GLOBAL IAASTD CHAPTER 4

OUTLOOK ON AGRICULTURAL CHANGE AND ITS DRIVERS

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Key messages

Recent global assessments provide a host of 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 the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment, and the UN Food and Agriculture Organization, 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. Note that neither of these approaches aims to predict the future – rather they provide a framework to explore key interlinkages between different drivers and resulting changes.

Agricultural assessment is a multidisciplinary task requiring the use of information, tools and models from different knowledge paradigms.
Agriculture is a complex system that can be described on the basis of economic, biophysical, socio-cultural and other parameters. However, its future is determined by an even larger complex of direct and indirect drivers. As models are meant to provide simplified descriptions of reality, none of the existing models 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. 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. While models can provide useful descriptions of possible future changes, it is important to understand their uncertainties and limitations.

Agriculture will need to adapt to several key changes in driving forces in the next decades. These include the challenges of ensuring food security for a larger global population, increasing productivity while sustaining the natural resource base, and adapting production systems to climate change. AKST plays a vital role in meeting these challenges.
A growing global population and changes in the diet and life-styles of people will increase demand for agricultural products and services. This demand has to be met while at the same time addressing the vital role agriculture and land use change play in global environmental problems. Productivity needs to be increased world-wide if one aims to minimize biodiversity losses from extension of agricultural land.

The projected increase in global population in the next 50 years (by about 2-3 billion people), on-going urbanization, and changing lifestyles will lead to a strongly increasing demand for food and pressure on the agricultural system.

Increasing income levels implies changing diets (from carbohydrates to protein based, thus, the livestock revolution), and changing manner of food preparation. This will create changes in food consumption patterns and more demand for non-home based preparation of food and the relevance of the supermarkets. Demand for food will also be affected by the demographic trends (the inverted pyramid). The projected urbanization will lead to more and more industrial growth but also decline not only in percentage of population depending on agriculture but also shrinkage in the area of land available for cultivation. The increasing rate of population ageing is expected to result in decline in population support ratio, which will ultimately lead to loss of potential working population for agricultural operations. Agricultural production and the technological input from AKST will have to consider urbanization and ageing in efforts to meet human population food demands of the future.

Political and social instability and institutional settings can have far-reaching implications for agricultural and food systems and AKST.

As with other socio-political drivers, it is difficult to assess the magnitude of these impacts in the future.

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.

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. This trend is likely to be sustained. Its impact on AKST is not fully explored.

The rapid expansion of irrigation and associated agricultural water withdrawal for improved productivity will 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. 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.

Agriculture will be significantly affected by climate change, as it is highly sensitive to climate.

The relevant changes in agriculture include not only changes in mean temperature but even more importantly, seasonal variability and extreme events. Global mean temperature is likely to increase by somewhere in between 1.3-5.8 degree Celsius during the 21st century. The outcomes of the impact will vary heavily by regions. Current studies indicate that negative impact tends to concentrate in low income regions. In some other regions, often at high latitude impacts could be net positive on yields. Developments in AKST will determine the capacity of food systems to respond to the likely changes. Agriculture is also a source of greenhouse gas emissions; both for CO2 and non-CO2 gases, and therefore agriculture can play a significant role in mitigation policies. In order to play this role, new AKST options for reducing emissions of methane from agriculture need to be developed.

Energy will play an increasingly important role in agriculture since changes in energy prices will influence agriculture's use and production of energy.

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. Increasing energy prices and changing subsidies are likely to be important for trends in agricultural production systems. At the same, agricultural may become an important producer of energy in the form of bioenergy, based on both energy-security and climate change considerations. The potential of bioenergy, however, is very controversial and depends on assumptions about overall efficiency, trade-offs with food production and biodiversity.

Growing demand for food, feed, fiber and fuel will lead to either intensification or additional land being taken into production.

Land cover, land use and AKST are intrinsically linked. A major uncertainty in the scenarios presented in literature stems from the assumed degree of extensification and intensification in agriculture as well as and of world food trade. In addition, changes in food demand and international trade play an important role. Transformations in AKST that lead to changes in level of use of land related goods and services are almost always caused by multiple, interacting drivers. Drivers can work together to create rapid land use and land cover change.

4.1 Introduction – Assessment for the Future: Food for Thought

4.1.1 Purpose and scope of this chapter

The previous chapters have highlighted the importance of agriculture in achieving development and sustainability goals. The relationships between agriculture and societal goals are many, and can be direct or indirect. The most obvious direct link is agriculture's role in provisioning food and reducing global hunger. In addition, the agricultural sector provides a range of other goods and services such as energy and fibers. However, in some case agriculture also hinders achievement of sustainability goals, especially where it constitutes a key factor in (global) environmental changes (such climate change, deforestation, and soil degradation). Such changes may jeopardize the provisioning of environmental services. Given these linkages, assessing potential development routes of the world agriculture system – and the specific role of agricultural knowledge, science and technology – is of crucial importance.

In Chapter 1, the conceptual framework for the IAASTD is introduced as a framework to study the relationship between agriculture and development and sustainability goals and their changes over time (see Figure 4.1). It should be noted that while agriculture is at the central focus in this assessment, it needs to be seen as part of a larger human society and so agriculture is dynamically linked to many other human activities. Changes in these activities can both directly and indirectly drive change in agriculture (i.e. labeled 'agricultural drivers' in Figure 4.1). In this context, a *driver* is any factor that changes an aspect of 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. Drivers are also linked to decision-making, as many of the drivers can be influenced by policy choices.

Several methods have been developed to assess possible future development, and using such methods several recent international assessments provide information on changes in agriculture and its drivers (however, most of these assessments did not focus on agriculture per se) . As context for the subsequent chapters in this report (that will look specifically at how future agricultural development can be influenced by AKST in order to achieve development and sustainability goals), this chapter overviews expectations presented in the current literature on how agriculture and its drivers may change in the future. By looking at plausible assumptions on future changes – in relation to the agriculture system – we aim to provide an idea of the most prominent challenges that agriculture might face over the next 50 years.

The chapter is organized as follows. Below, we first briefly define how the IAASTD framework has been used to structure our chapter. Next, in subchapter, 4.2 we discuss different approaches to discuss the realm of uncertain future developments – and introduce recent assessments of particular relevance to this report. Subchapter 4.3 discusses plausible futures for indirect drivers of the agricultural system and subchapter 4.4 discusses plausible future for direct drivers of the agriculture system. In the discussion of each driver, we focus on some of the relevant literature regarding how that driver is likely to change in the future – and specifically on evaluations provided by earlier assessments. Subchapter 4.5 assesses how – in the context of the changes in direct and indirect drivers – the agricultural system itself may develop. Finally, subchapter 4.6 summarizes the chapter in terms of implications for subsequent chapters.

