for discussing future developments underpinning agriculture and the role of AKST. In general, assessments are helpful in exploring possible development pathways for the most important drivers and their interactions. However, assessments are limited by the ranges of key scenario inputs they consider. For example, crop production has abruptly increased in the past few years (driven by demand for biofuels and increased food demand) with prices of some crops doubling. These price increases clearly exceed the range in price projections in existing assessments. Hence, although assessments are helpful in assessing interaction forces in terms of direction of change, they need to be treated carefully as they poorly capture abrupt changes falling outside the range of modeled scenarios.

Assessments of particular relevance for the IAASTD assessment include a wide range of exercises – some of which focus on agriculture, while others address agricultural development within the context of other issues. These assessments can be roughly grouped in two categories: Projection-based studies (which commonly set out to present a probable outlook or best estimate on expected future developments) and exploratory studies (which develop and analyze a range of alternative scenarios to address a broader set of uncertainties) (Box 4.1).

Prominent examples of projection-based assessments of direct relevance to IAASTD include the FAO's World Agriculture 2030 (Bruinsma, 2003) and IFPRI's World Food Outlook (Rosegrant et al., 2001). Important examples of recent international assessments that explore a wider range alternative scenarios include the global scenarios discussed by the Millennium Ecosystem Assessment (MA, 2005a), UNEP's Global Environment Outlooks (UNEP 2002, 2007; RIVM/UNEP 2004), IPCC's Scenarios as used in Third and Fourth Assessment Reports (IPCC 2001, 2007abc) and the Comprehensive Assessment of Water Management in Agriculture (CA, 2007).

Most of the above mentioned assessments have either focused on informing sustainable development in general or addressed cross-cutting environmental issues. Only two global scale assessments (i.e. IFPRI and FAO) have focused on projecting future agricultural production (yet even these have not addressed the full spectrum of agrarian systems and AKST from the perspective of a range of different plausible futures) (Table 4.1). It should be noted that, in addition, a range of national or regional projections of agricultural production and food security exists, but will not be discussed here.

All of the international assessments highlighted above have identified detailed assumptions about the future developments of key driving forces and reflected on a number of underlying uncertainties about how the global context may change over the coming decades. While the number of uncertainties about plausible or potential future developments is vast, a limited number of key uncertainties seem to reappear in several recent international assessments. This is well illustrated by looking at a few 'archetypical' scenarios (see Raskin, 2005; Westhoek et al., 2005;

van Vuuren, 2007). These scenario archetypes not only share the perspective on key uncertainties about future developments, but as a result also have similar assumptions for different driving forces (Table 4.2-4.3):

Economic optimism/ conventional markets scenarios; i.e. scenarios with a strong focus on market dynamics and economic optimism, usually associated with rapid technology development. Examples of this type of scenario include the A1 scenario (IPCC), the Markets First scenario (UNEP) or the Optimistic scenario (IFPRI).

Reformed Market scenarios; i.e. scenarios that have a similar basic philosophy as the first set, but include some additional policy assumptions aimed at correcting market failures with respect to social development, poverty alleviation or the environment. Examples of this type of scenarios include the Policy First scenario (UNEP) or the Global Orchestration scenario (MA).

Global Sustainable Development scenarios; i.e. scenarios with a strong orientation towards environmental protection and reducing inequality, based on solutions found through global cooperation, lifestyle change and more efficient technologies. Examples of this type of scenario include the B1 scenario (IPCC), the Sustainability First scenario (UNEP) or the TechnoGarden scenario (MA).

Regional Competition / Regional Markets scenarios; i.e. scenarios that assume that regions will focus more on their more immediate interests and regional identity, often assumed to result in rising tensions among regions and/or cultures. Examples of this type of scenario include the A2 scenario (IPCC), the Security First scenario (UNEP), the Pessimistic scenario (IFPRI) or the Order from Strength scenario (MA).

Regional Sustainable development scenarios; i.e. scenarios, that focus on finding regional solutions for current environmental and social problems, usually combining drastic lifestyle changes with decentralization of governance. Examples of this type of scenario include the B2 scenario (IPCC) or the Adapting Mosaic scenario (MA).

Business-as-usual scenarios; i.e. scenarios that build on the assumption of a continuation of past trends. Thus these scenarios are of a somewhat different quality than the archetypes presented above, as they are not constructed around key uncertainties. Instead business-as-usual scenarios might be described as projections. Examples of this type of scenario include the Reference scenario (IFPRI) or the Agriculture Towards 2030 scenario (FAO).

[Insert Box 4.1]

4.3 Indirect Drivers of Agricultural Change

4.3.1 Demographic drivers

4.3.1.1 Driving forces behind population projections.

Past and future demographic trends, such as those for fertility levels, mortality levels and migration, are influenced by varied social, economical, environmental and cultural factors. The "demographic transition" (Thompson, 1929; Notestein, 1945) has proved to be a useful concept to describe these trends in terms of several stages of transition. This notion is underlying most projections. Stage one refers to a pre-industrial society where both birth and death rates are high and fluctuate rapidly. In stage two, the death rates decline rapidly due to better economic, environmental and health conditions with increase in life spans and decrease in disease attacks. This stage began in Europe during the Agricultural Revolution of the 18th century. Less developed countries entered this stage in the second half of the last century. In stage three, birth rates decline and population moves towards greater stability due to increases in urbanization, female literacy and improvements in contraceptive measures. During stage four, there are both low birth and death rates. In 43 developed countries (accounting for about 19% of the world population) fertility has dropped to well below the replacement level (two births per woman) leading to a shrinking population.

International migration is also important factor that determines the future population size and composition. However, compared to fertility and mortality, future international migration is more difficult to predict because it is often influenced by short-term changes in social, economic and political developments (see also 4.3.3). It is estimated that during 2005, about 191 million persons (representing 3% of the world population) were migrants (UN, 2005b). Of these, 60% reside in the more developed regions, while the remaining 40% reside in less developed regions. How these numbers will change is important for future regional and national demographic developments. Scenario developers have tried to capture international relationships by describing changes in these factors in the storylines (e.g. IPCC, 2000; MA, 2005a), but there has been little feedback into the demographic assumptions (the MA is an exception).

4.3.1.2. Global population: Current trends and projections.

The population projections used in international assessment mostly originate from two important demographic institutions: the United Nations Population Division (UN, 2004) and the probabilistic projections from the International Institute for Applied System Analysis (IIASA) (IIASA, 2001; Lutz et al., 2001, 2004). However, population projections are also provided by the US Bureau of Census (US Census Bureau, 2003) and the World Bank (World Bank, 2004b). The range of the most commonly used projections indicates an increase of the global population from 6.5 billion today to 6.9 to 11.3 billion in 2050. The range of the latest UN scenarios spans a range from 7.7-10.6 billion (with 9.3 billion median) for 2050 (Fig. 4.3). These numbers are considerably lower than demographic projections that were published in the past. The most important reason for this is that fertility trends have been revised downwards in response to recent trends. This implies that the realization of these projections is contingent upon ensuring that couples have access to family planning measures and that efforts to arrest the current spread of the HIV/AIDS epidemic are successful in reducing its growth momentum.

Different global assessments have used different population projections (Table 4.4). The Special Report on Emission Scenarios (SRES), the Global Environment Outlook and the Millennium Assessment Working Group each used scenarios that covered a wide range of possible outcomes (all within the IIASA 95% probability interval). A comparison of these scenarios with the most recent projections for the world shows a downward revision to the medium projections. This implies that older assessments (e.g. the IPCC SRES scenarios) tend to have higher population projections than more recent assessments (the higher population projections of the IPCC-SRES are by now less plausible but not impossible). Among the total set of demographic projections, the Millennium Ecosystem scenarios are most advanced as it used explicit storyline elements to specify trends in total population numbers and also to specify the assumptions for underlying dynamics.

All scenarios indicate that the global population is mainly driven by population increases in less developed regions. In the UN medium scenario by 2050, the population of most developed regions declines by about 1.2 million per year while, in less developed regions, there is an increase of 35 million per year and the least developed countries experience an increase of about 22 million per year. As this trend is basically repeated in all other scenarios, one concludes that least developed countries will be the primary contributors to the increase in population; this situation may aggravate poverty.

Less information is generally found on international migration. Looking at the UN medium scenario, during the 2005-2050 period, the net number of international migrants from less to more developed regions is projected to be 98 million (UN, 2005b) at the rate of 2.2 million per annum. This migration rate is likely to have substantial changes on the age structure, size and composition of the population of the receiving nations and lead to populations of mixed origin. In the MA scenarios, the migration assumptions at the global level have been coupled to storylines, with high migration rates in scenarios assuming further globalization and lower rates in scenarios assuming stronger regional emphasis.

4.3.1.2. Urbanization and ageing of world population

Most assessments do not specify the extent of urbanization; however, the underlying UN scenarios provide information. In the UN medium projection, the world's urban population reached 3.2 billion persons in 2005 and is expected to rise to 5 billion persons by 2030 (UN, 2005a). At the same time, the rural population of the world is expected to decline slightly from 3.3 billion in 2005 to 3.2 billion in 2030. The share of urban population of the world, which was nearly 30% in 1950, is expected to reach more than 60% in 2030. The most changes are likely to happen in developing regions. The share of urban population in 2030 is expected to increase gradually to about 82% in developed countries, but increases from only 40% to 57% in less developed regions (UN, 2005b). As urbanization advances, this will have important consequences for agricultural systems; foremost will be feeding urban dwellers according to their changing diets (4.4.1) while also providing sufficient access to other resources such as clean water and other basic services. Urbanization can also increase pressure on crop areas as expansion of cities and industrial areas often occurs on good agricultural land. Finally, urbanization is likely to affect access to labor (see 4.4.6).

An important dominant demographic trend is the aging of population. During the 20th century, the proportion of older persons (60 years or above) continued to rise; this trend is expected to continue well into this century. For example, proportion of older persons was 8% in 1950, 10% in 2005 and is projected to reach about 22% by the middle of the current century (UN medium scenario). This implies that by 2050, the world is expected to have some 2 billion older persons; a tripling of the number in that age group within a span of 50 years. These trends in the UN medium scenarios are similar to those in other scenarios. The pace of population aging is much faster in the developing countries than in the developed ones. Hence, developing countries will have less time to adjust to the adverse impacts of aging. Moreover, population aging in developing countries is taking place at much lower level of socioeconomic development than that which has occurred in industrialized countries.

Trends in life expectancy are projected to continue in all scenarios. Using the UN medium scenario as an example: global average life expectancy (47 years in 1950-55) increased to to 65 years in 2000-2005 and is projected to increase to 75 years by mid-century. The UN projections assume that life expectancy may not increase beyond 85 years; some demographers believe this age represents an intrinsic limit to the human life span. Another important demographic trend is the decline in mortality in most countries, (including infant and under 5 years old mortality), because of better public hygiene and education, improved nutrition and advances in medical science (Lee, 2003). However, the mortality rate has increased in countries with deteriorating social and economic conditions and in those affected by HIV/AIDS epidemic.

4.3.1.4. Demographic change and its impact on agriculture.

Although population projections have slowed from past estimates, a large absolute increase in population raises serious concerns about the capability of the agricultural production and associated natural resource base (Pimentel and Wilson, 2004). A key question is whether agriculture can feed the expanding global population in the ensuing decades. A key issue involves the effects of increased urbanization on transport of agricultural products into urban areas, with associated development of infrastructure and markets. Direct consequences include a more distant relationship between consumer and producer and an increasingly important role for actors involved in food distribution and markets (e.g., supermarkets).

4.3.2 Economics and international trade

4.3.2.1. Future trends and scenarios of economic growth and the agricultural economy.

Economic change is a primary driver for future agricultural systems. The most employed indicator for economic change, GDP per capita, is used as a driver in most scenario studies.

Historically, GDP has grown substantially. Between 1950 and 2000 world GDP grew by 3.85% annually resulting in a per capita income growth rate of 2.09% (Maddison, 2003). Global GDP growth decelerated over time from 2.1% per year in the 1970s, to 1.3% per year in the 1980s, and to 1.0% annually in the 1990s (Nayyar, 2006), but this may have been a consequence of particular events such as the transition process in countries of the Former Soviet Union. Projections of future economic growth vary considerably. In many environmental assessment GDP projections are not an outcome – but an assumption (e.g. in SRES, GEO and the MA). All studies expect economic growth to continue. The World Bank short-term outlook, for instance, uses values that are comparable to historic rates (around 2%). The four scenarios in SRES show a wide range of global annual economic growth rates from 1 to 3.1% (van Vuuren and O'Neill, 2006) (Fig. 4.4 and 4.5). Many other studies use a somewhat smaller range.

All assumptions assume that growth in industrialized countries will be slower than those in developing economies (Table 4.5). Among the developing regions, Asia, particularly East Asia will continue to have higher growth rates. Different outlooks exist with respect to sub-Saharan Africa. Most recent assessments assume that institutional barriers will result in slower (though positive) economic growth than in other developing regions. Other current work (OECD, 2006), however, projects Africa to grow faster than Latin America, and slowing growth to 2030, except for MENA and sub-Saharan Africa. For the Asia region, alternative per capita income growth projections

(GDP per capita) for the four SRES scenarios, the four Millennium Ecosystem Assessment Scenarios, and the four GEO-3 scenarios (Westhoek et al., 2005) also show lower growth projections for the period 2025-2050 compared to 2000-2025.

4.3.2.2 Implications of income growth for agriculture

Changes in per capita income growth do affect the mix of economic activities, and this affects agriculture in a significant way, with important implications for access to labor. Along with economic development, demand for food quantity in countries initially increases and then stabilizes; food expenditures become more diverse (see also 4.4.1). At the same time, the demand for nonagricultural goods and services increases more than proportionally. A general tendency observed in the past (and assumed in most assessments) is that the economy responds to this trend by shifting resources out of agriculture; and the share of agricultural output in total economic activity declines (Fig. 4.6). While high-income countries typically produce more output per hectare as a result of higher inputs, industrial and service output grows much faster so the relative contribution of agriculture declines. Technological change further replaces most of the labor force in agriculture. In this context, it is important to note that many factors discussed in elsewhere in this chapter are closely related. For instance, demographic factors (graying of the population, labor supply) (4.3.1) may have important implications for growth projections. Similarly, developments in energy supply in the coming decades (e.g. oil scarcity) could have important consequences for economic projections. High economic growth rates are likely to have an upward pressure on energy prices and, in turn, might increase the demand for alternative fuels such as bioenergy.

4.3.2.3. International trade and agriculture

Increasing trade patterns in the future. Trade is as an important distinguishing factor for scenarios in several assessments: the MA, GEO and SRES have scenarios with and without trade liberalization. Nevertheless, in terms of actual trade flows the scenarios all show an increasing trade, even in scenarios without trade liberalization (Bruinsma, 2003; FAO, 2005; MA, 2005a). An important reason for this increase is that population growth and the development of agricultural production is expected to occur unevenly. The largest increase is expected for total trade in grain and livestock products (see also Table 4.6). Some region specific patterns are expected also, e.g., the OECD region is likely to respond to increasing cereal demands in Asia and MENA. The very rapid yield and area increases projected in sub-Saharan Africa could turn the region from net cereal importer at present to net grain exporter by 2050. Net trade in meat products increases 674%. Net exports will increase in Latin America, by 23000 Gg, while the OECD region and Asia are projected to increase net imports by 15000 and 10000 Gg, respectively (MA, 2005a). Asian demand for primary commodities, such as natural rubber and soybean, is likely to remain strong, boosting the earnings of the exporters of these products. China will become the world's largest importer of agricultural commodities in terms of value by 2020, with imports increasing from US $5 billion in 1997 to US $22 billion in 2020 (UNCTAD, 2005).

At a more aggregated scale important trends can be noted (see Rosegrant et al., 2001). The overall trade surplus in agricultural commodities for developing countries may dissappear completely and by 2030 they could, as a group, become net importers of agricultural commodities, especially of temperate zone commodities (FAO, 2003). At the same time, the agricultural trade deficit of the group of least developed countries could quadruple by 2030 primarily due to the fact that industrialized countries tend to be the major beneficiaries of trade arrangements (FAO, 2006b). Many countries have faced much less pressure to reduce support for their agricultural sector primarily due to the fact that commitments to liberalize were based on historically high levels of support and protection. The future of this driver hinges on the outcomes of the Doha Round of trade talks about agricultural support and market access. Export subsidies remain substantial with EU accounting for bulk of direct export subsidies (FAO, 2006b). Removal of price support and other subsidies to 2030 could result in moderately increasing international prices, while prices would fall substantially in countries with high levels of protection (FAO, 2006b).

The impact of trade on developing countries is very controversial. Most of the conclusions that imply developing countries stand to lose in future trade arrangements are premised on the fact that developing countries will still be dependent on industrialized countries for trade. There is extensive evidence of emerging South-South trade relations (UNCTAD, 2005). These relations could imply that even if industrialized countries form a substantial component of demand for exports from developing countries, the limited outlook for growth of industrialized countries puts them behind the emerging strong demand of Asian countries, particularly China and India. Developing countries that export non-oil primary commodities benefit from increased demand and rising prices for their exports despite low commodity prices.

Terms of trade have significant impacts on affordability of food imports and food security for countries with a large share of agricultural trade. Many of the lesser developed countries have faced deteriorating terms of trade since the 1980s. Agricultural terms of trade fell by half from a peak in 1986 to a low in 2001 (Fig. 4.7). Because many of these countries depend on commodity exports to finance food imports, a decline in terms of trade for agriculture threatens food security (FAO, 2004b). The region that has suffered most from declining terms of trade is sub-Saharan Africa. Since the 1970s, the deterioration of agriculture terms of trade in that region has led to a substantial reduction in the purchasing power of commodity exports. In addition to declining terms of trade, fluctuations and trends in prices negatively affected African agriculture. The declining and fluctuating export prices and increasing import prices compound socioeconomic difficulties in the region, as well as agricultural patterns (Alemayehu, 2000). Short-term outlooks such as those from the World Bank project this situation to persist (e.g. UNCTAD, 2005).

A number of model results recently reviewed (Beierle and Diaz-Bonilla, 2003) whether trade liberalization (in the form of reduced protection and export subsidies and lowered import restrictions) would benefit small-scale farmers and others in poverty in developing countries. Several key findings from their review and other assessments are:

- Most models demonstrate negative impacts of current industrialized country (OECD) trade protection policies but positive impacts from developed country liberalization on developing country welfare, agricultural production and incomes, and food security.
- Impacts vary by country, commodity, and sector, and for regions within countries.
- OECD market access restrictions harm developing countries, although effects of production and income-support subsidies are more ambiguous.
- Developing countries tend to gain more from liberalization of their own policies than from reforms by the OECD. Consumers in developing countries benefit widely from these reforms.
- Model results differ on the basis of assumptions such as the scope of commodity coverage, mobility of resources among alternative crops and between farm and non-farm employment, availability of underutilized labor, and static versus dynamic analysis.
- Multilateral liberalization reduces the benefits derived from preferential trade agreements, but these losses are relatively small compared to the overall gains from the broader reforms.
- Most models have not had sufficient resolution to analyze the impacts of reforms on small-scale and subsistence farmers, and other poor households (Gulati and Narayanan, 2002; Tokarick, 2002; Beierle and Diaz-Bonilla, 2003; Hertel and Winters, 2005).

4.3.2.4. Agricultural investments

The investment requirements to achieve projected scenarios are seldom computed. Based on an assessment of five key drivers for agricultural development (agricultural research, irrigation, rural roads, education, and clean water) investment requirements to generate modest levels of agricultural production growth have been estimated at US $579 billion during 1997-2020 (Rosegrant et al., 2001) (Table 4.7). According to this study, levels of investment required will vary from region to region, e.g. South Asia and Latin America would require the highest levels. Sub-Saharan Africa's investment requirements would total US $107 billion during 1997-2020 and would represent 19% of 1997 government spending on an annual basis. At the sector level, irrigation would account for 30% of the total investments, public agricultural research and rural roads for another 21% each, with educations' share the lowest at 13 percent.

Foreign Direct Investment (FDI) is an important source of capital flows for development. FDI for agriculture is generally lower than that of other sectors. In countries such as Vietnam, FDI in agriculture and rural areas is declining similar to other regions; IBRD/IDA commitments to the agricultural sector are also declining (Binh, 2004).

4.3.2.5 Implications for AKST

Projected income growth is likely to lead to shifts in food demand patterns, e.g., from cereals to meat consumption (see 4.4.1). It can be hypothesized that with this shift, sustainable technologies for intensive livestock production, and policy safeguards for meat safety (i.e. meat inspection services), and environmental regulation will be needed.

Higher incomes will also mean more expensive farm labor; this can be addressed through increased mechanization, and clustering of small farms, whenever applicable, for more efficient management (assuming sufficient access to capital and/or demand for labour in other economic sectors). Due to higher opportunity costs of time, supermarkets will be in high demand. In addition, food quality assurance will need to be met through certification, labeling, and appropriate packaging. These conditions are currently deficient in most developing countries.

With increased trade liberalization, developing countries would need science based regulatory frameworks for sanitary and phytosanitary issues and institutional market infrastructures to strengthen market information systems, including grades and standards. Human and organizational capacity to effectively implement the international standards will also need to be developed.

The projected decrease in FDI would create a need for more domestic investment in agriculture. Developing country decision makers will need tools to help in agricultural strategic planning and budget prioritization.

4.3.3 Sociopolitical drivers of alternative futures in agriculture and AKST

4.3.3.1 Types of sociopolitical drivers

The direct and the indirect drivers of AKST (Fig. 4.1) are influenced by public policies, which are the outcome of political processes. Therefore, the sociopolitical factors that influence public policy making and the implementation of public policies are important drivers of alternative futures in AKST. These factors include (a) the political system (type of political regime, political culture, ideology, political stability), (b) public administration and its effectiveness in policy implementation; (c) the structure of society (social stratification, social values, ethnicity; social conflicts); and (d) extent of regional and global collaboration. For an assessment of alternative scenarios for the future of agriculture and AKST, it is necessary to assess major trends of change in political and administrative systems and in society, and to evaluate how these changes will influence the choice of public policies and sociopolitical events. For obvious reasons, the possibilities to project sociopolitical change are more limited than the possibilities to project trends in other drivers such as, for example, demography.

4.3.3.2 Change in political systems and public policy choices

Major political trends after World War II were an increase in authoritarian regimes (autocracies) until the early 1970s, followed by a rapid decline (see Fig. 4.8). Accordingly, the number of democracies has increased rapidly since the early 1970s. The number of “anocratic” states, intermediate states where elites maintain power despite the existence of democratic procedures, has increased, too. A conventional thought is that these trends continue into the future (this underlies a large number of long-term scenarios including, for instance, most reference scenarios – but also 3 out of 4 scenarios in the Millennium Ecosystem assessment (Global Orchestration, Technogarden and Adapting Mosaic)). There has also been a trend towards increasing citizen participation in the formulation of development strategies. Sectoral policy documents such as agricultural sector strategies are increasingly developed with broad stakeholder consultation. Another important trend in political systems throughout the developing world is democratic decentralization, i.e., the transfer of political authority to lower levels of government.

How do these trends of democratization, decentralization and participatory policy making influence the choice of public policies? The relationship between democracy and economic development is complex (Bardhan, 1999), but changes in political systems that allow citizens to participate more broadly in political decision making will reduce “urban bias” (Lipton, 1977) and increase the attention given to agriculture, because this sector employs a large part of the population in developing countries. However, there is no empirical evidence of such an effect (see Fan and Rao, 2003). In democratic political regimes, agricultural interest groups are often able to exercise political pressure to obtain subsidies and protection, which typically benefit larger-scale more than small-scale farmers, whereas it is more challenging to create political pressure for investments in public goods, such as agricultural research (cf. Lopez, 2005). The influence of political regime type on other agricultural policies, such as access to land, agroenvironmental policies, and regulation against unfair competition, is not straightforward.

While the evidence on the link between political regime type and general agricultural policies is inconclusive, evidence suggests that democratization will lead to a stronger focus on food security. None of the great famines occurred in a democracy (Sen, 1981). Moreover, famines can be avoided by fairly elementary government actions, because they are rarely caused by absolute shortages in food supply according to (Sen, 1981). Subsequent work showed that the freedom of press does, in fact, play an important role in avoiding food crises and famines (cf. Sen and Drèze, 1989). In this light, an increase in number of democracies appears to imply that increased accountability would lead to less food crises.

For authoritarian regimes, political ideology, development orientation and the time horizon of the regime influence the commitment to agriculture and the choice of agricultural policies. Indonesia (under Suharto) and China are examples of authoritarian regimes that invested heavily in agriculture and rural development, though with limited recognition of the need for environmental sustainability. In Africa, there is evidence that military leadership has had a negative influence on public spending for agriculture (Palaniswamy and Birner, 2006). The trend towards democratization and citizen participation in policy making, which is projected to continue, has ambiguous implications with regard to alternative future scenarios for agricultural and food systems and AKST. Hence, it will be necessary to work with different assumptions when formulating scenarios.

For Asia, the political commitment to the agricultural sector is projected to continue as indicated by a relatively high budget share to this sector. In Africa, one can also observe an increased emphasis on agriculture; e.g., one indication is the Alliance for a Green Revolution in Africa, led by the former Secretary General of the United Nations, Kofi Annan. African Heads of State, in their Maputo Declaration, made a commitment to allocate at least 10% of their national budgetary resources to agricultural development (African Union, 2003). This goal is also supported by the Comprehensive Africa Agriculture Development Program (CAADP), which is high on the agenda of the New Partnership for Africa's Development (NEPAD). However, it still remains to be seen whether these commitments will indeed translate into increased investment on agriculture in Africa. In formulating scenarios, one also has to take into account regional and global trade agreements, which limit the choices that countries can make regarding their agricultural policies (see 4.2.1).

4.3.3.3 State capacity for policy implementation

To assess the impact of public policies on the development of AKST, it is necessary to consider government effectiveness, e.g. the quality of the bureaucracy, the competence and independence of the civil service, and the credibility of the government's commitment to its policies. Control of corruption is also important for the effective implementation of agricultural policies, especially in agricultural infrastructure provision, such as irrigation. Since agricultural development depends on the ability of the state to overcome market failures, which are prevalent especially in early phases of agricultural development (Dorward et al., 2004), changes in state capacity are an important sociopolitical driver. Governance problems tend to be greater in low-income countries; they are particularly prevalent in the Central African region, in spite of some recent improvements (Kaufmann et al., 2006). The state capacity for policy implementation can be improved by governance reforms, including public sector management reforms, the use of e-government, outsourcing and public-private partnerships, all of which are important in the agricultural sector. Improving state capacity is a long-term process, however, lasting often for several decades before a real impact can be achieved (Levi, 2004). Hence, for short- and medium-term scenarios, it will be useful to take into account the current variation in state capacity, as measured by governance indicator data sets (Kaufmann et al., 2006).

4.3.3.4 Social factors that shape the future of agriculture

The social factors that shape the future of agriculture include conflicts, changes in social values and social structure (related to social stratification, gender roles and ethnicity). In view of the complexity and country specificity of social factors, it is difficult to identify general global trends that can be used to formulate scenarios. There are, however, some projections on global trends; e.g., economic development gives rise to cultural changes that make individual autonomy, gender equality and democracy increasingly likely (Inglehart and Welzel, 2005).

These findings correspond to the “End of History” view that liberal democracy and Western values comprise the only alternative for nations in the post-Cold War world (Fukuyama, 1993). This view forms the basis of several scenarios in global assessments such as the A1b scenario in IPCC’s SRES scenarios and (to some degree) the Global Orchestration scenario (MA). This view has been challenged by the controversial “Clash of Civilizations” theory (Huntington, 1996); i.e., that people's cultural and religious identity rather than political ideologies or economic factors will be the primary source of conflict in the post-Cold War world, especially between Islamic and non-Islamic civilizations. Again, this view forms the basis of several scenarios (A2 in IPCC SRES; Order from Strength in MA). It should be noted, however, there is no evidence for an increase in the frequency of intercivilizational conflicts in the post-Cold War period (e.g., Tusicisny, 2004). With regard to agricultural development, internal conflicts and civil wars matter as much, or even more, than international conflicts. The number of wars reached a peak of 187 in the mid-1980s, but was reduced by half in 2000 (Marshall et al., 2003). Most of these wars were internal conflicts, and most of them occurred in poor countries.

Instability can be defined as the incidence of revolutionary and ethnic wars, adverse regime changes, genocides or politicides (government targeting of specific communal or political groups for destruction) (Goldstone et al., 2005). The percentage of countries experiencing periods of instability reached a peak of almost 30% in the early 1990s (Fig. 4.9). A predictive model with four variables (regime type, infant mortality, a “bad neighborhood” indicator - four or more bordering states in armed civil or ethnic conflict- and the presence or absence of state-led discrimination) showed that ethnically factionalized nascent democracies, without fully open access to political office and without institutionalized political competition, are particularly prone to wars and conflicts, even with favorable economic conditions (Goldstone et al., 2005).

The implications of wars and armed conflicts for agricultural development are far-reaching: crop and livestock production are reduced or abandoned due to insecurity, lack of labor, environmental degradation and destruction of infrastructure. Wars and conflicts may affect AKST in different ways, for example, by reducing the availability of public funds for agricultural research and extension, and by a loss of local knowledge due to displacement of agricultural producers.

Another important social factor shaping the future of agriculture is the capacity of communities and societies to cooperate, also referred to as social capital (see, e.g., Putnam, 1993). In agriculture, especially in small-scale agriculture, producer organizations play an important role in addressing market failures while avoiding government failures. They provide political voice to agricultural producers, help them to hold government organizations accountable, and engage in the provision of agricultural services. Their role has been increasing in recent years due to investments in their capacity and conducive factors such as democratization (Rondot and Collion, 2001).

4.3.3.5 Regional and global collaboration

The future of AKST will also depend on the development of regional and global political organizations; e.g., regional organizations, such as NEPAD or ECOWAS (Economic Community of West African States) play an increasing role in shaping agricultural policies. Global organizations such as the United Nations Food and Agriculture Organization (FAO), the World Organization for Animal Health, and the Consultative Group on International Agricultural Research (CGIAR) are important players in AKST, as are treaties, e.g., the International Treaty on Plant Genetic Resources, and issue-specific global networks, such as the Global Fund for Control of Highly Pathogenic Avian Influenza. Thus, the ability of the international community to cooperate to provide global public goods for agriculture is an important sociopolitical driver.

4.3.3.6 Sociopolitical factors in existing assessments

Predictive models are available and can be used for formulating future scenarios. Thus far, sociopolitical drivers have been included in assessments as scenario storylines. The IPCC SRES report used the degree of globalization versus regionalization as an important distinction between scenarios. The other axis is the extent to which a scenario focuses on social- and environmental objectives versus economic objectives. This basic idea (that relates to several of the factors discussed above) has been further specified in many other scenario studies (MA, 2005a; Westhoek et al., 2005).