4.1.2 The IAASTD conceptual framework: linking driving forces and AKST

As organizing structure of our assessment we use the framework of the IAASTD. The focus of this Chapter is mainly on the outer circle of the framework, i.e. changes in agriculture and its drivers. Discussion of the drivers of AKST will occur in the subsequent chapter (starting Chapter 5 with some illustrative modeling experiments; followed by detailed analysis in the next Chapters). The conceptual framework of the IAASTD (Figure 4.1) emphasizes the relationship between agricultural and human development and sustainability goals. It also shows that several drivers may impact this relationship. In this chapter, we discuss plausible changes in indirect and direct drivers (the lower 2 boxes of the framework) and the agricultural system itself (the upper left box). The main indirect drivers of change discussed here are:

1 Demographic developments, including changes in population size, age and gender structure, and spatial distribution;

2 Economic and International Trade developments, including changes in national and per capita income, macroeconomic policies, international trade, and capital flows;

3 Sociopolitical developments, including changes in democratization, the roles of women, of civil society, and of the private sector, and international dispute mechanisms;

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

5 Education, cultural and religious developments, including changes in choices individuals make about what and how much to consume and what they value.

A range of direct drivers relevant to agricultural systems and AKST are highlighted in the remainder of this chapter: These include:

1. Changes in food consumption patterns, i.e. consumptions levels of crops and meat products;

2. Land use change, i.e. land availability as a constraint to agriculture;

3. Natural resources, i.e. the impact of agriculture on natural resources and the constraints of natural resource availability and management on agriculture;
4. Climate change, i.e. the impacts of climate change on agriculture
5. Energy, i.e. the relationship between energy and agriculture and the impact of large-scale bioenergy production;
6. Labor, i.e. the relationship between agriculture and the demand and supply of labor force.

4.2 Forward-looking assessments

4.2.1 Approaches to forward-looking assessments

Recent international assessments have made use of a variety of different methods to develop forward-looking outlooks and to explore key interlinkages between different driving forces and resulting changes. Such methods range from near-certain predictions, to best-guess projections or alternative scenarios, to open-ended speculations about future developments – all of which differ substantially in the underlying assumptions and guiding rationales. Nevertheless, all of these forward-looking approaches have in common that they set out to develop perspectives on possible future pathways and understand related uncertainties in a structured manner.

The type of forward-looking approaches best suited to address a specific issue and its related set of future developments, depends much on the level and type of uncertainty that needs to be accounted for. Uncertainties have a range of sources, including the level of understanding of the underpinning causal relationships (i.e. 'what is known about driving forces and their impacts?'), the level of complexity of underpinning system's dynamics (i.e. 'how do driving forces, impacts and their respective feedbacks determine future developments?'), the level of determinism of future developments (i.e. 'to what degree do past trends and the current situation pre-determine future developments?'), the level of uncertainty introduced by the time horizon (i.e. 'how far into the future?'), or even the surprises and unexpected / unpredictable future developments.

As a consequence, when assessments are faced only with relatively low levels of uncertainty with regard to future developments, some approaches allow predicting - or at least - projecting plausible future developments with some degree of confidence. Conversely, where the context of high uncertainty makes predictions or projections meaningless, exploratory scenario approaches can help structure of possible future developments and their implications - see Figure 4.2.1.

Recent international assessments of particular relevance to the International Assessment of Agricultural Science, Technology and Knowledge for Development (IAASTD) - recognising considerable level of both complexity and uncertainty - have primarily made use of approaches that are either based on projections or exploratory scenarios.

Projection-based studies set out to present one (or, in some cases, several) probable outlook on future developments. Commonly, such projections are necessarily based on reducing the level of uncertainty within a forward-looking assessment, either by addressing a limited time horizon or by focusing only on a sub-set of the underlying socio-economic and environmental system. Projections unfold their full usefulness when they are compared against different variants to highlight expected outcomes of policy assumptions and well-defined options. Projections have also been referred to as future baseline, reference scenario, business-as-usual scenario, or best-guess scenario. Key examples of recent projection-based assessments of immediate relevance to IAASTD include the Food and Agriculture Organization's World Agriculture 2030 (FAO, 2002), IFPRI's World Food Outlook (IFPRI, 2001) or OECD's Environment Outlook (OECD, 2007).

Conversely, forward-looking assessments based on more exploratory approaches aim to widen the scope of discussion about future developments, or even set out to identify emerging issues. These types of assessments build on the analysis of alternative projections or scenarios that highlight a range of plausible future developments on par. Such scenarios have been described as plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships (MA, 2006). Multiple projections or scenarios are most useful when strategic goals are discussed and reflected against a range of plausible futures, or when aiming to identify and explore emerging issues. Several recent assessments have presented multiple plausible futures as sets of qualitative narratives backed-up by quantitative modelling. Important examples in the wider context of agricultural assessments include the global scenarios developed by the Millennium Ecosystem Assessement (MA, 2006), UNEP's Global Environment Outlooks (UNEP 2002, 2007; RIVM/UNEP 2004), IPPC's Third and Fourth Assessment Reports (IPCC 2001, 2007) and the Global Scenarios Group (Raskin et al. 1998; Gallopin et al. 1997).

While different approaches to developing and analysing projections and explorative scenarios exist, some common features have emerged in past assessments (see, for example, EEA, 2002). These include:

- Current state, i.e. a description of the initial situation of the respective system, including an understanding of past developments that lead to the current state;
- Driving forces, i.e. an understanding of what the main actors and factors are, and how their choices influence the dynamics of their system environment;
- Step-wise changes, i.e. a description of how driving forces are assumed to develop and interact, and affect the state of a system along different future time-steps;

· Image(s) of the future, i.e. a description of what a plausible future may look like as a consequence of assumptions on drivers, choices and their interactions.

4.2.2 Recent forward-looking global assessments

Recent assessments.

Recent international assessments provide a wealth of information about expected or plausible future developments - either on the prospects for agriculture or by presenting integrated perspectives on the range of possible developments of driving forces and pressures that shape the future of agriculture, food systems or food security. Recent international assessments that are of particular relevance for IAASTD include a very wide range of exercises, summarized in Table 4.2.1. These assessments provide a starting point and source of information for any new forward-looking assessment – and in the remainder of this chapter assumptions and expectations on key agricultural drivers developed in recent assessments are introduced.

Within the set of recent assessments, the work by the Millennium Ecosystem Assessment (MA), Food and Agriculture Organization (FAO) and International Food Policy Research Institute (IFPRI) are particular relevant given their special focus on ecosystem services, food and agriculture.

Relevance of earlier exercises for agriculture and AKST

As shown by Table 4.2.1., recent assessments have mostly focused on broad sustainable development or environmental issues - and with this include many of those driving forces and components that shape future of agriculture, food systems or food security. Here we provide a basic overview of some important characteristics of these scenario exercises from the perspective of the agricultural sector. For most of the more general assessment, the relationship is necessarily indirect; only for the 2 agriculture projection studies (IFPRI and FAO), the relationship is direct. None of these studies, however, addresses the full spectrum of agrarian system and AKST from the perspective of a range of different plausible futures. And even if the projections provided by FAO and IFPRI, address agricultural production and services to some degree, the attention paid to AKST elements is relatively low also in these assessments. This highlights a need for new work to integrate plausible futures with regard to the interactions between global environmental change, agrarian and food systems as well as addressing AKST in more detail.