4.3.4. Science and technology

Scientific breakthroughs and technological innovations in the last century fueled substantial gains in agricultural productivity in many countries (see FAO statistics). These innovations not only helped meet the world's gross food and fiber needs but, along with new transport and storage technologies, transformed much of northern agriculture from subsistence to commercial market-oriented farming, thus offering more opportunities for participation in global markets. Technology is considered a core driver of future changes, affecting economic growth, social and environmental change and agriculture productivity.

4.3.4.1 Previous Assessments

The Intergovernmental Panel on Climate Change (IPCC, 2000) discusses in detail the approaches and problems encountered in predicting the impact of science and technology on global change. The IPCC identifies five commonalities in the innovation process (Box 4.2). Although the IPCC is particularly concerned with how the innovation process may affect the energy sector, these five commonalities could reasonably be applied to the agricultural sector.

[Insert Box 4.2]

There is widespread agreement that the innovation process is complex and difficult to predict. There is still no agreement on what assumptions to make regarding 1) how government and investment in industrial research and development (R&D) will impact the innovation process, 2) the motivation of producers of new technologies and 3) the role of consumers. Therefore, models and assessments mostly describe technology change in much more aggregated parameters such as exogenously assumed yield changes or learning-by-doing functions (e.g. for production costs of energy technologies). Different assumptions concerning these technology parameters have been used as important drivers to contrast the IPCC-SRES scenarios, i.e., technology change was assumed to be lower in scenarios with less globalization (resulting in lower yield improvement and less rapid economic growth). IPCC-SRES scenarios have also been built around the direction of technology change (IPCC, 2000).

The Millennium Ecosystem Assessment (MA, 2005a) recognizes science and technology as a major driver of change in ecosystems and their services. The MA identified three key concerns regarding technological trends. First, the institutions needed to foster the research and development process are not yet well established in much of the developing world. Secondly, the rate of spread of new technologies may be outpacing the time frame required to identify and address their negative consequences. Lastly, technologies can produce unexpected consequences that might lead to disruptions of ecosystems affecting large numbers of people. Like in the IPCC-SRES scenarios, the rate of technology change was used to contrast the different MA scenarios (Fig. 4.10).

The Global Environment Outlook report (GEO 3) (UNEP, 2002), focused on the distribution of benefits and costs of technological developments in the future. To the extent that technological innovation is increasingly undertaken by the private sector and driven by profit, benefits are seen as primarily accruing to those who are most powerful in the marketplace. The assessment suggests that cautious government policies and empowerment of consumers may act as disincentives to technological innovation by the private sector. However, such an approach may also result in more equitable distribution of benefits. The quantitative assumptions resemble those of the IPCC-SRES scenarios.

4.3.4.2 Important trends for the future

Trends in investment. Although the innovation process is complex, investment in research and development is central. Typically, the ratio of R&D expenditures to GDP is an indicator of the intensity of R&D activities over time and in relation to other economies. OECD nations typically spend 2.26% of their GDP in overall R&D while Nicaragua can afford to spend only 0.07%.

While there is an increase in absolute R&D expenditures in agriculture, there is a concern that investment in agricultural R&D is declining in North America, Western Europe and East Asia relative to overall spending on research. While existing scenarios are not explicit on agricultural R&D trends, a plausible trend could be a further increase in absolute numbers but a decreasing ratio compared to overall GDP leading to concerns about the ability to use AKST as a response to challenges. However, several trends in R&D investment that could mitigate these concerns. First, there appears to be a trend toward increasing globalization of R&D, driven by multinational corporations seeking to take advantage of knowledge of local and regional markets, technical expertise, fewer restrictions on intellectual property, and lower costs for R&D in non-OECD countries. Secondly, many countries with large public sector R&D investments continue to promote international linkages, and this emphasis is likely to become more significant as globalization continues (OECD, 2006b). Thirdly, and perhaps most importantly, China, with a very large, poor, rural population, now ranks second in R&D expenditures (Fig. 4.11). It is plausible that China will shortly become the major center for agricultural research, particularly research relevant to poor rural areas. (A more detailed discussion of investment in agricultural R&D is presented in chapter 8.)

Trends in performing sector. In the last century, key innovators were national agricultural research systems, including universities, agricultural field stations, agricultural input companies, and extension services (Ruttan, 2001). Two international organizations, CIMMYT in Mexico and IRRI in the Philippines, contributed significantly to the advancement of the Green Revolution, and were mainly funded by the public sector in the first half of the last century. In contrast, in the United States, the private sector has always played a central role in the development of agricultural equipment and the performance of agricultural research and development. Private-sector research grew substantially in the last decades of the 20th century as legal rights were obtained for genetic modifications (Huffman and Evenson, 1993). Given these trends, it is safe to conclude that the future of biotechnology as applied to agriculture will likely be driven by demands for specific traits to enhance production and add value. Value added output traits with consumer-oriented benefits, such as improved nutritional and other health-related characteristics, will attract the support of the private sector because these traits will turn many agricultural commodities into premium priced and quasi-specialty products (Shimoda, 1998). Again, while existing scenarios do not explicitly relate to these issues, new scenario development focusing on the agricultural sector could provide a richer assessment basis with the inclusion of these trends.

Internationally competitive biotechnology research and development systems are expected to emerge, accelerating the pace of biotechnology research. Although the investment in biotechnology is on the rise in various countries, there are scientific, political and economic uncertainties associated with it. Due to potential environmental and health risks associated with GM products, the EU has imposed stringent regulatory measures on foods containing or produced from GMOs (Meijer and Stewart, 2004). On the other hand, the production and consumption of GMOs has been widespread in other countries, such as the US and Canada. The future of agriculture will depend on how the debate on GMOs unfolds. A directly related factor, which is important for future GMO use as well, are societal choices with respect to high-input agriculture in general (Giampietro, 2007).

Another noticeable trend that could influence future agricultural development is the increase in unregulated trade in agricultural inputs and outputs in many countries (see 4.3.2). This process has created a new set of incentives for investment in private research and has altered the structure of the public/private agricultural research endeavor, particularly with respect to crop improvement (Falcon and Fowler, 2002; Pingali and Traxler, 2002).

Finally, since the World Summit on Sustainable Development (WSSD) held in Johannesburg in 2002, more research has gone into local and traditional knowledge systems. Nongovernmental organizations, research bodies, funding agencies, and the United Nations system are lending financial and technical support to locally prioritized research and development efforts that value, investigate, and protect the local and traditional knowledge systems.

Trends in adoption. The full benefits of scientific breakthroughs will not be realized without the dissemination and adoption of new technologies. There is a great deal of unused scientific knowledge and technologies ‘on the shelf’ for immediate application, particularly for developing country agriculture. In each country, the successful local development of technologies or the transfer and adaptation of innovations from others will depend on incentives and barriers faced by investors and producers (USDA, 2003). Poor farmers can adapt new technology if small risks are associated with it; with larger risks, they may need guarantees from the state or insurance providers. Many existing on-the-shelf technologies could be adopted if the perceived risks of using them were significantly lowered or if some of the hindrances to adoption, such as missing input supply chains, poor or non-existent marketing channels for surplus production, and little or no access to credit or new knowledge were reduced or eliminated. Adoption of GMO material by small farmers may be limited by high costs of planting material, restrictions on the replanting of seeds, and uncertainty of market acceptability. If these concerns are not addressed, much biotechnology will likely not be adopted by poor farmers. Existing scenarios assuming high rates of technology change imply high rates of adoption.

4.3.5 Education, culture and ethics

4.3.5.1 Education

Many international organizations have addressed the issue of poverty alleviation through the diffusion and improvement of rural basic to tertiary education with global, regional or country-specific programs (see CGIAR, 2004; FAO, 2006a; UNESCO, 2006). There also are programs implemented by organizations from developed countries (e.g. Noragric[1]) to help individual developing countries identify and address problems with their rural education systems (Noragric, 2004).

[1] Dep. Int. Environ. Dev. Studies Norwegian University of Life Sciences

Presently there are numerous, thorough studies that demonstrate education is a necessary (but not sufficient) driving force for alleviating hunger and poverty. However, there are very few assessments, scenarios or projections of plausible futures for educational policies directed toward this end. In fact, the scenarios of the major existing assessments relevant for agriculture (see 4.2) provide very little information on this issue (some attention is paid in IPFRI modeling). On historic trends, UNESCO's databases[2] show that information provided by countries on multiple educational variables seldom is complete on either a yearly or a serial basis (or both). Hence it is not surprising that few educational indicators have been projected into the future. One educational indicator that has been projected into the future is the school-age population. Two features stand out: (a) projected changes in school age population are highly variable among countries; and (b) there may be no change in the population aged 5-14 (in some countries this age group decreased, whereas the opposite trend was predicted for other countries in this group).

One important unknown is what proportion of the population aged 15-19 and 20-29 would receive a rural (or agricultural) higher education and/or training. In poor countries with large rural populations it is likely that emphasis on rural and agricultural education will take a growing share of the total educational effort as measured in terms of GDP, but that a decreasing share of the GDP is likely in those countries in transition to a larger-scale and/or more mechanized agriculture. While this agricultural transition will require less unskilled human labor, it will require professional practitioners able to address the challenges of reduced land availability, changing climates, and increased demands for sustainable farming practices, while maintaining or increasing productivity. If sustainability is considered an important production paradigm, the curricula of rural education would need to include management of complex production systems like agroforestry, polycultural, and silvo-pastoral systems.

There are many methods for estimating the costs and benefits of educational policies; the cost-benefit analysis (CBA) is possibly one of the most used. The results of many CBA studies for developing countries in Africa, Asia and Latin America between 1960 and 1985 have been compiled and summarized (Hough, 1993). Major conclusions from this study were (i) private Rate-of-Returns[3] (RR) are always higher (27%) than social RRs[4] (19%); (ii) RRs are always highest (32%) at the lowest level of education, but vary across regions; (iii) social RRs to higher education are always lower (14%) than those to secondary education (16.7%), but the converse was true with private rates (24.3% and 21.3% for higher and secondary education, respectively);

[2] http://www.uis.unesco.org/ev_en.php?URL_ID=3753&URL_DO=DO_TOPIC&URL_SUBCHAPTER=201
[3] These RRs take into account the costs borne by the students and/or their families in regard to net (post-tax) incomes.
[4] These RRs relate all the costs to society to gross (before deduction of income tax) incomes.

(vi) public subsidies are particularly high in the cases of both primary and higher education, and in general, the poorer the country, the more subsidized is its education, particularly higher education, and (vii) where time series data on earnings exist, there appears to be a decline in RRs over time (Psacharopoulos and Patrinos, 2004). Finally, some types of education that exhibit higher rates-of-return are general education for women and lowest per-capita income sector, and vocational education.

4.3.5.2 Culture

Culture has had a profound influence on the creation of new agricultural systems, as well as on the continued improvement of existing ones and will continue to do so in the future. However, as with education – cultural factors are often difficult to capture in scenarios.

One factor where culture plays a role is in diets. On an aggregated level changes in diet seem to mostly follow closely changes in income, independent of cultural factors or geographical location (FAO, 2002b). However, at equivalent incomes, cultural differences become conspicuous drivers of food quality and type (FAO, 2002b) (e.g., low pork consumption rates in some regions and low beef consumption rates in others). These factors are generally taken into account in the projections of existing assessments (see also 4.4.1).

Organic agriculture has been increasing in the past, and further expansion seems likely – certainly if the actual costs of agricultural commodity and food production were reflected in both domestic and international agricultural prices. It is, however, unlikely that organic farming will become a real substitute for industrial agricultural production systems: even if organic farming yield were similar to conventional yield (see e.g. Badgley et al., 2007). Production costs would likely be higher because it is a more labor-intensive activity and it might have additional standardization costs (OECD, 2002; Cáceres, 2005). Organic farming therefore does not play a very important role in the scenarios of existing assessments though it could have an impact on poverty and hunger alleviation in, for instance, least developed countries with large rural populations, mostly of small-scale farmers living from subsistence traditional agriculture. This trend may be explored in new scenarios.

Another factor that might be considered is that traditional and indigenous cultures may be sources of agricultural knowledge useful for devising sustainable production systems. However, the future of that knowledge is likely to be grim in a globalized world if those who retain this knowledge do not receive assistance to pursue their futures in a manner acceptable to their value system (Groenfeldt, 2003). The practical knowledge stored in traditional and indigenous agriculture could be conserved if it were the subject of interdisciplinary inquiry by research organizations and universities (Thaman, 2002; Rist and Dahdouh-Guebas, 2006) with the aim of adapting otherwise unsustainable production systems to the likely incoming environmental shocks, such as the changing climate caused by global warming (cf. Borron, 2006), natural resource depletion (e.g. irrigation water), and pollution.

4.3.5.3 Ethics

The use of biotechnology (see 4.3.4) may have considerable benefits for society, but will likely raise ethical concerns about food and environmental safety (FAO, 2002b). The adaptation of these technologies in different scenarios should therefore be related to assumptions on ethical factors. In the next decade, development of biotechnological products will be faster for issues that relate to challenges recognized by the general public (e.g. herbicide-tolerant plants) than for other areas.

4.3.6 Changes in biogeophysical environment

Over the last 50 years, the use of fertilizers, primarily N fertilizers, has increased rapidly (FAO, 2003; IFA, 2006). In the same period, the quantity of nutrients supplied in the form of manure has increased as well (Bouwman et al., 2005). Increased use made a major increase in crop production possible. However, only a portion of the supplied nutrients are taken up by crops, with the remainder lost in different forms to the environment. These losses cause progressively serious environmental problems (Galloway et al., 2002; MA, 2005a), some of which can directly affect agriculture through a reduction in water quality and through climate change, and can indirectly affect agriculture through increased pressure for agricultural systems to minimize off-site environmental impacts.

To produce more food and feed in the future, the fertilizer demand is projected to increase from 135 million tonnes in 2000 to 175 million tonnes in 2015 and to almost 190 million tonnes in 2030 (Bruinsma, 2003). These projections are based on assumed crop yield increases. In the "Constant Nitrogen Efficiency scenario" the use of nitrogen fertilizers is projected to grow from 82 million tonnes in 2000 to around 110 million tonnes in 2020 and 120–140 million tonnes in 2050 (Wood et al., 2004). In the "Improved Nutrient Use Efficiency scenario" the use increases to around 100 million tonnes in 2020 and 110–120 million tonnes in 2050. These nitrogen fertilizer projections are based on the crop yields projected by AT 2030 (FAO, 2003) and they have been used for the Millennium Ecosystem Assessment (MA, 2005a). As the number of livestock is projected to increase as well, the quantity of manure is expected to increase, especially in Asia (Fig. 4.31; Bouwman et al., 2005).

The increased use of fertilizer and manure will lead in many regions in the world to increased losses of reactive N and of phosphorous (P) to the environment, causing increasingly more severe environmental problems. Emissions do not only stem from agriculture; the combustion of (fossil) fuels and emissions from industries and households lead to increased levels of N and P in the environment (Fig. 4.13). These emissions have already caused a range of environmental problems (MA, 2005a). The presence of excess nutrients (N, P) in water can lead to eutrophication (Bennett et al., 2001; Galloway et al., 2002) causing algal blooms, changes in resident organisms, low dissolved oxygen , and generally lower water quality. Nitrogen losses to groundwater can increase nitrate (NO_3) concentrations to levels which can have serious effects on human health. Aerial deposition of reactive N into natural terrestrial ecosystems, especially temperate grasslands, shrub lands, and forests, could lead to lower plant diversity. Nitrous oxide is a powerful greenhouse gas. In 2000, nitrous oxides stemming from agriculture were responsible for more than 6% of global greenhouse gas emissions (EPA, 2006).

Nutrient loading will become an increasingly severe problem, particularly in developing countries and in East and South Asia (MA, 2005a). On the basis of projections for food production and wastewater effluents, the global river N flux to coastal marine systems may increase by 10–20% in the next 30 years. While river N flux will not change in most wealthy countries, a 20–30% increase is projected for poorer countries, which is a continuation of the trend observed in the past decades. The export is expected to reach 50 million tonnes year^{-1} by the year 2030 with the Pacific Ocean experiencing the greatest increase (Bouwman et al., 2005; MA, 2005a).

4.4 Assessment of Direct Drivers

4.4.1. Food consumption patterns

4.4.1.1. Expected changes in food consumption patterns and nutritional transformation

As incomes increase, direct per capita food consumption of maize and coarse grains declines as consumers shift to wheat and rice. When incomes increase further and lifestyles change with urbanization, a secondary shift from rice to wheat takes place. In general, existing assessments project a continuation of these trends. The expected income growth in developing countries (see 4.3.2) could become a strong driving force for increases in total meat consumption, in turn inducing strong growth in feed consumption of cereals. With growing urbanization, consumption is expected to shift as well towards increased consumption of fruits, vegetables, milk and milk products and to more consumer-ready, processed foods (increasingly procured in (international) supermarket chains, and fast food establishments). At the same time, growth in per capita food consumption in developed countries is expected to continue to slow as diets have reached on average reached saturation levels. These trends will lead to an increase in the importance of developing countries in global food markets (Cranfield et al., 1998; Rosegrant et al., 2001; Schmidhuber, 2003).

Several drivers of nutritional transformation are 1) gains in purchasing power of food, 2) declining food prices, 3) shifts in demographic patterns, 4) growing urbanization, 5) changes in women's roles, 6) an enhanced understanding of the impact of diets on health, 7) government interventions towards certain foods, 8) influence exerted by the food industry, 9) growing international trade, and 10) an increasing globalization of tastes (Schmidhuber, 2003). Urbanization is generally associated with factors like higher incomes, more opportunities for women to enter the paid-work sector; and a major boost in the amount of information, goods and services. In relation to dietary habits this translates into access to a large variety of food products, exposure to different, 'globalized' dietary patterns, adoption of urban life-styles with less physically intensive activities requiring less food energy, and a preference for pre-cooked, convenient food. Moreover, urbanization entails a physical separation of the agricultural sector from the postharvest sector and the final consumption sector (Smil, 2000; Giampietro, 2003; Schmidhuber, 2003).

Shifts in food expenditures. Decisions on food purchases will continue to be related to other household expenditure choices, such as housing, clothing, education, and health costs. With greater affluence the number of low-income countries that spend a greater portion of their budget on basic necessities, including food, will decline (Seale et al., 2003). Shifts in food expenditures for selected countries (see Table 4.8) with expected slow declines in food budget shares over time as well as slow declines in expenditures on grains are also projected (Cranfield et al., 1998).

Changes in agricultural production and retailing systems. The nutritional transformation will induce changes in agricultural production systems. Increased consumption of livestock products, e.g., will drive expansion of maize production for animal feed. Given that diets will continue to change with increasing incomes and urbanization, a doubling of cereal yields may be required. Because of the high rate of conversion of grains to meat, some analysts have argued that a reduction in meat consumption in industrialized countries, either through voluntary changes in dietary patterns, or through policies such as taxes on livestock, would shift cereal consumption from livestock to poor people in developing countries (e.g., Brown, 1995). While the long-term prospects for food supply, demand, and trade indicate a strengthening of world cereal and livestock markets, the improvement in food security in the developing world will be slow and changes in the dietary patterns in industrialized countries are not an effective route to improve food security in developing countries (Rosegrant et al., 1999).

At the same time, the agricultural production sector is catering more to globalized diets through growing industrialization and intensification of the food production process. Retailing through supermarkets is growing at 20% per annum in some countries and is expected to penetrate most developing countries over the next decades, as urban consumers demand more processed foods, shifting agricultural production systems from on-farm production toward agribusiness chains. International supermarket chains directly accelerate the nutritional transformation; e.g., the increase in the availability of yogurt and pasteurized milk has led to increases in consumption of dairy products in Brazil. Supermarkets will emerge in China and most other Asian developing countries, and more slowly in sub-Saharan Africa over the next three to five decades. The penetration of supermarkets for 42 countries based on the major drivers of change, including income, income distribution, urbanization, female participation in the labor force and openness to foreign competition through foreign direct investment, explains 90% of the variation in supermarket shares (Traill, 2006). Income growth was an important determinant for further supermarket penetration in Latin America, and further income growth and urbanization are crucial determinants for future supermarket growth in China (Traill, 2006).

The food retailing sector will increasingly serve as the primary interface between consumers and the rest of the agricultural sector (Fig. 4.14). Food processing industries and supermarkets are expected improve food safety and support dietary diversification; on the other hand, they might contribute to less healthy diets through retailing of less healthy foods, such as refined white flour with reduced levels of fibers, minerals, and vitamins, or through oil hydrogenation processes.

4.4.1.2 Changing food consumption patterns in global assessments

Studies focusing on food and agriculture have seldom projected changes in food consumption patterns to 2050 at the global level; most projections in this area focus at the national level (Bhalla et al., 1999). Only two food and agriculture focused studies have done so: the FAO World Agriculture Outlook towards 2030/2050 interim report (FAO, 2006b) and IFPRI's food supply and demand projections (Von Braun et al., 2005 using the IFPRI IMPACT model) (Table 4.9). Most studies and assessments agree that overall calorie availability continues to increase and dietary diversification continues following country and locale-specific pathways of nutritional transformation. Calorie availability levels in these studies tend to asymptotically reach maximum availability levels of 3,500-4,000 kcal per capita (Tables 4.10-4.11; Fig. 4.15-4.17).

- that the global consumption of meats and milk, fats, and sugars increases considerably, while consumption of roots and tubers, pulses, and cereals as food is stable or slightly declines.
- In regions with an average total daily consumption of less then 2500 kcal per capita (sub-Saharan Africa and South Asia) the situation slightly improves over time, but in 2050 the

average food intake is still significantly lower then in other regions;

- In regions with low access to calories, food consumption increases in general more in more globalizing worlds (A1b, B1 -- IPCC SRES scenarios; Policy First --GEO-3 UNEP; GO -- Millennium Ecosystem Assessment Global Orchestration scenario);
- In regions with high average total daily consumption the consumption remains stable or increases only slightly, with little or no differentiation between the scenarios;
- In middle-income regions (South East Asia, Central America, South America) food consumption slowly rises towards the level of OECD countries; with little differentiation across the scenarios
- differences in the consumption of animal products are much greater than in total food availability: both between regions, between scenarios and between years;
- food demand for livestock products more or less doubles in sub-Saharan Africa and South Asia from around 200 in 2000 to around 400 kcal/day by 2050; again with the highest values in globalizing scenarios. Consumption levels by 2050 can surpass 600 kcal/day in parts of Africa and South Asia;
- In most OECD countries with already high availability of kilocalories from animal products (1000 calories/capita/day or more) consumption levels are expected to barely change, while levels in South America and countries of the Former Soviet Union increase to OECD levels.

4.4.1.4 Implications for health

Changes in food demand to 2050 are expected to contribute to increased nutrition and human health. Dietary diversification will likely increase if urbanization and income growth proceed. On the other hand, obesity rates and associated diseases are expected to increase. Obesity is increasingly becoming a public health concern as it contributes to increased mortality through non-communicable diseases such as diabetes, hypertension, stroke, and cardiovascular diseases, among others. Factors responsible for increases in obesity include a mix of biological and ecological factors such as gene-mediated adaptation, increases in labor mechanization, urbanization, sedentary activities and lifestyle changes (Caballero, 2001). It is estimated that by 2020, 60% of the disease burden in developing countries will result from non-communicable diseases, further exacerbated because of obesity (Caballero, 2001).

4.4.2 Natural resources

The sustainable use and management of natural resources presents a critical factor for future agriculture. The development and adoption of appropriate AKST and management practices will be needed to ensure food security and agricultural livelihoods. One of the greatest challenges likely to continue facing global agriculture is resolving conflicts caused by growing competition for soil, water, and other natural resources on which agriculture depends (Antle and Capalbo, 2002). Conversely, the sustainable management of these natural resources will determine productivity in agriculture and food systems.

4.4.2.1 Water

Water availability for agriculture is one of the most critical factors for food security in many regions of the world, particularly in arid and semiarid regions in the world, where water scarcity has already become a severe constraint on food production (Rockstrom et al., 2003; CA, 2007). With increasing population, urbanization, changing diets and higher living standards water demand is increasing rapidly. Assuming the amount of potentially utilizable water does not increase, there will be less water available on a per capita basis. In 1989, approximately 9,000 m^3 of freshwater per person was available for human use. By 2000, that number had dropped to 7,800 m^3 and it is expected to decline to 5,100 m^3 per person by 2025, when the global population is projected to reach 8 billion. Already 1.2 billion people live in areas where water is physically scarce, and this number may double by 2050 (CA, 2007). The problem is becoming more urgent due to the growing share of food produced on irrigated land; the rapid increase of water use in industry and households; increasing water use for environmental and ecological purposes; and water quality deterioration (Rosegrant et al., 2002).

The last 50 years saw great investments in large scale, surface irrigation infrastructure as part of a successful effort to rapidly increase world staple food production and ensure food self-sufficiency. During this period, in many countries more than half of the public agricultural budget and more than half of World Bank spending was devoted to irrigation (Faures et al., 2007). Spending on irrigation reached a peak of over US$1 billion per year in the late 1970s (in constant 1980 US dollars) but fell to less than half that level by the late 1980s (Rosegrant and Svendsen, 1993). The irrigated area roughly doubled from 140 million ha in the 1960s to 280 million ha in 2003, primarily in Asia (FAO, 2006c). By contrast, irrigation in sub-Saharan Africa is applied to less than 4% of the total cultivated area. The agricultural sector is expected to remain the major water user accounting for 69% of the withdrawals and 84% of the consumptive uses.

Many projections agree that water will increasingly be a key constraint in food production in many developing countries, and call for the need to improve water management and increase water use efficiency (Seckler et al., 2000; Shiklomanov, 2000; Vörösmarty et al., 2000; Rosegrant et al., 2002; Bruinsma, 2003; World Water Assessment Program, 2006; CA, 2007). The assessments differ in their views on the best way forward. Scenario analysis conducted as part of the Comprehensive Assessment of Water Management in Agriculture (CA, 2007) indicates that growth in global water diversions to agriculture varies anywhere between 5 and 57% by 2050 depending on assumptions regarding trade, water use efficiency, area expansion and productivity growth in rain fed and irrigated agriculture (de Fraiture et al., 2007) (Figure 4.18). Trade can help mitigate water scarcity if water-scarce countries import food from water abundant countries (Hoekstra and Hung, 2005). Cereal trade from rain fed areas in the temperate zones (USA, EU, Argentina) to arid areas (Middle East) reduces current global irrigation water demand by 11 to 13% (Oki et al., 2003, de Fraiture et al., 2004); but political and economic factors may prove stronger drivers of agricultural systems than water (de Fraiture et al., 2004).

Enhanced agricultural production from rain fed areas and higher water productivity on irrigated areas can offset the need for the development of additional water resources (Molden et al., 2000; Rosegrant et al., 2002; Rockstrom et al., 2003). However, the potential of rain fed agriculture and the scope to improve water productivity in irrigated areas is subject to debate (Seckler et al., 2000; Rosegrant et al., 2002). Only 5% of increases in future grain production are projected to come from rain fed agriculture (Seckler et al., 2000). Over 50% of all additional grains will come from rain fed areas, particularly in developed countries, while developing countries will increasingly import grain (Rosegrant et al., 2002). Projected contribution to total global food supply from rain fed areas declines from 65% currently to 48% in 2030 (Bruinsma, 2003).

Currently, agriculture receives around 70% of total water withdrawal and accounts for 86% of consumption. Projections in growth of irrigated areas vary: 29% (Seckler et al., 2000); 24% (FAO, Bruinsma, 2003); and 12% (Rosegrant et al., 2002) (Table 4.12).The global irrigated area is expected to grow from 254 million ha in 1995 to between 280 and 350 million ha in 2025. However, towards 2050, the proportion of water used for agriculture is likely to decrease slightly, mainly at the expense of more intensive growth in other water demands such as environment, industry and public water supply. The regional water withdrawal and consumption shares for agriculture will vary as a function of stage of industrialization, climate and other management and governance factors. In many water scarce areas current per capita water consumption is unsustainable. Globally, water is sufficient to produce food for a growing and wealthier population, but continuance today’s water management practices will lead to many acute water crises in many parts of the world (CA, 2007).

While major tradeoffs will occur between all water using sectors, they will be particularly pronounced between agriculture and the environment as the two largest water demanding sectors (Rijsberman and Molden, 2001). Signs of severe environmental degradation because of water scarcity, over-abstraction and water pollution are apparent in a growing number of places and the adverse impacts of irrigation on ecosystems services other than food production are well documented (Pimentel and Wilson, 2004; MA, 2005a; Khan et al., 2006; CA, 2007). Reduction in ecosystem services often has severe consequences for the poor, who depend heavily on ecosystems for their livelihoods (Falkenmark et al., 2007). Aquifer depletion and groundwater pollution threaten the livelihoods of millions of small-scale farmers in South Asia; in response, various local initiatives to recharge groundwater and stop over-use have been developed (Shah et al., 2007).

4.4.2.2 Soils and fertilizers

Sustainable management of soil is vital to agricultural productivity and food security. Among the many driving forces that will affect soils and their utility in sustaining world agriculture are population growth, land use planning and policies, land development and growth and demands for agricultural products (Blum, 2001). These driving factors operate directly and interact in different ways to produce positive (sustainability) and negative effects (degradation) on soil. Soil degradation due to improper farming practices has had more devastating effects on soil quality in many developing countries than the industrialized world. While demand for food has risen with increasing population, the present productivity from the arable land of the developing world has not been able to support its increasing population. The challenge is highly likely to persist towards 2050.

At the global level, out of the total ice-free land area of 13.4×10^9 ha, only 4.9×10^9 ha are agricultural lands. The Food and Agriculture Organization Database (WRI, 1997; FAO, 2006c) has provided individual country assessments on quantity of arable land and other indicators for national and global assessments. Out of the agricultural lands, 3.2×10^9 ha are in developing countries, while 1.8×10^9 ha are in industrialized countries (FAO, 2003). Some (1.3×10^9 ha) of this area has been classified as low productivity. About half of the potentially arable land is actually cultivated, while remaining lands are under permanent pastures, forests and woodland (Scherr, 1999). In the future, feeding an increasing population will remain a challenge, particularly as per capita land availability decreases and soil degradation continues.

Population pressure and improper land use practices are expected to continue giving rise to soil degradation, manifesting itself through processes such as erosion, desertification, salinization, fertility loss. Especially in regions with low (average) fertilizer use, many fields have a negative soil nutrient balance. Although the fertilizer use projections show an increased use for sub-Saharan Africa, application rates remain too low to compensate losses and crop yields will therefore remain low. Some believe that land degradation will not be a major issue in food security for the future generations (Crosson, 1994; Rosengrant and Sombilla, 1997); others argue that it will be a major constraining factor for food production in the future (Brown and Kane, 1994; Hinrichsen, 1998).