Also, an analysis of recent scenarios exercises shows, that while some elements related to the future of food systems is touched upon, food security per se is not addressed specifically – see Table 4.2.2. (For a description of the food system concept, see GECAFS, 2006). Food availability (including production, distribution and exchange) is covered more comprehensively by the various exercises. Most addressed both qualitatively and quantitatively various production indicators, and provide assumptions on yields for various crops, area under certain crops, input use or exchange mechanisms. Also the consumption side of the food system as well as the access to food (including affordability, allocation and preference), has often been addressed through modeling food demand in different scenarios –even if with limited detail only. For example, assumptions on 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.

The area that is the least covered by the reviewed scenario exercises is food utilization. The IFPRI and MA exercises calculated the number of malnourished children under each scenario, which serves a very basic indicator of hunger and whether nutritional standards are met. But nutritional outcomes under different diets and their possible changes are hardly addressed. Only little, if anything, is said in any of the exercises on food safety issues or the social value of food, which could both have important consequences for food preferences. The MA does however quantitatively assess certain health indicators which could be used to give a further indication on the nutritional status of people in the various scenarios. This broad analysis shows the need for further in depth research 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. In addition, our understanding of the various linkages of the food systems and food security determinants with environmental changes is in some cases only developing now.

Relationship of scenarios in different assessment exercises

All of the reviewed exercises have developed their own assumptions about a number of underlying uncertainties and future developments of key driving forces, and arrived at different sets of scenario logics. Nevertheless, many of scenarios display some similarities, and it has been argued, that a limited set of ‘archetype’ scenarios reappears in recent scenario-based assessments (see Raskin et al., 2005; Westhoek et al., 2006; Zurek, 2006; van Vuuren, 2007):

1 *Economic optimism/ conventional markets scenarios;* i.e. scenarios with a strong focus on market dynamics and economic optimism, usually associated with rapid technology development.

2 *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.

3 *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.

4 *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.

5 *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 decentralisation of governance.

6 *Business as usual;* i.e. scenarios that build on the assumption of a a continuation of past trends. (Thus this archetype is of a somewhat different quality than the above, as it mostly comes from studies with a strong model- and weak storyline-orientation.)

These scenario archetypes share important assumptions for different domains, as highlighted in general terms in Table 4.2.3.

Table 4.2.4 indicates how recent scenarios relate to these different archetypes. In some cases, however, this is not straightforward - and scenarios share characteristics of more than one archetype. It should be noted that the 2 specific studies focused at agriculture cover only a limited set of scenario archetypes (and thus a subset of plausible futures).

4.3 Assessment of indirect drivers: How have indirect drivers changed over time and what is the likely range of change to 2050?

4.3.1 Demographic drivers

The relationship between agriculture and demographic drivers is strong. Food security implies a state in which every human being can have access to, afford and utilize sufficient nutritious food to maintain a happy and healthy living. This is possible only if food production keeps pace with population as already emphasized by Malthus. Further, about 43 percent of the population of the world depends on agriculture and this sector dominates economies of 25 percent of the world's countries (FAO, 2003; Fischer et al., 2002). The share of agriculture dependent population varies across different regions of the world ranging from just 7.2 percent in Europe to 64.7 percent in sub-Saharan Africa (Table 4.2.2.1).

4.3.2.1. Global population: Current trends and projections.

The United Nations Population Division (UN, 2005a) has estimated that the world population was 6.5 billion at mid-2005 with an increase of 380 million over the population size of 2000. This implies that over the past thirty years there has been an increase of 2.4 billion (Figure 4.2.2.1). During this period, there have also been strong changes in underlying factors: e.g. fertility rate has fallen from 5 births per woman to 2.65 births, while the life expectancy has increased from 46.6 years to 65.4 years. The annual absolute increment of global population that peaked at about 80 million per year in 1975 is now about 76 million.

This does not imply that little additional population growth is to be expected. **Figure 4.2.2.2** shows world population projections from 2000 to 2050 by four different organizations, viz, Population Division, United Nations (UN, 2005a), United States Census Bureau (US.BoC,2003), International Institute of Applied Systems Analysis (IIASA, 2001; Lutz et al., 2004)) and the World Bank (World Bank, 2004). Under the medium variant projection by UN, it is expected that the population will reach a level of 9.1 billions by the mid of this century. The full UN range is 7.7-10.6 billion for 2050. The IIASA range is even larger going from 6.6 to 11.3 billion. Other projections lie near the UN medium and IIASA mean. The realization of these projections is contingent on ensuring that couples have access to family planning and that efforts to arrest the current spread of the HIV/AIDS epidemic are successful in reducing its growth momentum.

Population at global level continues to increase driven by population increases in less developed regions. Figure 4.2.2.1 provides the projected figures for 2005 -2050 for the three regions: i) more developed (MDR) ii) less developed (LDR) and iii) least developed (LDC). By 2050, the population of most developed regions will decline by about 1.2 million per year whereas, in less developed regions, there will be an increase of 35 million annually and least developed countries will experience an increase of about 22 million per year. Hence the least developed countries will have maximum contribution for the population accumulation.

Different global assessments have used different numbers for population projections as indicated in Table Table 4.2.2.2. 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 to most recent projections for the world, shows a downward revision to the medium projections. For 2100, patterns of projections are qualitatively similar to those found for 2050, but larger in magnitude. It shows a general downward shift in the full range of projections (Van Vuuren and O'Neill, 2006). Of these set, the Millennium Ecosystem scenarios are relatively advanced with a very explicit consideration of storyline elements in the assumptions for underlying dynamics.

4.3.2.2. Urbanization and ageing of world population.

Apart from the absolute numbers, also the structure of the population is important. The world's urban population reached 3.2 billion persons in 2005 and is expected to rise to 5 billion persons by 2030 (UN, 2005). 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. In more developed regions, the process of urbanization has already gained momentum with 75 percent of the population living in urban areas in 2005, whereas in the less developed regions the level of urbanization is low with only 43 percent of the population are urban residents. The share of urban population of the world, which was 29.1 percent in 1950, is expected to reach 60.8 percent in 2030. It is projected that about 82 and 57 percent respectively of the populations of the more developed and less developed regions will be urban dwellers in 2030 (UN, 2005b). As urbanization advances, policy planners, especially in developing countries will face multiple problems, the foremost one being feeding their urban dwellers according to their changing diets with agricultural outputs from dwindling crop areas, work to prevent under nutrition and also distribution of natural resources like water and other basic services equitably. According to IFPRI, one way to reduce the pressure on cities is for developing-country governments to invest in the rural areas, particularly in the agriculture sector that forms the base of the economy in most developing countries (Wilson, 2001).