Crops are highly depended on an adequate supply of nutrients, notably N, P and potassium (K). The use of mineral fertilizer has increased significantly over the last 50 years, from 30 million tonnes in 1960, to 70 million tonnes in 1970 to 154 million tonnes in 2005 (IFA, 2006). This increased use is one of the drivers behind the increase in crop yield over the last 50 years. About two third of the global N fertilizer is currently used in cereal production (Cassman et al., 2003). Fertilizer use is expected to increase by 188 million tonnes by 2030 (FAO, 2004a). The projections for 2030 indicate that approximately 70% of the increase in total crop production will stem from higher yields per ha and about 30% from expansion of harvested areas. The increased (and more efficient) use of fertilizers is one of the key drivers to attain these higher crop yields.

The use of mineral and organic fertilizers is very diverse between countries and regions (Palm et al., 2004; Bouwman et al., 2005; IFA, 2006). Nitrogen input varies from virtually nil to over 500 kg N per ha; with these differences likely to continue (Daberkow et al., 2000; Bruinsma, 2003; Bouwman et al., 2005). The use of fertilizers is expected to increase further in South and East Asia; in sub-Saharan Africa the present low application rates are projected to persist and seriously hamper crop production. Low application is caused by a range of factors, which without targeted policies and interventions are likely to persist. These factors include a weak crop response to fertilizers (e.g. limited water availability, poor soil conditions), unfavorable price relations between input and output, and low net returns (Kelly, 2006).

The increase in consumption of animal products is, next to population growth, one of the major causes of the increase of global fertilizer use. World meat consumption (and production) is expected to grow by 70% in the period 2000-2030 and 120% in the period 2000-2050 (FAO, 2006b). The production and consumption of pig and poultry meat is expected to grow at a much higher speed than of bovine and ovine meat. Over the last years there has been a major expansion in large scale, vertically integrated industrial livestock systems, and this development is expected to continue over the coming decades (Bruinsma, 2003). These systems can lead to concentration of manure; although manure is a valuable source of nutrients, concentrated spreading of manure leads to significant emissions, to air, soil and water.

4.4.3 Land use and land cover change

Growing demand for food, feed, fiber and fuel, as well as increasing competition for land with other sectors (e.g., human settlement, infrastructure, conservation, and recreation), drive the need for change in the use of land already dedicated to agricultural production, and often for additional land to be brought into production. The significance of the cumulative historical growth in demand for agricultural products and services is reflected in the fact that agriculture now occupies about 40% of the global land surface. There is also clear evidence that this enormous change in land use and land cover has brought about, and continues to bring significant impacts on local, regional and global environmental conditions, as well as on economic and social welfare. In turn, such impacts spur demand for specific types of improvements in agriculture. AKST can help mitigate negative outcomes and enhance positive ones.

In this context, AKST can be seen as playing a dual role in both shaping and responding to a dynamic balance of land use and land cover conditions that deliver specific mixes of agricultural and other goods and services. As human well-being needs and preferences evolve in different societies, so too will the goals and priorities for the development of new AKST. The relative scarcities of land in Japan and labor in the USA shaped their agricultural research priorities (Hayami and Ruttan, 1985). Global experience with rampant land degradation caused by inappropriate production practices that gave rise to degradation of land cover, migration and often further expansion of the agricultural frontier has driven the search for new knowledge on sustainable farming technologies and land management practices. Land use/cover change is a complex process with multiple factors and drivers acting synergistically. In the tropical study, deforestation was frequently driven by an interplay of economic, institutional, technological, cultural, and demographic factors (Geist and Lambin, 2004) (Fig. 4.19). There are numerous other studies that link environmental land cover change to socioeconomic factors (e.g. Hietel et al., 2005; Xie et al., 2005).

4.4.3.1 Global land cover and land use change

Current drivers. Globally, there are a small number of recurrent drivers of land use and land use change (Fig. 4.19): demographic; economic; technological; policy; and cultural. Yet, some factors play a decisive role in determining land use and thus land use change. For example, globally 78% of the increase in crop production between 1961 and 1999 was attributable to yield increases and 22% to expansion of harvested area (Bruinsma, 2003). While the pattern of yield increases outpacing increases in harvested area was true for most regions, the proportions varied. For example, 80% of total output growth was derived from yield increases in South Asia, compared to only 34% in sub-Saharan Africa. In industrial countries, where the amount of cultivated land has been stable or declining, increased output was derived predominantly through the development and adoption of AKST that served to increase yields and cropping intensities. Thus, the role of land use change and (adoption of) AKST has varied greatly between regions. Particularly in Latin America, land abundance has slowed the introduction of new technologies.

Projected global land cover and land use changes. Few global studies have produced long-term land cover and land use projections. The most comprehensive studies, in terms of land type coverage, are the Land Use and Cover Change Synthesis book (Alcamo et al., 2005), IPCC Special Report on Emissions Scenarios (SRES) (IPCC, 2000), the scenarios from the Global Scenarios Group (GSG) (Raskin et al., 2002), UNEP's Global Environment Outlook (UNEP, 2002), the Millennium Ecosystem Assessment (MA, 2005a) and some models from Stanford University's EMF-21 Study of the Energy Modeling Forum (e.g., Kurosawa, 2006; van Vuuren et al., 2006). Recent sector specific economic studies have also contributed global land use projections, especially for forestry (Sands and Leimbach, 2003; Sathaye et al., 2006; Sohngen and Mendelsohn, 2006; Sohngen and Sedjo, 2006) (Fig. 4.20). Note that some scenario exercises are designed to span a range of diverse futures (e.g., SRES, GSG, and MA). For example, under the SRES scenarios agricultural land area could increase by 40% or decrease by 20% by 2050. Other scenarios focus on a single projected reference land-use characterization (e.g., GRAPE-EMF21, IMAGE-EMF21, GTM-2007). The more recent scenarios suggest greater agreement than under SRES or GSG, with agricultural land extent stable or growing by 10% by 2050.

In general, the recent scenarios for agricultural land use (cropland and grazing land) have projected increasing global agricultural area and smaller forest land area. The developments in forest land are, for the most part, the inverse of those for agriculture, illustrating the potential forest conversion implications of agricultural land expansion, as well as providing insights into current modeling methodologies. To date, long-term scenarios have not explicitly modeled competition between land use activities (Sands and Leimbach, 2003, is an exception). A new generation of global modeling is forthcoming that will directly account for the endogenous opportunity costs of alternative land uses and offer new more structurally rigorous projections (e.g., van Meijl et al., 2006; Hertel et al., 2007).

Projected changes in agricultural land are caused primarily by changes in food demand and the structure of production as defined by technology, input scarcity, and environmental condition. Scenarios with a greater extent of agricultural land result from assumptions of higher population growth rates, higher food demands, and lower rates of technological improvement that limit crop yield increases. Combined, these effects are expected to lead to a potentially sizeable expansion of agricultural land. Conversely, lower population growth and food demand, and more rapid technological change, are expected to result in lower demand for agricultural land.

There are very few published global scenarios of changes in urban areas (Kemp-Benedict et al., 2002; UNEP, 2004). All show a steep increase over the next decade, with about half estimating a stabilization of urban areas by 2025. Final total urban area is about 50% larger than in 1995. Although the total increase in area is relatively small, the implications for agriculture might be disproportionately large, since most of the urban growth is at the expense of high-value agricultural lands.

4.4.3.2. Regional and local changes

Regional and local drivers of land use change are even more complex than global drivers because a large number of direct drivers act in addition to global (indirect) drivers. For example, in cultivated systems, cultural, socioeconomic, and educational background as well as expectations, perceptions, preferences, and attitudes toward risk of farmers and farm households can play significant roles in shaping land use choices.

Tropical deforestation depicts the connectedness of multiple drivers. In the humid tropics, deforestation is primarily the result of a combination of commercial wood extraction, permanent cultivation, livestock development, and the extension of overland transport infrastructure (e.g. Strengers et al., 2004; Verbist et al., 2005; Busch, 2006; Rounsevell et al., 2006). However, regional variations exist. Deforestation driven by swidden agriculture (see 4.5.1.2) is more widespread in upland and foothill zones of Southeast Asia than in other regions. Road construction by the state followed by colonizing migrant settlers, who in turn practice slash-and-burn agriculture, is most frequent in lowland areas of Latin America, particularly in the Amazon Basin. Pasture creation for cattle ranching is causing deforestation almost exclusively in the humid lowland regions of mainland South America. Expansion of small-scale agriculture and fuelwood extraction for domestic uses are important causes of deforestation in Africa (Geist and Lambin, 2002; FAO, 2006b) and Latin America (Echeverria et al., 2006). Recently, two new land use types that are partly related to new drivers have emerged: bioenergy production (see 4.4.5.4) and soybean expansion driven by international markets, but also by the development of GMOs has rapidly become a major threat in Latin America (see Box 4.3).

The range of combinations of factors is not infinite, and single-factor causes are rare (Reid et al., 2006). A significant share of land use changes involves lifestyle choices and shifting consumption patterns; governance; global markets and policies. Underlying causes often have a strong influence on local land use and cover changes. In the same way land use alters, in multiple ways agricultural production and AKST.

[Insert Box 4.3]

At the global scale, soybean is one of the fastest expanding crops; in the past 30 years planted area more than doubled (FAO, 2002b). Of the world's approximately 80 million ha, more than 70% are planted in the USA, Brazil and Argentina (Grau et al., 2005). Argentina's planted area increased from less than a million ha in 1970 to more than 13 million ha in 2003 (Grau et al., 2005). Soybean cultivation is seen to represent a new and powerful force among multiple threats to biodiversity in Brazil (Fearnside, 2001). Deforestation for soybean expansion has, e.g., been identified as a major environmental threat in Argentina, Brazil, Bolivia and Paraguay (Fearnside, 2001; Kaimowitz and Smith, 2001). In part, area expansion has occurred in locations previously used for other agricultural or grazing activities, but additional transformation of native vegetation plays a major role. New varieties of soybean, including glyphosate-resistant transgenic cultivars, are increasing yields and overriding the environmental constraints, making this a very profitable endeavor for some farmers (Kaimowitz and Smith, 2001). Although until recently, Brazil was a key global supplier of non-GM soya, planting of GM soy has been legalized in both Brazil and Bolivia. Soybean expansion in Brazil increased; as did research on soybean agronomy, infrastructure development, and policies aimed at risk-reduction during years of low production or profitability (Fearnside, 2001). In Brazil alone, about 100 million ha are considered to be suitable for soy production. If projected acreage in Argentina, Brazil and Paraguay are realized, an overproduction of 150 million Mg will be reached in 2020 (AIDE, 2005).

Global forces are the main determinants of land use change, as they amplify or attenuate local factors (Lambin et al., 2001). Less visible but of no lesser importance is the build-up of small impacts at lower levels of the spatial and temporal scales to generate impacts at higher levels; cumulative impacts are caused by incremental impacts at the individual level and are felt usually after some period of time at the regional or even the national level. The issue of scale is implicated in these and similar instances and makes the use of "scale-sensitive" analytical approaches imperative. Multiscale efforts bring global, regional, and local studies together (e.g. MA, 2005ab).

Many recent scenarios include land cover and land use changes, and many of those include explicit information on the main land use drivers. The scenarios also acknowledge the complexity of environmental, social, and economic drivers of land use change. However, due to lack of data, a limited subset of drivers is included in the modeling efforts. The dynamics of land use (and thus of land cover) are largely governed by human (e.g., policy and socioeconomic) factors, that are well-documented as indirect drivers (see 4.2), but poorly represented as direct drivers. Important drivers to consider for land use dynamics are: the perceptions and values of local stakeholders land resources, its goods and services; land tenure and property rights and regulations; the development and adoption of new sources of AKST; and urban-rural connections.

4.4.4 Climate variability and climate change

Agricultural systems are already adapting to changes in climate and climate variability in many part of the world. This is in particular the case in arid areas. The IPCC concluded in its latest assessment that it is very likely that humans caused most of the warming observed during the twentieth century (IPCC, 2007a). The report also indicates that future climate change is to be expected, as a function of continuing and increasing emissions of fossil fuel combustion products, changes in land use (deforestation, change in agricultural practices), and other factors (for example, variations in solar radiation). Changes in climate will not only manifest themselves in changes in annual means (precipitation, temperature) but also in changes in variability and extremes.

4.4.4.1 Driving forces of climate change.

A set of scenarios (IPCC Special Report on Emissions Scenarios- SRES) was used to depict possible emission trends under a wide range of assumptions in order to assess the potential global impact of climate change (IPCC, 2000). Subsequent calculation showed that these scenarios resulted in atmospheric concentrations of CO_2 of 540–970 parts per million in 2100 compared with around 370 parts per million in 2000. This range of projected concentrations is primarily due to differences among the emissions scenarios. Model projections of the emissions of other greenhouse gasses (primarily CH_4 and N_2O) also vary considerably by 2100 across the IPCC-SRES emissions scenarios. The IPCC scenarios are roughly consistent with current literature – with the majority of the scenarios leading to 2100 emissions of around 10-22 GtC (Van Vuuren and O'Neill, 2006) (Fig. 4.21) with projections by the IEA-2006 World Energy Outlook in the middle of this range. The IPCC-SRES scenarios do not explicitly include climate policies. Stabilization scenarios explore the type of action required to stabilize atmospheric greenhouse gas concentrations (alternative climate policy scenarios may look into the impact of a particular set of measures; or choose to peak concentrations). Ranges of stabilization scenarios giving rise to different stabilization levels are compared to development without climate policy (Fig. 4.22) (IPCC, 2007c). The ranges in emission pathways result from uncertainty in land use emissions, other baseline emissions and timing in reduction rates.

4.4.4.2 Projections of climate change.

IPCC calculations show that different scenarios without climate policy are expected to lead to considerable climate change: the global mean surface air temperature is expected to increase from 1990 to 2100 for the range of IPCC-SRES scenarios by 1.4 to 6.4 C° (IPCC, 2007a) (Fig. 4.23). The total range given above is partly a consequence of differences in emissions, but also partly an impact of uncertainty in climate sensitivity, i.e. the relationship between greenhouse gas concentration and the increase in global mean temperate (after equilibrium is reached). Over the last few years, there has been a shift towards expressing the temperature consequences of stabilization scenarios more in terms of probabilistic expressions than single values and/or ranges. A 50% probability level for staying below 2^oC corresponds approximately to 450 ppm CO_2-eq, while for 2.5^oC the corresponding concentration is around 525 ppm CO_2-eq. Similarly, a scenario that would lead to 2^oC warming as the most likely outcome could also lead to a 0.9 to 3.9 ^oC warming (95% certainty). Handling uncertainty therefore represents an important aspect of future climate change policy. Costs of stabilization increase for lower concentration levels, and very low concentration levels, such as 450 ppm CO_2-eq may be difficult to reach (IPCC, 2007c).

Combining the current scenarios with climate policy and the expected temperature increase for different greenhouse gas levels shows that the former would decrease the lower bound of the expected temperature increase to about 0.5-1.0 °C above the 1990 level (i.e. based on an insensitive climate system and using a strong climate policy scenario) (Van Vuuren et al., 2006). This implies that although these values may be uncertain, climate change is very likely. High rates of temperature change are in fact most likely to occur in the first half of the century as a result of climate system inertia, the limited impacts of climate policy and lower sulfur emissions. The latter are currently having a cooling effect on the atmosphere. Whereas the computation of global mean temperature is uncertain, the patterns of local temperature change are even more uncertain (Fig. 4.24) (IPCC, 2007a).

For precipitation, climate models can currently provide insight into overall global and regional trends but cannot provide accurate estimates of future precipitation patterns in situations where the landscape plays an important role (e.g., mountainous or hilly areas). A typical result of climate models is that approximately three-quarters of the land surface has increasing precipitation. However, some arid areas become even drier, including the Middle East, parts of China, southern Europe, northeast Brazil, and west of the Andes in Latin America. This will increase water stress in these areas. In other areas rainfall increases may be more than offset by increase in evaporation caused by higher temperatures.