An important dominant demographic trend is the ageing of populations mainly due to decline in fertility and to a lesser extent, by increases in life expectancy. During the twentieth century, the proportion of older persons (those aged 60 years or over) continued to rise and this trend is expected to continue well into the twenty first century. For example, the proportion of older persons was 8 percent in 1950 and 10 percent in 2005 and is projected to reach about 22 percent by mid-century. As the twenty-first century began, the world population included approximately 600 million older persons, triple the number recorded 50 years earlier. By 2050, the world is expected to have some 2 billion older persons; once again, a tripling of the number in that age group within a span of 50 years. The pace of population ageing is much faster in the developing countries than in the developed ones. So developing countries will have less time to adjust to the consequences of population ageing. Moreover, population ageing in the developing countries is taking place at much lower levels of socio-economic development than has been the case in the developed countries. Figure 4.2.2.3 illustrates this through differences in population structure for countries at different economic development levels. The changes have also enormous consequences for the ratio between working age population – and the part of the population that is (usually) supported.

4.3.2.3. Driving forces behind population projections.

Demographic trends are influenced by varied social, economical and cultural factors. The projections have identified distinct trends in the three components: fertility levels, mortality and migration. The demographic transition (Thomson and Notestein) is a way to describe these trends in terms of several stages of transition. 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 drop rapidly due to better economic and environmental conditions with increase and life spans and decrease in disease attack. This stage began in Europe during the Agricultural Revolution of the 18th century while less developed countries entered this stage during the second half of the 20th. Currently countries in this stage are Nigeria, Kenya and Bangladesh. Many countries such as the East Asian Tigers (China, Brazil and India) have crossed this stage due to fast social and economic change. But African countries appear to remain in this stage due to stagnant development and the effect of AIDS. In stage three birth rates decline and population moves towards greater stability due to increases in urbanization and female literacy and improvements in contraceptive technology. India, Mexico and Brazil are some of the countries in this stage of transition. During stage four there are both low birth and low death rates. In 43 developed countries, which account for about 19 percent of the world population, fertility has dropped to well below replacement level- two births per woman- leading to a shrinking population. Few countries like Sweden, Germany, Japan and Italy have undergone an economic transition from manufacturing-based industries into service and information-based industries. In all these countries, there is a natural decrease in the population as birth rates have fallen below the death rate (Figure 4.2.2.3).

In the UN medium scenario, fertility per woman declines from 2.6 to just over 2 children, at the same time, it is projected that also trends in life expectancy continue: the increase from 47 years in 1950-55 to 65 years in 2000-2005 is followed by a further increase to 75 years by mid-century. In particularly in higher income countries, a major question remains how high life expectancy may go. The UN projections still assume that the life expectancy may not increase beyond 85 years and some demographers fix this age to represent an intrinsic limit to the human life span (DeFries et al., 2002). Another important demographic trend observed during the 20th century, is the decline of mortality, including infant mortality and under 5 years mortality (see Figure 4.2.2.5) in most countries, because of better public hygiene, improved nutrition and medical practices based on scientific advancement (Lee, 2003). However, in countries with deteriorating social and economic conditions and in countries affected by Human Immunodeficiency Virus/Acquired Immuno-Deficiency Syndrome (HIV/AIDS) epidemic, mortality has been increasing. (for example, Eastern Europe, Russian Federation Ukraine). As of January 2006, the Joint United Nations Program on HIV/AIDS(UNAIDS) and the World Health Organization (WHO) estimated that AIDS has killed more than 25 million human beings so far and another 40 million adults (15-49 years) are currently living with the disease. In 2005 alone, AIDS claimed between an estimated 2.8 and 3.6 million, of which more than 570,000 were children. Sub-Saharan Africa (SSA) which has just over 10 percent of the world's population is most severely affected due to AIDS devastation (UN,2005c and Figure 4.2.2.6). In AIDS affected countries the life expectancy has drastically dropped. It is projected that in these countries, the epidemic would peak in 2010, with no further growth in HIV infection after that year.

Finally, international migration is an important social factor for the population size and composition in some countries. However, unlike 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, which are impossible to predict. It is estimated that during 2005, about 191 million persons (representing 3 percent of the world population) were migrants (UN, 2005b), an increase of 116 million over the corresponding figure for the year 1960. Of these, 60 percent reside in the more developed regions, while 40 percent reside in less developed regions. During 2005, the United States of America was the largest recipient of migrants with a total of 38 million. The percentage of migrants is on the increase from 1985 to 2005 in most developed regions (North America and Europe) whereas in less developed regions it is almost at a constant level (Table 4.2.2.3).

During 2005-2050, 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 annually. This in turn will have substantial changes in age structure, size and composition of the population of the receiving nations leading to populations of mixed origin. Globalization should in principle help equalize international incomes and reduce the need for people to emigrate in search of higher wages.

4.3.2.4. Demographic change and its impact on agriculture.

No doubt population projections represent a slowdown from past estimates, but 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). Continued production of an adequate food supply is directly dependent on ample fertile land, fresh water, energy, along with the maintenance of biodiversity. As the human population grows, the requirements for these resources also grow. Even if these resources are never depleted, on a per capita basis they will decline significantly because they must be divided among more people. Today the life span of human population has increased with better living conditions (Eberstadt,1995). But can agriculture feed the expanding global population in the ensuing decades? World grain productivity increased by 2 percent annually from 1950 to 1990, but productivity has been rising by only 1 percent for the past 10 years. The trends of decreasing grain productivity coupled with increase in population growth and decrease in agricultural land may result in large rise in undernourished people especially in less developed countries. In addition, higher oil prices are providing economic justification for diversion of increasing amounts of grain, sugar, and oilseed crops for biofuel production. Hence, projections of food supply and demand must consider the ability of food systems to feed a much larger and wealthier taking into account stagnant or declining stock of natural resources.

AIDS and its impact on agriculture. Agriculture is the largest sector in most of the SSA economies and AIDS has its impact on all sectors of the society, reduction in population growth and in some cases decrease in population size, health, education and economic growth. It has a number of impacts on agriculture and farm households also. It depletes not only human capital base, which results in reduced labor availability, but also the capital availability, which is diverted to cover costs related to sickness and death. There are a number of direct impacts. Families affected by AIDS are unable to cultivate all the land at their disposal and they are left fallow resulting in decline in total output from agriculture. Thus there are reduction in both areas of land under cultivation and yield. Further, due to non-availability of labor, cash crops are abandoned and less labor incentive crops are selected. Therefore, there is decline in crop variety and change in cropping pattern. In addition, to meet the cost of medicine, farmers are tempted to sell their livestock and it implies there is decline in livestock production also. A study in Cote d'Ivoire showed that households with an AIDS patient spent twice as much on medical expenses as other households. There is also a loss of agricultural skills because when parents are sick they are unable to train their children in agricultural operations. As a consequence of all these, there is a decline in the quality and quantity of food and hence there is a reduction in household food security. Further, AIDS has slowed economic growth in AIDS affected African countries with a decline in per capita gross domestic product (GDP). Over the long term HIV/AIDS can impact on agricultural output through reduced investments in soil conservation, irrigation, seeds and fertilizers and veterinary medicines.