Although climate models do not agree on the spatial patterns of changes in precipitation, they do agree that global average precipitation will increase over this century. This is consistent with the expectation that a warmer atmosphere will stimulate evaporation of surface water, increase the humidity of the atmosphere and lead to higher overall rates of precipitation. An important factor for agriculture is also the changes in inter-year variability, but while some report important increases in this factor, this is still very uncertain (see IPCC, 2007a). Climate change may also affect agriculture if it causes substantial melting of glaciers that feed major rivers that are used for irrigation. Without additional storage to capture increased summer runoff, more water will flow unused to the ocean, leading to water scarcity in the drier months (see IPCC, 2007a).

4.4.4.3 The potential impact of climate change on future agricultural yields.

The impacts of climate change on agriculture have been assessed by IPCC (IPCC, 2007b). In fact, two combined effects have to be accounted for: the impacts of climate itself and the rising atmospheric CO_2 concentration. Increased concentrations of CO_2 can increase yields and make plants more stress-resistant against warmer temperatures and drought (although the extent to which this occurs is uncertain, and depends on crop type). Climate change can lead to both increases and decreases in yields, depending on the location of changes of temperature and precipitation (climate patterns) and the crop type (Parry et al., 1999; Alcamo et. al., 2005). A crucial factor is whether farmers are able to adapt to temperature increases by changing planting dates or crops, or crop varieties (Droogers, 2004; Droogers and Aerts, 2005).

The preponderance of global agricultural studies (Adams et al., 1999; Parry et al., 1999, Fischer et al., 2001) shows that climate change is not likely to diminish global agricultural production by more than a few percent, if at all, by 2050; some regions may benefit (i.e., North America, Europe) and some regions may suffer (i.e., the tropics). Any losses would be on top of substantial gains in world production (which could be 55% greater than current by 2030). As another indicator of this trend, a small but growing suite of modeling studies generally predict that world crop (real) prices are likely to continue to decline through the first 2-3^{o}C of warming before increasing with additional warming. Hence, 2-3^{o}C of warming appears to be a crucial threshold for crop prices.

While the global situation looks manageable, there are reasons for serious concern at regional levels. The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), reported that a number of models simulate the potential production of temperate crops (wheat, maize, rice) to absorb 2-3^{o}C of warming before showing signs of stress (Easterling and Apps, 2005). More recent assessment work found that agronomic adaptation extends the threshold for warming to beyond 5^{o}C for those crops (Fig. 4.25). Existing tropical crops exhibit immediate yield decline with even slight warming (Fig. 4.25) because they are currently grown under conditions close to maximum temperature tolerances. Adaptation gives tropical regions a buffer of approximately 3^{o}C of warming before yields of wheat, maize and rice decline below current levels.

Two regions that are likely to experience large negative impacts of climate change on agricultural production are Asia and Africa. Studies indicate that rice production across Asia could decline by nearly 4% over this century. In India, a 2^{o}C increase in mean air temperature could decrease rice yield by about 0.75 tonnes ha^{-1} and cause a decline in rain fed rice in China by 5 to 12%. Sub-Saharan Africa could lose a substantial amount of cropland due to climate change-induced land degradation. Based on results from one climate model (HadCM3), as many as 40 food-insecure countries of sub-Saharan Africa may lose an average of 10 to 20% of their cereal-production potential due to climate change. Whether such declines are problematic depends on possibilities for trade and responses from agronomic research. However, some studies suggest that the impacts of climate change within a region are likely to be extremely heterogeneous, depending on local conditions. Several crop and livestock systems in sub-Saharan Africa that are highly vulnerable may experience severe climate change (Thornton et al., 2006). These include the more marginal mixed (crop-livestock) and pastoral systems in parts of the Sahel, East Africa, and southern Africa. In some areas, growing seasons may contract, and crop and forage yields may decline substantially as a result (Jones and Thornton, 2003). Vulnerable households in such places will need to adapt considerably if food security and livelihoods are to be preserved or enhanced.

While most studies still focus on changes in means, in fact changes in variability and extreme weather events may be even more important for agriculture than the changes in means. For instance, changing the frequency of dry years may seriously affect agriculture in certain areas. Climate change will not be a major challenge to agricultural production systems in temperate regions until well into this century. In the tropics, especially Asia and Africa, however, even with adaptation, food (especially grain) production may decline with only modest amounts of climate change. Modeling studies also suggest that real food prices will reverse their long-term decline at about 3^{o}C of warming, resulting in increasing prices thereafter.

4.4.4.4 Climate change mitigation and agriculture.

According to several assessments, agriculture and forestry can play a significant role in mitigation policies (FAO, 2006d; IPCC, 2007c) as it is also a major source of greenhouse gases (GHGs) (Fig. 4.26). This particularly holds for methane (CH_4) and nitrous oxide (N_2O), both with higher global warming potential than CO_2. Methane emissions are primarily caused by livestock production and flooded rice fields, while N_2O emissions are related to the use of organic and inorganic N fertilizers. Finally, CO_2 emissions are also caused by land use changes and agricultural practices.

Several studies have found that reducing non-CO_2 greenhouse gases from agriculture and CO_2 emissions from land use change can effectively reduce emissions. These multigas emissions reduction scenarios are able to meet climate targets at substantially lower costs for the same targets as was found in the EMF-21 study (IPCC, 2007c; Lucas et al., 2007). A variety of options exists for mitigation of GHG emissions in agriculture (Table 4.13). Effective options are improved crop and grazing land management, restoration of drained organic (peat) soils and restoration of degraded lands (IPCC, 2007c). Lower, but still significant mitigation is possible with improved water and rice management, conservation plots, land use change and agroforestry. The relevant measures depend highly on the carbon price, i.e., the market price for reducing GHG emissions. At low carbon prices, profitable strategies are minor changes in present production systems, such as changes in tillage, fertilizer application, livestock diet formulation and manure management. Higher prices could allow the use of costly animal feed-based mitigation options, or lead to changes in land use. Effective options however, depend in general on local conditions, including climate, agricultural practices and socioeconomic circumstances; there is no universally applicable list of effective options (IPCC, 2007c).

4.4.4.5 Consequences for AKST

Based on the discussion above, challenges for AKST in the field of agriculture consist of:

- Adaptation. As climate change is likely to result in at least 2^{o}C warming by the end of the century, and possibly >6^{o}C, agricultural systems need to adapt to climate change. This will be even more important in developing countries than in developed countries. Effective adaptation should focus on extremes as well as changes in means. AKST will need to create less vulnerable system and AKST actors will need to provide information on options for adaptation.
- Mitigation. Agriculture is also a major source of emissions. Although some technologies already exist to reduce CH_4 and N_2O emissions from agriculture, further progress is required to reduce emissions beyond 2020.

4.4.5 Energy

4.4.5.1 Trends in world energy use

There are very important relationships between energy and agriculture. The industrial revolution led to improved access to energy services based on fossil energy (e.g. Smil, 1991) and allowed for higher production levels per unit of land or labor in the agriculture sector. In turn, this allowed for a dramatic increase in the global population, a (related) decrease in arable land per capita, and a movement of the work force away from agricultural production.

Global energy use during the last century increased by about 2.5% annually, with a clear transition in consumption of primary sources from coal to oil to natural gas (Fig. 4.27). The large majority of current scenarios project a continuation of these trends. Global energy use continues to grow; in the first decades growth will primarily be based on fossil fuel consumption. Primary energy consumption projections can be found in the IPCC-SRES scenarios, World Energy Outlook (IEA, 2002; IEA, 2004) United States Department of Energy (US DoE, 2004) and the OECD environmental outlook (OECD, 2006). The differences between the different scenarios (Fig. 4.28) can be explained in terms of underlying economic growth assumptions and assumed emphasis on dematerialization. In nearly every scenario, the largest contribution to global energy increase comes from developing countries. The scenarios also share the projection that in 2030 the majority of global energy use needs come from fossil fuels. Nevertheless, clear differences in the energy mix may occur. The most important determinants are the stringency of future climate policy, differences in technology expectation, and assumed societal preferences. Studies also indicate that global energy consumption could increase by 25-100% in the next 30 years, a huge challenge to production. In the longer term, the energy mix may diversify in many different ways, ranging from almost total coal use (e.g. IPCC's A2 scenario) versus nearly total renewable energy (e.g. under stringent climate policy scenarios). The growing awareness of both the "global warming" and "peak oil" issues is finally forcing decision makers and the general public to put energy high on policy agendas.

4.4.5.2 The relationship between energy use and agriculture

The food and energy systems have historically interacted in several ways (e.g. Pimentel and Pimentel, 1979; Pimentel, 1980; Stanhill, 1984; Leach et al., 1986; Smil, 1987, 1991a; Stout, 1991, 1992). As indicated above, a dominant trend during the last century was increasing energy use leading to continuous increasing productivity of agricultural land. The implication of this trend can be seen when comparing the performance of industrialized and developing countries, in the relationship between energy inputs and yields (Giampietro, 2002). Agricultural production represents only a small part of global energy consumption. However, energy consumption not only occurs in the production stage. In the EU, the food supply chain used nearly 4 EJ of primary energy, or about 7% of total consumption (Ramirez-Ramirez, 2005). Within this total, nearly 45% is consumed by the food processing industries, around 25% by agriculture, around 10-15% by transport of foodstuffs and fodder and the remainder (5-10% each) for fertilizer manufacturing and transport of agricultural products.

The rapid population growth expected in developing countries (is likely to have important implications for the relationship between energy use and agriculture. Increasing food production will require a strategy of intensification and consequently a further increase in the consumption of fossil energy for agricultural production. As this process is likely to coincide with structural changes in the economy, lower labor supply in agriculture will also lead to further intensification. As a result, systems in developing countries are expected to see considerable growth in energy consumption for food processing. Overall, this is likely to lead to further growth in agriculture energy demand, although at a lower rate than overall growth of energy consumption.

One additional factor is the role of energy prices; current high prices for oil and natural gas do have consequences, primarily on fertilizer use and transport, for agriculture. Projections for energy prices in the next decades have been revised upward in most reports (e.g. IEA, 2006), but still a considerable uncertainty remains. Higher projections are found for those projections that take into account further increased demand in Asia and restrictions (e.g., limited investments, depletion) on increases in supply.

4.4.5.3. Bioenergy

Climate change, energy security and the search for alternative income sources for agriculture have increased interest in bioenergy as an alternative fossil fuel. Many scenario studies, with and without climate policy constraints, project a strong increase in the use of bioenergy, with major implications for future agriculture (see IPCC, 2007c). However, at the same time there is a strong debate on the implications of bioenergy use; the outcome of this debate will critically influence its future use (see also Slesser and Lewis, 1979; Smil, 2003; Smeets and Faay, 2004; Hoogwijk et al., 2005). Crucial controversies with respect to bioenergy use include whether bioenergy can provide net energy gains, reduce greenhouse gas emissions, cost-benefit ratio, environmental implications and the effects on food crop production (Box 4-4).

The potential for bioenergy production typically is based on land use projections (e.g. Smeets and Faaij, 2004). From a technical perspective, bioenergy could supply several hundred exajoules per year from 2050 onwards compared to a current global energy use of 420 EJ of which some 10% is covered by bioenergy already, predominantly in the form of traditional bioenergy. The major reason for the divergence among different estimates of bioenergy potentials is that the two most crucial parameters, land availability and yield levels in energy crop production, are very uncertain. The development of cellulosic ethanol could lead to much higher yields per hectare (see Chapter 6). Another factor concerns the availability of forest wood and agriculture and forestry residues. In particular, the use of forest wood has been identified as a potentially major source of biomass for energy (up to about 115 EJ yr^{-1} in 2050) but very low estimates are also reported.

[Insert Box 4.4]

In evaluating the information on bioenergy potential, the costs, land requirements and the environmental constraints will determine whether biomass can be transformed into a viable net energy supply to society. Hence, the drivers are 1) population growth and economic development; 2) intensity of food production systems, 3) feasibility of the use of marginal/degraded lands, 4) productivity forests and sustainable harvest levels, 5) the (increased) utilization of biomaterials, 6) limitations in land and water availability. Scenario studies evaluate bioenergy mostly in terms of competition against energy carriers and thus give an indication of demand. Bioenergy use in various energy scenarios varies widely (Fig. 4.29). In these scenarios, use of bioenergy varies between 0 and 125 EJ yr^{-1} in 2030 and 25 and 250 EJ in 2050.

Implications for agriculture. Based on the discussion above, one possible outcome in this century is a significant switch from fossil fuel to a bioenergy-based economy, with agriculture and forestry as the leading sources of biomass. (FAO, 2006f). The outcomes can be unclear. One can envision the best scenarios in which bioenergy becomes a major source of quality employment and provides a means through which energy services are made widely available in rural areas while it gives rise to environmental benefits such as carbon reductions, land restoration and watershed protection. One the other hand, one can envision worst case scenarios in which bioenergy leads to further consolidation of land holdings, competition for cropland and displacement of existing livelihoods while it incurs environmental costs of decreased biodiversity and greater water stress (World Bank, 2005a).

Currently, bioenergy fuel use is rapidly expanding in response to government policies and subsidies, high energy prices and climate policy initiatives. In this context, bioenergy can also offer development opportunities for countries with significant agricultural resources, given lower barriers to trade in biofuels. Africa, with its significant sugar cane production potential, is often cited as a region that could profit from Brazil's experience and technology, though obstacles to realizing it (infrastructure, institutional, etc.) should not be underestimated. Obviously, transporting bioenergy across the world would become a major new challenge as well.

While there is controversy on the size of the effect, major bioenergy use certainly affects environmental resources (e.g. water, land and biodiversity. Therefore, it is very important to understand and quantify the impacts and performance of bioenergy systems for determining how successful the use of biomass for energy (and materials) is, how the benefits of biomass use can be optimized and how negative impacts can be avoided.

4.4.5.5 Most important implications for AKST

Large scale use of bioenergy could transform the agricultural system into a net producer of energy. As indicated in latter parts of this assessment, the potential of bioenergy is such that it requires data and information tools for decision making based on solid technical, social and economic knowledge. The intrinsic interdisciplinary character of bioenergy means that implications for AKST will encompass areas as varied as agricultural and energy policies, natural resources and biodiversity protection and rural development. Interaction between the agricultural sector and the energy, environment and indutrial sectors as well as sustainability protocols will be vital for succesful bioenergy use. From the overall bioenergy chain point of view, it is important to monitor and further improve systems with respect to 1) implications for soil and water; 2) supply of agricultural inputs (fertilizer, fuel, machinery); 3) increasing overall efficiency and 4) minimizing effects on biodiversity.

4.4.6 Labor

4.4.6.1 Trends in employment of labor in agriculture

Hardly any information on labor projections is found in the currently published scenario studies. Therefore, historical trends are used here to assess future trends. Over the last 10 years, there has been a global decline in the relative share of employment in agriculture: from 46% in 1994 to 43% in 2004. However, agriculture continued to be the largest source of employment (around 60%) in sub-Saharan Africa, South Asia and East Asia. At the same time, the share of agriculture in total employment in developed countries is small: only 4% in 2004 and likely to decline further. As the trends observed above (both in time – and across regions) are global, they are projected to continue, leading to ever lower numbers employed in agriculture. This decline underlies many of the economic projections of future scenarios. The share of agriculture in total employment will decrease dramatically in developing countries and decline more slowly in industrialized countries.

4.4.6.2 Labor productivity in agriculture

Future trends in labor productivity are expected to increase, based on the evidence over the past decade. Labor productivity in the world increased by almost 11% over the past ten years (ILO, 2005). This increase was primarily driven by the impressive growth in labor productivity in Asia and the industrialized economies. The transition economies have also contributed to the world's recent growth in productivity. The Latin America and the Caribbean realized productivity increase of just over 1% over 10 years, mainly due to the economic crisis in the beginning of the century. There were no changes in the Middle East and North Africa, while sub-Saharan Africa experienced declining productivity on average.

Similar trends in future productivity are anticipated. Based on historical data for 71 countries from 1980 to 2001, agricultural GDP per worker in sub-Saharan Africa on average grew at a rate of 1.6% per year slower than for countries in Asia, Latin America, the transition economies and the Mediterranean countries (Gardner, 2005). Agricultural GDP per laborer and national GDP were positively correlated based on data for 85 countries for 1960-2001. Within each of the regional grouping (Africa, Asia, and Latin America), the countries that grew fastest in national GDP per capita also grew fastest in agricultural GDP per worker, with a few notable exceptions, e.g., Brazil (Gardner, 2005; ILO, 2005). Levels of productivity in Latin America are the highest in the developing world, followed by the Middle East and North Africa and the transition economies. East Asia, South Asia and sub-Saharan Africa, where the majority of the poor live, have considerably lower average labor productivity (World Bank, 2004a).

An increase in agricultural labor productivity has a more significant direct effect on poverty reduction than increases in total factor productivity (ILO, 2005) and there are indirect effects on poverty from changes in food production and food prices (Dev, 1988; ILO, 2005).

Productivity gains can lead to job losses, but productivity gains also lead to employment creation, since technology also creates new products and new processes; hence, the increasing trends in productivity could lead to expanded employment in other sectors such as information and communications technologies (ILO, 2005).There will be a critical need to provide adjustment strategies (financial assistance and retraining) for displaced workers and to ensure growth in the long-term.

While in the short run, increased productivity might affect growth of employment in agriculture adversely, this outcome may not hold in the long run. Economic history shows that over the long-term, the growth of output, employment and productivity progress in the same direction (ILO, 2005). However, social costs in the short-term can be high.

4.4.6.3 Gender perspectives in agricultural labor

As agriculture and food systems evolve over the next decades, gender issues and concerns are highly likely to continue to be central to AKST development, at least in the developing countries where women have played a significant role in traditional agricultural production. Over the years improvements in agricultural technologies have seldom been targeted as recipients of improved technologies. Yet there are more women working in agriculture than men, e.g., women in rural Africa produce, process and store up to 80% of foodstuffs, while in South and South East Asia they undertake 60% of cultivation work and other food production (UNIFEM, 2000).

Employment of female vis-à-vis male workers is likely to decline in the future as women obtain more employment in other sectors. Historically, there has been a global decline in the world over the last 10 years (47% in 1994 to 43% in 2004). While this may imply further declines in the future, it may also be true that female employment in agriculture will increase as a result of changing production patterns.

The increasing participation of women in subsistence production in agriculture is highly likely to continue facilitating male out-migration to urban areas and to other sectors such as mining and commercial farming (at lower costs to society than would otherwise be possible). The greater number of men moving out of the agricultural sector is highly likely to continue. A slightly increasing feminization of the agricultural labor force in most developing countries may reflect the fact that women are entering into high value production and processing and thus less likely to abandon their agricultural ventures (Mehra and Gammage, 1999).

4.5 Existing Assessments of Future Food Systems, Agricultural Products and Services

4.5.1 Assessments relevant for changes in food systems

Existing assessments provide information how agricultural and food systems might change in response to the changes in the direct and indirect drivers discussed in the previous subchapters (note that the outcomes of these assessments may be compared to the reference scenario presented in Chapter 5). Over the past 50 years, there have been at least 30 quantitative projections of global food prospects (supply and demand balances). We have reviewed several recent global assessments (see 4.2) that provide information relevant for future agriculture and food systems, either directly (i.e. assessments with an agricultural focus) or indirectly (other assessments that include agriculture). Important organizations that provide specific agricultural outlooks at the global scale include the Food and Agriculture Organization of the United Nations (FAO), the Food and Agriculture Policy Research Institute (FAPRI), some of the research centers of the Consultative Group on International Agricultural Research (CGIAR) such as the International Food Policy Research Institute (IFPRI), the OECD, and the United States Department of Agriculture (USDA). Other food projection exercises focus on particular regions, such as the European Union. Finally, many individual analyses and projections are implemented at the national level by agriculture departments and national level agricultural research institutions.

In subchapter 4.2, we introduced a selection of global assessments and discussed their objectives and use of scenarios. None of these -- IPCC's Assessment Reports (IPCC 2001, 2007abc), UNEP's Global Environment Outlooks (UNEP 2002, 2007; RIVM/UNEP, 2004), the Millennium Ecosystem Assessment (MA, 2005a), IFPRI's World Food Outlook (Rosegrant et al., 2001), FAO's World Agriculture AT 2015/2030 (Bruinsma, 2003) and IWMI's Comprehensive Assessment of Water Management for Agriculture (CA, 2007)-- address the full spectrum of the food system and AKST from the perspective of a range of different plausible futures (Table 4.14). This is not surprising given the different objectives of these assessments (see 4.2), but it does imply that an assessment that meets development objectives cannot be met solely through analyzing earlier assessments. Although the projections provided by FAO and IFPRI address agricultural production and services to some degree, the attention paid to AKST elements is relatively limited. This highlights a need for new work to integrate plausible futures with regard to the interactions between driving forces and food systems while addressing AKST in more detail. Analysis of recent scenarios exercises indicates that while some elements related to the future of food systems are touched upon, the focus of these exercises is more on production and consumption than on the distribution component of food systems. Most studies addressed qualitative and quantitative production indicators, and provide assumptions on yields for various crops, area under certain crops, input use or exchange mechanisms. Consumption as well as access to food (including affordability, allocation and preference), has often been addressed through modeling food demand in different scenarios. For example, assumptions regarding allocation of food through markets are made indirectly under different scenarios by assuming whether and how well markets and governance systems function. Food preferences are usually covered in a more qualitative manner through assumptions made about changes due to various cultural and economic factors (Zurek and Henrichs, 2006).

The area least covered by the reviewed scenario exercises is food utilization (Zurek and Henrichs, 2006). The IFPRI and MA exercises calculated the number of malnourished children under each scenario (a very basic indicator of hunger and whether nutritional standards are met), but nutritional outcomes under different diets and their possible changes are seldom addressed. Little, if anything, is said in any of the exercises concerning food safety issues or the social value of food, both of which can have important consequences for food preferences. The MA does quantitatively assess certain health indicators; these could be used to give a further indication on human nutritional status in different scenarios. Further in-depth research is needed on some of the specific food systems variables and their changes in the future, specifically for those related to food utilization, as well as a number related to food accessibility.

4.5.2 Indication of projected changes

Food systems can be classified into 1) production and 2) distribution and delivery. Most assessments discussed here concentrate much more on the first. The Millennium Ecosystem Assessment, the global food projections by IFPRI and the Agriculture towards 2015/30 study by FAO provide the most relevant information in the context of the IAASTD (see Table 4.9). It should be noted the Millennium Ecosystem Assessment used four diverging scenarios (Global Orchestration, Technogarden, Adapting Mosaic and Order from Strength). Together these four scenarios cover a broad range of possible outcomes for the development of different ecological services.

4.5.2.1 Changes in production systems

Agricultural production systems can be classified in different ways. A system based on two key dimensions of cultivated systems: an agroecological dimension and an enterprise/management dimension was proposed for MA (Cassman et al., 2005). Such an approach can easily be coupled to both biogeographic factors and long-term trends in agricultural management, and hence provides a very useful structure to assess potential future changes in production systems.

It provides a basis to integrate socioeconomic analysis (looking at the economic and social viability of agricultural systems) and biophysical analysis (looking at the environmental consequences). Unfortunately, however, the different existing assessments generally tend to analyze information at a much more aggregated scale, because data is lacking, particularly on agricultural management in developing countries.

General trends. In the system proposed above a useful distinction can be made along the management axis in the degree of intensification. Such a distinction would include 1) intensive (or fully colonized) agroecosystems (e.g. producing crops, often in monocultures, intensive livestock and specialized dairy farms) (ii) intermediate (partially colonized) agroecosystems (e.g. pastoralism, agroforestry, slash and burn); and (iii) the exploitation of uncontrolled ecosystems (e.g. fishing in the ocean or in big rivers, hunting and gathering). From a human perspective, this distinction of intensification refers to an assessment of costs and benefits. Taking out products from an exploited ecosystem requires a degree of "investment" (e.g. tilling the soil, taking care of animals, preparing fishing nets), which needs to deliver an adequate return in terms of value. This distinction is relevant also from an ecological perspective. In the case of sustainable fishing, hunting and gathering, the basic structure of the ecosystem is preserved. In partial colonization, humans manage to produce crop plants and/or livestock at a density higher than that typical of natural ecosystems. Full colonization, finally, generates agroecosystems with very little in common with the natural ecosystem that they replace. Historically, there has been a trend towards intensification of agricultural systems, although in many areas extensive systems are also still common. In crop, livestock, forestry and fishery production systems, further intensification is projected to meet increasing demand worldwide. A natural consequence of the related increase in agricultural inputs (e.g. energy, fertilizers) will also be further pressure on natural ecosystems. Without intensification increasing demands would need to be met by further expansion.

Global crop production. Worldwide, numerous cropping systems can be distinguished based on agroecological parameters, cultivation and the type of crops grown. In terms of cultivation, these categories range from irrigated systems, to high external-input rain fed and low external-input rain fed systems, shifting cultivation and mixed crop and livestock systems. In time, a noticeable trend can be observed in many countries from low-input systems to high-input systems. This shift follows from an assessment of costs and benefits, weighing the costs of inputs against the increased yield levels. The shift to high-input systems had occurred in several regions of the world by the middle of the last century, but in other areas it has occurred during the last 40 years (e.g. the Green Revolution in Asia). A basic underlying driver of this shift is increasing global food demand as a result of increasing population (see 4.3.1 and 4.4.1). Low-input systems still provide a substantial share of total agriculture, in addition to providing livelihoods for hundreds of millions of resource-poor people in developing countries. For instance, shifting cultivation is the dominant form of agriculture in tropical humid and sub-humid upland regions, and low-input rain fed systems are still important in many parts of the world (FAO, 2002b).

All assessments provide relatively little information on trends in underlying production systems for food crops; the discussion is more on an aggregated crop level with most attention focused on cereals. Worldwide, cereals represent about two-thirds of the total crop production and the total harvested area. In all assessments, the production of cereals is expected to increase (Fig. 4.30). Interestingly, differences among the scenarios of these different assessments are very small. One underlying reason is that in all cases, the increase of global cereal production seems to be coupled to the increase in the global population. The increase in cereal production in the next few decades ranges from around 0.9% annually (lowest MA scenarios) to 1.3% (the IFPRI projection), which is slightly below the annual increase for the total crops production reported in these assessments. This number is, however, considerably lower than the increase in production over the past 30 years (around 2.1% and up to 3.1% annually in developing countries) (also the historic increase is nearly equal to the increase in population over the same period). These numbers are aggregated: for both the historic numbers and the projections there is a large variation at the regional and country scale, implying important trends in food trade and food security. Finally, it is important to note that in the time frame of the scenarios an increasing share of cereals will be used as animal feed to supply the very rapidly growing demand for livestock products.

There are two main sources of growth in crop production: 1) expansion of harvested land area and 2) yield increases. Globally, over the last three decades yield increases for cereals have provided about 70-80% of production growth, while harvested land expansion contributed about 20-30% of growth. In the scenarios developed by these assessments, contribution of expansion of harvested land to increase in cereal production ranged from as low as 5 to around 30%. The lowest numbers are reported for the MA scenarios that assume high levels of technology change (Global Orchestration and Technogarden); all other scenarios find values that are near, or somewhat below the historic values. The lower contribution to total production from the expansion of crop area can be attributed to increasing land scarcity and possibly the lower overall rate of production increase. A decreasing quality of land brought into production, however, could imply that a greater percentage of gains in total production will be attributable to crop area expansion than has historically been the case (as indicated in the MA). Even in the two scenarios with little global expansion of harvested land, a considerable expansion of arable land still occurs in Africa, Latin America and partly in Asia, but this is compensated for by a decrease of harvested area in temperate zones. In the other scenarios, the largest expansion also occurs in these regions. The yield growth in these scenarios is about 0.6-0.9% annually at a global level. Several factors contribute to this (reasons are reported in more detail in the FAO and IFPRI assessment than in the MA), including increased irrigation and shifts from low-input to high-input agriculture. In any case, the assumed yield growth in each of the scenarios is considerably below the historic rate of change. The suggested trends in expansion of agricultural land in tropical zones are controversial, with questions about how this expansion can happen in many parts of the tropics (particularly in Africa) in any meaningful way.

For total agricultural land (all crops), similar trends are reported, although the area expansion is somewhat higher than for cereals alone. Across the assessments, the area in crop production increases from 1.5 billion ha (or 11% of the earth's land surface) to 1.60 to 1.77 billion ha. As indicated by FAO, this expansion is within the scope of total land available for crop production. The fact that the assessments considered here agree on a rather flexible continuous response of the agriculture system to demand increases is interesting, as more skeptical views have also been expressed. An important implication, however, is further loss of the area available to unmanaged ecosystems.

Global livestock production. Livestock production systems differ greatly across the world. Confined livestock production systems in industrialized countries are the source of most of the world's poultry and pig meat production, and hence of global meat supplies (FAO, 2002b). Such large-scale livestock systems are also being established in developing countries, particularly in Asia, to meet increasing demand for meat and dairy products. Livestock production also occurs in mixed crop-livestock farming systems and extensive grazing systems. Mixed crop-livestock systems, where crops and animals are integrated on the same farm, represent the backbone of small-scale agriculture throughout the developing world. Globally, mixed systems provide 50% of the world's meat and over 90% of its milk, and extensive pasture and grazing systems provide about 20-30% of beef and mutton production. To date, extensive grazing systems in developing countries have typically increased production by herd expansion rather than by substantial increases in productivity, but the scope for further increases in herd numbers in these systems is limited. The share of extensive grazing systems is declining relative to other systems, due both to intensification and to declining areas of rangeland. Considering all food production systems together, livestock production is the world's largest user of land (about a quarter of the world's land), either directly for grazing, or indirectly through consumption of feed and fodder.

As incomes increase, demand for animal products increases as well. This trend, which has been empirically established in all regions, is assumed to continue in the scenarios of the three assessments considered here. As a result, meat demand is projected to increase at a greater rate than the global population. Changing dietary preferences also contribute to this increased demand in the scenarios. Interestingly, future meat production varies considerably more than future cereal production among the scenarios (Fig. 4.31). Assessments indicate similar growth rates for other animal products such as milk.

The increases in meat production will occur through a number of means, including changes that lead to intensified production systems, such as expansion of land use for livestock, and more efficient conversion of feed into animal products (Fig. 4.34). Both the MA and FAO assessments indicate that most of the increases in world livestock production will occur in developing countries; second, while scenarios differ in their projections of future pasture area, compared with crop land area most scenarios expect very little increase in pasture land. For grazing systems, this means that some intensification is likely to occur particularly in the humid-subhumid zones where this is feasible. Considerable intensification is likely in the mixed systems, with further integration of crop and livestock enterprises in many places. Strong growth is implied for confined livestock production systems; in the FAO scenario at least 75% of the total growth is in confined systems, although there are likely to be strong regional differences (e.g., less growth of these systems in Africa). This is a continuation of historic trends. The major expansion in industrial systems has been in the production of pigs and poultry, as they have short reproductive cycles and are more efficient than ruminants in converting feed concentrates (cereals) into meat. Industrial enterprises now account for 74% of the world's total poultry production, 40% of pig meat and 68% of eggs (FAO, 1996). At the same time, a trend to more confined systems for cattle has been observed, and a consequent rapid increase in demand for cereal- and soy-based animal feeds (these trends are included in the projections discussed in the previous subchapter) (see Delgado et al., 1999).