4.3.2.5. Population change and AKST.

Population growth induces necessity for more food production, which in turn demands more agricultural land and (or) increase in productivity. The first option cannot sustain forever because land area is fixed. Hence, the second alternative, viz., increase in productivity of major food crops must be given highest priority. This is possible by the application of modern technologies in agriculture. Technology is the main driving force of productivity and economic growth. Historical studies attribute about half of economic growth to technological change and the other half to the combined effect of all other driving forces, such as the larger and better-qualified labor force and accumulated stock of capital. Many studies also indicate that technology could play a similar important role in the future. This is further discussed in other subchapters of this Chapter.

4.3.2 Economics and International Trade

4.3.2.1 Introduction

This sub-chapter addresses a series of basic indirect drivers related to the agricultural economy, including gross domestic product (GDP), trade related issues, and agriculture value added.

Determinants of agricultural growth, such as expenditures and investments in agriculture; and financial flows are also discussed.

4.3.2.2. Future trends and scenarios of economic growth and the agricultural economy.
Economic growth measured as GDP per capita is used as economic driver in most scenario studies. Between 1950 and 2000 world GDP grew by 3.85 percent annually resulting in a per capita income growth rate of 2.09 percent (Maddison, 2003 as cited in MA 2005, and presented in Table 4.3.2.-1). The World Bank (2003, cited in Van Vuuren and O'Neill, 2006) estimated overall growth of 13 percent between 1990 and 2000 in per capita GDP or about 1.3 percent per year. According to Nayyar (2006), global GDP growth decelerated over time from 2.1 percent per year in the 1970s, to 1.3 percent per year in the 1980s, and to 1.0 percent annually in the 1990s.Projections of future economic growth vary considerably. One set of projections for future GDP per capita forms part of the Special Report on Emission Scenarios (SRES) study (Van Vuuren and O'Neill, 2006) (Fig. 4.3.2-1 and Fig. 4.3.2-2). Four scenarios are defined with assumed levels of economic growth (A1, A2, B1, B2). Overall, global annual economic growth rates ranged from 1-3.1 percent. The range of economic growth projections of the US Department of Energy (USDoE) is somewhat smaller (1.2-2.5 percent), but in line with shorter-term projections by the World Bank (World Bank 2004).
Recent FAO income growth projections out to 2050 include per capita income growth projections of 2.1 percent annually during 2000-2030 and 2.7 percent per year from 2030-2050. Assumptions are continued relatively strong growth in the group of developed countries (2.2 percent and 2.4 percent per year for the same periods) and accelerating growth for the group of developing countries at 3.6 percent annually for 2000-2030 and 4.0 percent per year during 2030-2050 (Table 4.3.2-2). While world agriculture grew at rates of 2.1-2.3 percent in the last four decades, the future may see some drastic decline to 1.5 percent per annum in the next three decades and on to 0.9 percent in the subsequent 20 years to 2050 (FAO 2006). However, some developing countries that experienced very slow growth in the past may see accelerated growth during this period.

The Millennium Ecosystem Assessment proposed four alternative scenarios: A Global Orchestration scenario with relatively lower population growth, coupled with high income growth and high levels of investment; a TechnoGarden scenario with medium to low population growth slightly lower economic growth, and a focus on increasing growth in technological development; an Adapting Mosaic scenario with higher population growth, and lower economic growth, focused on local learning and community-based management, and an Order from Strength scenario with the lowest overall economic growth and highest population growth (Table 4.3.2-3). Figure 4.3.2-3 compares, for the example of 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 (Westhoeck, 2005). The figure shows lower growth projections for the period 2025-2050 compared to 2000-2025.
In general, growth accelerates for developing countries and continues to slowly decline in OECD countries. In 2000, the world average GDP per capita was $5,102. In 2050, the range of per capita incomes under the MA scenarios is projected to range from $9,838 (implying average growth of 1.2 percent per year) to $22,282 (at an annual average rate of growth of 2.6 percent). The latest draft OECD outlook (2006) also shows slowing growth across time periods out to 2030, but they treat these projections of 'real GDP' as reflecting purchasing power parity (Table 4.3.2-4).

4.3.2.3 Implications of income growth for agriculture

Income growth does go hand in hand with fertility decline as expectations shift about the economic costs of bearing and rearing offspring and about their subsequent income benefits. Higher expected incomes overall may enhance incentives for parents to invest more in fewer children (see, for example, Becker and Lewis 1974; Schultz 1981), and typically results in the slow but steady replacement of family farm labor with hired labor or agricultural mechanization. Broader social development, like increased female education can reduce fertility rates via delayed onset of marriage and childbearing as well as being an increased incentive for women to enter the formal workforce, thereby cutting into incentives for childbearing and rearing. But it takes time for this effect on fertility decisions to play out in terms of lower population growth rates (since this effect is balanced against declining mortality and since not all of the child-bearing cohort is affected, at least initially). Indeed, analysis of the timing of fertility decline in relation to economic development indicators has revealed wide variation from country to country (see Bongaarts and Cotts Watkins, 1996; they attribute much intercountry difference to socio-cultural factors). Further details can be found in the sub-chapter on demographic drivers.

Changes in per capita income growth do affect the mix of economic activities, and this affects agriculture in a significant way. At low incomes, demand for food quantity initially increases and then stabilizes; and food expenditures become more diverse (see also the sub-chapter on changing food consumption patterns). Also, the demand for nonagricultural goods and services increases more than proportionally. Agricultural producers respond to this trend by shifting resources out of agriculture; and the share of agricultural output in total economic activity declines. Figure 4.3.2-4 documents the shift in economic structure in the past two centuries of the world’s largest economies from agricultural production to industry and services. The shift away from agriculture and toward nonagricultural goods and services must be interpreted carefully (MA, 2005).

High-income countries typically produce more output per hectare as a result of higher inputs, but industrial and services output grows much faster so the relative contribution of agriculture declines. Technological change further replaces most of the labor force in agriculture.
It is important to note that developments for many factors discussed in separate sub-chapters in this chapter are closely related. For instance, demographic factors (graying of the population, labor supply) 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. Similarly, 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.

4.3.2.4. Globalization in context.
Globalization describes a process of integration of local and national economies into the world economy but can also prescribe a strategy of development based on rapid integration with the world economy (Nayyar, 2006). There are traditionally three dimensions of globalization: international trade, investments and finance, and labor flow. Much has been written about globalization and its trade policy dimensions and the corresponding winners and losers along the way (Anderson and Martin, 2005; Coxhead and Jayasuriya, 2003; Runge et al., 2003; Falcon and Naylor, 2005; to name a few). Some authors warn that trade policy reforms are not at all a panacea; such reforms need to be complemented by other policy measures to alleviate potential adverse environmental impacts, and to implement safety nets for the poor (Polaski, 2006).