Finally, while there are good economic arguments for the concentration of large numbers of animals in confined systems, there can be significant impacts on surrounding ecosystems, something that is only recently started to be assessed in sufficient detail in agricultural assessments. The effects primarily involve N and P cycles. While some types of manure can be recycled onto local farmland, soils can quickly become saturated with both N and P because since it is costly to transport manure for long distances.

Forestry. The FAO assessment pays considerable attention to forestry and the outlook for forestry, but mostly in a qualitative way. The MA also considers the future of forestry, but focuses more on the extent of natural forests than the development of forestry as a production system (although some data is available). Overall, both assessments agree on that the general trend over the last decades of a decreasing forest resource base and an increasing use of wood products will continue.

Important driving forces for forestry include demographic, sociopolitical and economic changes, changes in extend of agricultural land, and environmental policy. Both population and economic growth affect forestry directly via an increase in demand for wood and indirectly via the impact on agricultural production. There is strong evidence that with rising incomes, demand for forest products increases, especially for paper and panel products. The increasing demand for wood products is also assumed in the scenarios of the FAO and MA (Fig. 4.35). The demand for industrial roundwood is expected to increase by about 20-80%. The lowest projection results from the Technogarden scenario (assumes a high efficiency of forest utilization in order to protect forests) while the highest projection results from the Global Orchestration scenario (reflecting the very high economic growth rate).

The use of wood products as a source of energy (fuelwood) is not expected to grow fast, and may even decline. The use of fuelwood is particularly important at lower incomes; wealthier consumers prefer and can afford other forms of energy. As a result, fuelwood consumption is a function of population growth (increasing fuelwood demand) and increased income (decreasing demand), with the net results being a small decline and rise over the next 30 years. The impact of environmental policies on forestry may be important: e.g., increasing protection of forests and strategies to mitigate climate change may both result in encouraging less deforestation and reforestation initiatives to offset energy related greenhouse gas emissions.

The resulting trends in forested areas are presented in the MA for forests as a whole. The MA scenarios mostly show a further decline in forest area, but at a much slower rate than historically. In fact, the slow global deforestation trend is a result of a net reforestation in temperate zones, and a net deforestation in tropical areas. The slower deforestation trend is a direct result of the lower rate of expansion of agricultural areas coupled with greater forest conservation efforts.

Fisheries. Potential trends in world fisheries are discussed in qualitative terms in the FAO assessment, while the MA provides some projection for world fish consumption. Both assessments indicate that production of wild capture fisheries is approaching (or has passed) its sustainable limits, indicating that no real increase is expected. This implies that any growth in production will need to come from aquaculture (which is already the fastest growing component of world fisheries; especially in developing countries). It should be noted, however, that currently aquaculture mostly relies on feed that is provided by wild capture fisheries and can also cause serious pollution. Further growth, therefore, relies on finding sustainable ways to increase aquaculture. The MA reports both more conservative views (supported by ecological models) and more optimistic models (supported by agroeconomic projections). The FAO assessment presents a similar open-ended view on the future of aquaculture, indicating growth is likely to occur, but provided sustainable sources for feed are found.

4.5.2.2 Changes in food distribution and delivery.

As indicated earlier, the amount of information on how other parts of the food system may change in the future is far less elaborated than the information on production systems. Based on the driving forces discussed earlier in this chapter, and the limited information found in the 3 assessments looked at here some trends may be hypothesized:

- Assessments expect agricultural trade to increase, as indicated earlier (see 4.3.1). These increases are most pronounced in the globalization scenarios (assuming a reduction of trade barriers) – but also occur in scenarios that assume a more regional focus as a result of increasing demand for agricultural products. Obviously, this trend may have very important implications for both commercial and small-scale farmers in developing countries. Another implication may be the increasing importance of multinational companies.
- As discussed earlier, urbanization is likely to continue in all scenarios. As a consequence, food will increasingly be available to consumers via retailers and supermarkets, a trend that represents a continuation of a major trend already taking place in developing countries (Reardon et al., 2003. This trend will slowly influence the importance of different actors in the food systems (see 4.4.1), although consequences are hard to assess. The role of farmers may, for instance, be very different in the MA's Global Orchestration scenario (with a strong market focus) than under the MA's Adaptive Mosaic scenario (in which farmers may successfully organize themselves). Important consequences of the trend towards retailers and supermarkets (and underlying urbanization) also include changes in diets (4.4.1), an increasing focus on production standards, demanding quality and safety attributes, and an increasing commercialization of up-stream production processes.
- There are direct relationships between the above discussed demographic trends and agricultural production processes as well. For instance, location in relation to urban centers affects access to markets for purchased inputs and the costs of such inputs often leading to confined agricultural in periurban zones (thus reinforcing trends towards the intensified systems discussed earlier). Confined production systems facilitate the management of nutrition, breeding and health (responding to the need for production standards), but do so at the cost of increased investment demand. There are economies of scale in the provision of such processing services and the associated product

marketing, and possibly in the supply of inputs (feed and feed supplements) and genetic material (e.g. day old chicks or semen). Again, this implies that under most of the scenarios discussed an increase in cooperative group activity or vertical integration of small-scale producers with large scale processing and marketing organizations.

- None of the assessment explored scenarios that completely challenge currently seen developments, such as a 1) strongly rising demand for ecologically produced food in developed countries, 2) an adoption of vegetarian diets across the world (the MA scenarios only explore slower and more rapid increase in meat demand), 3) major shifts in productivity levels as result of successful development in GMOs or other new agricultural technologies, or 4) a trend towards healthy food (vegetables, fruits) versus more high animal protein diet.

4.6 Relevance for Development and Sustainability Goals and AKST in the Future

Agriculture is a complex system that can be described by economic, biophysical, sociocultural and other parameters. However, its future is determined by an even larger set of direct and indirect drivers. Global assessments, e.g., provided by the IPCC, the MEA, and FAO, and reviewed in this chapter, have addressed plausible future developments in agriculture. These assessments have made use of different approaches to address future agricultural changes, and usually employ either detailed projections accompanied by limited policy simulations or scenario analyses that consider a wide range of uncertainties in an integrated manner. Neither of these approaches aims to predict the future, but rather provide a framework to explore key interlinkages among different drivers and their resulting changes. Though these recent global assessments provide a host of information on plausible future developments regarding agricultural production systems and their driving forces, none of these assessments has explicitly focused on the future role of AKST.

4.6.1 What development and sustainability goals can to be addressed through AKST?

Some of the trends in direct and indirect drivers benefit agriculture and its role in realizing more sustainable development. Other trends, however, imply considerable challenges. Among the most important drivers identified in this chapter are:

- Land use change (balancing land claims in response to an increasing demand for agricultural products with the objective of protecting natural ecosystems)
- Changes in trade patterns (in particular consequences for smallholder farmers)
- Land degradation and water scarcity
- Climate change
- Urbanization (in particular with respect to consequences for food-supply chains)
- Demand for bioenergy

- Governance
- Breakthrough in crop and soil management, including ecological intensification, biotechnology and information technologies applied to agriculture
- Investments in AKST (both the volume and direction)

The projected increase in the global population in the next 50 years (2-3 billion people), on-going urbanization, and changing lifestyles are likely to lead to a strongly increasing demand for agricultural products and services. Assessments indicate that this could exert pressure on the natural resource base. Historic evidence shows shifts towards more meat-intensive consumption patterns with increasing incomes, and projections are similar for the future. The demand for agricultural products will need to be met while simultaneously addressing the critical role agriculture and land use change play in global environmental problems. In this context, demand for agricultural products, land use, biodiversity and AKST are intrinsically linked. In addition to demand for food, feed and fiber, demand for bioenergy is expected to increase. A major uncertainty in the land use change scenarios presented in the literature stems from the assumed degree of extensification and intensification of agriculture. Most assessments indicate that roughly 70-80% of the extra production is projected to stem from intensification. This implies that increasing demands are also partly met by expansion of cultivated land. This is particularly the case in sub-Saharan Africa, Latin America and East Asia. AKST may help in addressing the need for productivity gains while simultaneously considering the role of agriculture and land use on local, regional and global environmental problems.

There are many reasons for increasing agricultural trade, such as increasing demand for food, increasing interregional relationships and commodity specialization, possibly facilitated by trade liberalization. Interestingly, even scenarios that assumed no further trade liberalization reported increases in agricultural trade (driven by increased demand for agricultural products). Several studies report that further globalization and liberalization will affect countries and groups within countries in different ways. While agricultural trade among developing countries is likely to increase, as a group they may become net importers of agricultural commodities with a possibility of further widening agricultural trade deficit. Conversely, industrialized countries tend to become net beneficiaries of trade arrangements as they are expected to face less pressure to reduce their support for agriculture.

Existing assessments (in particular the MA) also highlighted the role of agriculture as a major contributor to global environmental change, such as land degradation, nutrient pollution and increasing water scarcity. The rapid expansion of irrigation and associated agricultural water withdrawals for improved productivity is expected to continue to depend on availability of water resources sufficient to produce food for the growing world population while at the same time meet increasing municipal, industrial and environmental requirements. Earlier assessments indicate that water availability for agriculture is one of the most critical factors for food security, particularly in arid and semiarid regions in the world, where water scarcity has already become a severe constraint to food production. Water scarcity and increasing rates of soil degradation in many regions may limit the ability of agriculture systems to reduce food insecurity and to meet the MDG target of halving hunger by 2015. Moreover, increasing rates of land degradation in many regions may limit the ability of agriculture systems to provide food security. A final important factor is the role of agriculture in the N cycle, with effects on both local and regional scales. Decreasing these impacts may require important changes in soil fertility management. AKST must continue to address the need to develop sustainable agricultural systems in these regions. In this context, it should be noted that there are several scenarios that highlight many opportunities for enhancing the positive role of agriculture in providing ecosystem services, minimizing its environmental impacts and adapting to global environmental change.

Agriculture, a highly climate-sensitive sector, is already strongly affected by climate variability in many parts of the world, and it will be even more affected by climate change in the future. The relevant changes in climate of importance to agriculture include not only changes in mean temperature and precipitation, but even more importantly, seasonal and inter-annual variability and extreme events. The outcomes of the impact of climate change will vary significantly by regions. Current studies indicate that negative impacts tend to concentrate in low income regions. In some other regions, often at high latitude, there could be net positive impacts on yields. Developments in AKST will certainly influence the capacity of food systems to respond to the likely changes. Agriculture is also a source of CO_2 and non-CO_2 greenhouse gases and therefore can play a significant role in mitigation strategies. In order to play this role, new AKST options for reducing emissions of methane and NO_X from agriculture are needed.

The projected urbanization will likely to coincide with a decline in the percentage of population depending directly on agriculture for their livelihood. At the same time, projected increasing income levels are likely to lead to changing diets and changing manner of food preparation. The consequences of this for the food supply chain, and in particular the role of retailers can be an important factor in future agriculture. Demand for food is also very likely to be affected by other demographic changes, e.g., the aging population in many industrialized countries. AKST will have to address the impact of changes from urbanization, consumption patterns and the agricultural labor force on agricultural production and technologies in order for food demands of the future to be met.

Energy will continue to play an increasingly important role in agriculture. Various forms of agriculture use different levels of energy; with transitions in agricultural production systems in general leading to a substitution of energy for labor. Most assessments also expect higher energy prices which could encourage the use of more energy-efficient technologies in agricultural production as well as in processing and distributing food. The most important factor with respect to energy, however, is that agriculture may become an important producer of energy in the form of bioenergy, based on both energy-security and climate change considerations. Existing assessments indicate a major increase in bioenergy production; this might lead to a tradeoff between energy security and food security, especially for the poor. In several scenarios large areas are devoted to bioenergy production. Because of potential environmental and food security impacts, bioenergy is very controversial and its value depends on assumptions about overall efficiency, tradeoffs with food production and biodiversity. Reports show that bioenergy production based on conversion of cellulose to ethanol or other hydrocarbon fuels will have less impact on food security and biodiversity than 1st generation fuels. In this context, AKST can play an important role in the development of bioenergy systems, as well as address the need to make agricultural systems more energy efficient.

While governance and other sociopolitical issues are hard to quantify in scenarios, it is known that these factor will be critically important for the future of agriculture. Scenarios primarily address these issues by building scenarios that are based on contrasting underlying assumptions concerning the role of government. Several scenarios expect governance effectiveness to increase over time (reducing the corruption that is perceived to be prevalent in developing economies). However, improving states' capacities in governance and effectiveness in policy implementation is a long term process, and effects are still uncertain. Some scenarios emphasize these uncertainties by showing consequences of failed reforms (e.g. the Order from Strength scenario of the Millennium Ecosystem Assessment). Key options discussed in existing assessments include building "soft" infrastructure, such as networks, organizations, and cooperatives, in order to produce social capital that may reduce conflicts at all governance levels. These may facilitate common-pool agricultural resource management; and enhance the access of farmer groups to markets.

4.6.2. What are the conditions needed to help AKST realize development and sustainability goals?

AKST functions within a larger system of knowledge generation, technological development and diffusion. The formal funding of this larger system will therefore affect AKST. Global spending on all research and development (R&D) is likely to increase in the future both absolutely and as a percentage of total global economic activity, though many countries outside North America, Western Europe and East Asia with small economies will probably continue to have low investments in R&D.

Public investment in AKST is increasingly less driven by the needs of agriculture per se, but is a spin off of other research priorities such as human health and security. There is a trend in many areas to reduce investment in traditional agricultural disciplines in favor of emerging research areas such as plant and microbial molecular biology, information technology and nanotechnology. This trend is likely to be sustained and its impact on AKST is not fully explored. However, China, with a very large, poor, rural population, is now the country with the second largest total R&D expenditure. It is possible that China may make substantial investments in research relevant to poor rural areas.

Assessing potential development routes of the world agriculture system is of crucial importance if AKST is to realize development and sustainability goals. As discussed previously, there are multiple significant direct and indirect drivers of the agricultural system and many of these are likely to change significantly within the decades. Though the time horizon for research may be reduced in the future, there is now and likely to be in the future a significant lag between the recognition of development and sustainability goals and the time required for AKST to contribute to addressing those goals. Frameworks that consider important drivers of change and their interlinkages can be used to initially explore and at least partially assess the likely consequences of developing particular technologies. Additionally, the impact of these technologies can be considered when projecting future outcomes, thus giving policy makers and others the opportunity to explore and assess different approaches to AKST. However, no model provides a full description of potential changes in agriculture and AKST in the coming decades.

While a number of modeling paradigms exist, most represent agriculture primarily from a particular disciplinary perspective. Given its importance and complexity, there is a clear need for a forward looking assessment that is focused on agriculture and can consider the impact of AKST. There are two main approaches in the literature with respect to future outlooks: 1) the use of multiple scenarios and 2) the use of one central projection. The first handles uncertainties better, but is more complex and time consuming. To date, agricultural assessments use one central projection whereas most environmental assessments multiple scenarios. The use of multiple models in assessments can help explore and understand sensitivities and uncertainties. Linking different types of models can result in a more comprehensive exploration of important issues.