The evidence on globalization is far from conclusive. While from theoretical point of view scholars argue that globalization leads to increased economic growth, evidence is not convincing. For instance Nayyar (2006) indicates that while benefits have accrued to the industrialized world and a small number of developing countries, for many developing countries, and their people, this has not yielded benefits in terms of economic growth because there necessary preconditions were not met. Others find that nations with lower trade barriers, more open economies, and transparent government processes tend to have higher per capita income growth.

In relation to this issue, there is also a wide range of literature on the question of whether *income* convergence is a logical attribute of larger economic systems and whether such convergence can actually be observed in the past. There is evidence of convergence within large regional markets, which act more or less as a common market. Examples are the European Union and the USA (Quah, 1996; Sala-i-Martin, 1996). Similar evidence on convergence is found within groups of low-income countries, such as Western Africa (Sala-i-Martin, 1996;Jones, 2002). Whether convergence occurs globally is more controversial, and depends partly on the metrics used (Ben-David, 1996; Pritchett, 1997). Over the last decades Asia (low-income) has experienced higher growth rates than the OECD (high-income) average. At the same time, neither Latin America nor Africa has contributed to this convergence. While historical evidence is inconclusive, most scenarios on future economic growth assume higher growth rates for low-income region than for high-income regions, as has been shown above.

China seems to be a real winner in the globalization regime – and also experiences high growth rates in most scenarios. The role of cross-border flows, particularly in terms of technology transfers appears to be an important determinant of their domestic productivity (Rao et al., 2004). The export of agricultural and food products increased three-fold during 1985-2000 while soybean became an important import product. This success was achieved primarily as a result of policy changes (van Tongeren and Huang, 2004; Fan et al., 2000), which were implemented, in part, to support China's accession to the WTO.

Some authors argue that improved market access globally is a critical support for development goals. Evidence suggests that nearly two thirds of the economic gains from dismantling merchandise trade barriers and farm subsidies would come from agriculture, gains that apply to the world as a whole and to developing countries as a group (Anderson and Martin, 2005). In addition, more than 50 percent of the gains in developing countries from agricultural reform would come from liberalization by developing countries themselves for two reasons: 1) agricultural tariffs are even higher in developing than more developed countries, and 2) a large minority of developing country trade is with other developing countries. Hence, about 90 percent of the welfare gains from removing distortions to agricultural incentives globally were estimated to come from reducing import tariffs, while only 2 percent is due to export subsidies and 5 percent to domestic measures. However, such gains do not necessarily translate into poverty alleviation (Anderson, Martin, and van der Mesnburgghe, 2006). The subsequent subchapters address trade issues and financing in more detail.

4.3.2.5. Trade and agriculture

The issue of trade and agriculture is central to many areas of international relations. For many countries, particularly developing countries, agricultural imports are an important source of food supplies. The trend of growing imports, particularly of food, is likely to persist over the coming decades (see, for example, Rosegrant et al. 2001). On the other hand, the potential for export of agricultural products by developing countries is a critical factor for development. The emphasis of trade liberalization and export orientation in the past decade has led to growth in world merchandise trade (UNCTAD, 2003: p1). This subchapter assesses potential drivers for future trade in agriculture based on past trends.

According to the FAO's World Agriculture: towards 2015/2030, the overall trade surplus in agricultural commodities for developing countries has virtually disappeared and the outlook to 2030 suggests that they will become, as a group, net importers of agricultural commodities, especially of temperate zone commodities. Further, the agricultural trade deficit of the group of least developed countries (LDC's) has been widening rapidly and could quadruple by 2030 (FAO, 2005).

The FAO report base the conclusion on the various drivers, but fundamentally on the fact that developed countries tend to be the major beneficiaries of trade arrangements:
Tariffs continue to curb trade: The Uruguay Round's 1994 Agreement on Agriculture (AoA) provided for non-tariff barriers such as quotas to be replaced by equivalent tariffs. While the reductions made since 1994 have complied with these goals, it is not clear that market access has improved significantly.
Domestic support remains high: AoA also covered domestic support, which can distort trade by allowing domestic producers to sell at lower prices than would economically be viable. The FAO report concludes that in reality many countries have faced much less pressure to reduce support for their agricultural sector. This is mainly 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. It is generally noted that these talks are basically about agricultural support and market access. Export subsidies are still substantial: AoA also brought direct and indirect subsidies for agricultural exports. The FAO report concludes that the EU still accounts for bulk of direct export subsidies. In 1998 it spent US$5.8 billion, more than 90 percent of all such subsidies covered by the AoA.

Limited benefits of trade liberalization: Most studies assert that complete liberalization of agricultural trade could produce overall welfare gains (for consumers and taxpayers in developed countries and exporters in developed countries), while urban and landless rural consumers in developing countries might face higher prices. Some studies show that developing countries will benefit only if they liberalize themselves. The FAO study showing removal of price support and other subsidies to 2030 found that international prices could rise moderately, while prices would fall substantially in countries with high levels of protection. Liberalization would somewhat slow the process of increased net food imports by developing countries.

Most scenarios assume a continuation of high protection levels for most agricultural commodities but include alternative scenarios with reductions or complete elimination of trade barriers. For example, in the Millennium Ecosystem scenarios, the Global Orchestration scenario assumed full trade liberalization.

Most of the conclusions implying that developing countries stand to lose in future trade arrangements are premised on the fact that developing countries will still be dependent on developed countries for trade relations. However, UNCTAD's Trade and Development Report of 2005 provided an extensive evidence of emerging South-South trade relations that are likely to support trade development in future. Even if developed countries are still going to form substantial demand for developing countries' exports, their poor growth outlook puts them behind the emerging strong demand of Asian countries, particularly China and India. Moreover, developing countries exporting non-oil primary commodities benefited from increased demand and rising prices for their exports—despite the fact that real commodity prices are still more than one third below their 1960-1985 average. Fluctuations in commodity price on the other hand tend to constrain the ability of many developing countries to attain a path of stable and sustained growth (see Table 4.3.2-5).

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. According to UNCTAD China will become the world's largest importer of agricultural commodities in value terms by 2020; with imports increasing from US$5 billion in 1997 to US$22 billion in 2020 (UNCTAD, 2005: p59).

*The role of terms of trade.*The terms of trade are defined as the index of the value of a country's exports compared to its imports (Obstfeld and Rogoff, 1996). The movements of 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 been facing 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. 4.3.2-5). 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, 2004). Developed countries with a more varied portfolio of exports have not experienced any long-term changes in their overall terms of trade over the years. 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 were impacting negatively on African agriculture. According to Alemayehu (2000:47) price indices (1985=100) for agricultural raw material peaked in 1990, tropical beverages in 1986, and food in 1989. The African Development Bank concluded that declining and fluctuating export prices and increasing import prices are compounding socio-economic difficulties of the region – as well as agricultural patterns (Alemayehu, 2000). Moreover, short-term outlooks such as those from the World Bank expect this situation to persist. The UNCTAD's 2005 report shows that the terms of trade for developing countries exporting agricultural products will not see strong improvement. Most of the African countries exporting agricultural products are still experiencing weaker terms, while the counter part Latin American countries are showing improvements from the base year of 2000. FAO projections indicate a continuing deepening of the net trade deficit of developing countries in volume terms. Net imports of the main commodities in which they are deficit, such as cereals and dairy products, will continue to rise. Their net trade surplus for traditional exports will likely rise less rapidly (FAO 2006).

The MA scenarios give various outlooks for agricultural trade. Under the Global Orchestration scenario, trade liberalization and economic opening helps fuel rapid increases in food trade (MA 2005). Total trade in grain and livestock products increases from 196 megatons to 670 megatons by 2050, which is the largest increase among the MA scenarios. Net grain trade increases more than 200percent from 1997 to 2050. The OECD region responds to the increasing cereal demands in Asia and MENA. The very rapid yield and area increases projected in Sub-Saharan Africa turn the region from net cereal importer at present to net grain exporter by 2050. Net trade in meat products increases 674 percent. Net exports will increase in Latin America, by 23 megatons, while the OECD region and Asia are projected to increase net imports by 15 megatons and 10 megatons, respectively (MA 2005).

Under Order from Strength, trade is not encouraged, but still total trade in food commodities doubles by 2050 relative to 1997. Most trade is done intra-regionally. Under the TechnoGarden scenario, trade liberalization also grows rapidly. Total trade for grains and meat products grows to 543 megatons by 2050. Net cereal trade is dominated by Asian net imports of 124 megatons and OECD net exports of 159 megatons, and net imports in MENA of 70 megatons. Net meat trade is dominated by net imports in OECD region, supplied through net exports from Latin America, Sub-Saharan Africa, and Asia. Under the Adapting Mosaic scenario, total grain and meat trade increases to 560 megatons by 2050. Cereal trade increases by 175 percent over the 1997 levels, accounted for by increased net imports in Asia and the Middle East/North Africa region and increased net exports of the OECD region. Sub-Saharan Africa becomes a net cereal exporter by 2050. Total net meat trade increases by 31 megatons. By 2050, Asia is projected to supply about 20 megatons of livestock products to all other regions except Latin America.

4.3.2.6. Agricultural expenditures.

The investment requirements to achieve projected scenarios are seldom computed. However, cost estimates have been developed to achieve the Water Supply and Sanitation goals and investment requirements to meet the Millennium Development Goals to by 2015 have also been developed.

Rosegrant et al. (2001) estimated investments requirements in agriculture and supporting service sectors for alternative food projections. Based on an assessment of five key drivers for agricultural development: agricultural research, irrigation, rural roads, education, and clean water, they estimate investment requirements to generate modest levels of agricultural production growth at US$579 billion during 1997-2020 (Table 4.3.2-6). Levels of investments required will vary from region to region. South Asia and Latin America would require the largest levels of investment. Sub-Saharan Africa's investment requirements would total US$107 billion during 1997-2020 and would represent 19 percent of 1997 government spending on an annual basis. At the sector level, irrigation would account for 30 percent of the total investments, public agricultural research and rural roads for another 21 percent each, with educations' share being the lowest at 13 percent.

Efficiency in the use of resources will also be a source of productivity growth, and development of human capital will be key (Hayami and Ruttan, 1985). As education and extension investments increase, farmers' efficiency increases could result in higher productivity with reduced input requirements per unit of production.

4.3.2.7. Financing agricultural development.

Foreign Direct Investment (FDI) is an important source of capital flows for development. FDI for agriculture is generally lower than that of other sectors (Binh, 2004). Binh also concludes that for countries such as Vietnam, FDI in agriculture and rural areas is declining, similar to the experience of other regions. The World Bank's *Agricultural Investment Sourcebook* also shows a decline in IBRD/IDA commitments to the agricultural sector. The three-year moving average declined from over US$2,500 million in 1991-1993 to just over US$1,000 million in 2001-2003 financial years (World Bank, 2004). However, the World Bank recently introduced a Rural Strategy, which has since led to a rise in commitments in agriculture during 2001-2002, but it is not clear at this point if this level will be maintained or even further increased. This has been motivated by the need to support countries to meet their MDG goals. Moreover, while until 2000, irrigation and drainage were the most supported sectors (+US$60 million), followed by general agriculture, fishing and forestry (US$40-50 million), by 2003, commitments to irrigation and drainage had declined to about US$30 million, a level similar to agricultural commitments, in general. Other sub-sectors included crops, agricultural markets and trade, forestry, agricultural extension and research, agroindustry, and animal production. In fact, while realizing the long time lags between investment and visible impact, investment in agricultural research, education, and rural infrastructure are often the most effective areas to promote agricultural growth and poverty reduction.

Similarly, the DBSA *Activities Report 2004/05* showed a multiplier effect of R1 billion investments in various sectors on the GDP and employment (DBSA, 2005: 13). Accordingly, agriculture's impact on GDP ranked ninth among 17 sectors (evenly distributed at around R 1,000 million). However, the sector ranked number one in its impact on employment (at about 16,000 jobs). This implies that financing agricultural development yields reasonable returns.

4.3.3 Socio-political drivers of alternative futures in agriculture and AKST

4.3.3.1 Introduction: pathways of influence

This subchapter deals with the socio-political drivers of agricultural and food systems and AKST. The term "political" refers to factors that are related to politics, that is, to the processes of decision-making on public policies at the sub-national, national and international level, and to the processes of implementing these policies. The term "social" is used here broadly to refer to human society. Socio-political drivers play an important role in AKST development as emphasized in Figure 4.3.3.-1. Discussion possible future changes in these drivers, however, is somewhat complicated by the fact that knowledge is less quantitative and/or captured in a limited set of well-structured theories. Nevertheless, several useful concepts exist to allow some further steps to be made.

As indicated in Figure 4.3.3.-1, alternative futures of the agricultural and food system (Box F) — and of AKST as a subsystem thereof—are influenced by a set of direct drivers (D) and indirect drivers (Box I). Both are in turn influenced by public policies (O). For example, economic drivers are influenced macro-economic and trade policies. The development of science and technology is driven by a governments' commitment to invest in this field create an enabling environment. Obviously, agricultural and food policies have a particularly strong influence on the development of the agricultural and food systems. Therefore, the present subchapter concentrates on this policy field. The actual influence of public policies depends on their implementation, which is in turn influenced by the effectiveness of government institutions (A). The structure of the society (S) and its interaction with the political system has a strong influence on political processes and their outcomes. Also other factors such as economic factors (Subchapter 4.2.1) and educational, cultural and ethical factors (Subchapter 4.2.4) influence policy-making and implementation.

Social and political factors can also influence the direct and indirect drivers of agricultural development through other pathways than policy-making and implementation. Political stability (W) is an important factor that influences the direct and indirect drivers of agricultural development. Civil strife and internal and cross-border conflicts and wars can have a considerable negative impact on agricultural production. Social factors can also have a direct influence on the factors that are classified as direct and indirect drivers in this chapter. For example, the capacity of communities to cooperate (social capital) can influence land use, as documented in the literature on common-pool resources such as range lands and irrigation systems (Ostrom, 1990). Here, we consider changes in society (S), changes in the political system (Box P) and changes in the administrative system (A) as socio-political drivers. For an assessment of alternative scenarios for the future of agricultural and food systems and AKST, it is necessary to assess major trends of change in society and in political and administrative system. Likewise, it is essential to evaluate how these changes will influence the choice of public policies and socio-political events.

4.3.3.2 Data sources for socio-political drivers

A challenging task for assessing changes in socio-political drivers is the availability of data sources that measure these drivers in a comparable way while covering a significant number of countries. Time series data are particularly valuable to understand past trends and derive projections for future scenarios. For obvious reasons, the possibilities to project socio-political change are, however, more limited than the possibilities to project trends in other drives such as demography. The most important data sources on socio-political drivers include the ones indicated in Table 4.3.3.1.

4.3.3.3 Change in political systems and public policy choices

Different dimensions of the political system influence the choice of public policies: the type of political regime (democratic versus authoritarian), the type of electoral system, the degree of political competition, political rights and civil liberties, the political culture and the predominant political ideologies (Figure 4.3.3.1).

With regard to political regimes, the major trends after World War II were an increase in authoritarian regimes (autocracies) until the early 1970s, and a rapid decline of this regime type thereafter (see Figure 4.3.3.-2). Accordingly, the number of democracies has increased rapidly since the early 1970s. The number of “anocratic” states—intermediate states where elites maintain themselves in power despite the existence of democratic procedures—has increased, too. Based on these trends, one possible hypothesis is that such trends also continue into the future. There has also been a historic trend towards citizen participation in the formulation of development strategies. Sectoral policy documents such as agricultural sector strategies, are increasingly being developed with broad stakeholder consultation. Another important trend of change 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 and decentralization influence the choice of public policies? Even citizen participation can be considered as a value in its own right, there is no evidence that it does necessarily lead to policy choices that promote economic development. As Bardhan's (1999) comparative-institutional analysis shows, the relationship between democracy and economic development is rather complex, and the evidence from cross-country studies is not very persuasive. A recent survey of cross-country studies that focused specifically on the relationship between indicators of good governance, choice of public policies and pro-poor growth found no conclusive evidence regarding the relation between indicators of voice and accountability or political and civil liberties and various measures of pro-poor growth (Resnick and Birner, 2005). However, UNDP (2002) found that, at least, democracies do no worse than dictatorships in reducing poverty.

With regard to agricultural policy, one may assume that changes in the political systems that allow citizens to participate more broadly in political decision-making will reduce the well-recognized "urban bias" (Lipton, 1977) and increase the attention 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 for instance Fan and Rao (2003) looking into government spending). However, in democratic political regimes, agricultural interest groups are often able to exercise political pressure to get subsidies and protection, which benefit farmers individually, whereas it is more challenging to create political pressure for investments in public goods, such as agricultural research (compare Lopez, 2005).

While the evidence on the link between political regime type and general agricultural policies is inconclusive, the question arises whether democratization will lead at least to a stronger focus on food security. In his seminal work on famines, Sen (1981) showed that none of the great famines occurred in a democracy. His major argument is that famines can be avoided by fairly elementary government actions, because they are rarely caused by absolute shortages in food supply. Subsequent work showed that the freedom of press does, in fact, play an important role in avoiding food crises and famines (compare Sen and Drèze, 1989). However, the increase in the number of democracies invokes the question whether all the new democracies are in fact able to provide for enough voice and accountability to avoid food crises and famines, as predicted by Sen's argument. The latest food crises in Niger cast some doubts on this argument. The left-hand diagram in Figure 4.3.3.-3 shows a simple scatter diagram, which maps the "Voice and Accountability" index of the Aggregate Governance Indicators data set quoted above (Kaufmann et al., 2003) against the population of undernourished people (FAO, 2004). The data refer to sub-

Saharan African countries in 2002 and suggest that the relationship between these variables is not very strong. For authoritarian regimes, there is evidence that political ideologies, 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 did invest heavily in agriculture and rural development. In Africa, however, there is evidence that military leadership has a significant negative influence on public spending for agriculture (Palaniswamy and Birner, 2006).

With regard to alternative future scenarios for agricultural and food systems and AKST, one can conclude that while trend towards democratization and citizen participation in policy-making is likely to continue, the implications for agricultural policies and other public policies are not straightforward. Hence, it will be necessary to work with different assumptions when formulating scenarios.

For Asia, it appears justified to assume that a the political commitment to the agricultural sector, as indicated by a relatively high budget share to this sector, will continue.
For Africa, one can assume that the investment in agriculture will increase, because the 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).

In formulating scenarios, one also has to take into account that regional and global trade agreements limit the choices that countries can make regarding their agricultural policies (see Subchapter 4.2.1).

4.3.3.4 Public administration and policy implementation

To assess the impact of public policies on the development of AKST, it is necessary to take policy implementation into account (e.g. public service provision, the quality of the bureaucracy, the competence and independence of the civil service, and the credibility of the government's commitment to its policies). These factors can be summarized as "governance effectiveness." Figure 4.3.3.-4 displays a "government effectiveness map", based on the respective indicator in the Aggregate Governance Indicators data set (Kaufmann, et al. 2005). As the map shows, government effectiveness is particularly low in the Central African region. Various reforms have been put to increase government effectiveness and reduce corruption. One can distinguish between "demand-side" strategies, which increase the ability of citizens to demand public services, and "supply-side" strategies, which increase the capacity of the public administration and other service providers to supply public services. In AKST, public sector reform strategies are having a strong impact on agricultural extension, where a variety of reforms has transformed public sector extension into pluralistic models of financing and providing extension services (Rivera and Alex, 2005). In agricultural research, public-private partnership have gained increasing importance, too.

With regard to the formulation of scenarios for agricultural and food systems and AKST, it appears reasonable to assume that the effectiveness of policy implementation in low income countries will increase over time. However, improving state capacity is a long-term process, lasting often for several decades before a real impact can be achieved (Levi, 2004). For the governance effectiveness indicator quoted above one could not observe an improvement of average values in any of the major regions of the developing world during the last decade, in spite of all reform efforts (Kaufmann et al, 2005). Hence, for short- and medium-term scenarios, it will be useful to take the current variation in state capacity, as indicated in Figure 4.3.3.-4, into account.

4.3.3.5 Social change and political stability

There is a range of social factors that matter both for public policy choices and for political stability (e.g. ethnicity, social stratification, social values and the capacity of communities and societies to cooperate, also referred to as social capital (see, e.g., Putnam, 1993)). In view of the complexity and country specificity of social factors, it is difficult to identify general global trends that can be considered in formulating scenarios. There are, however, some projections on global trends that may be considered. Based on the findings from the World Values Survey (see above) covering societies on all six inhabited continents, Inglehard and Welzel (2005) predict that economic development gives rise to cultural changes that make individual autonomy, gender equality and democracy increasingly likely.

These findings correspond to the “End of History” view that liberal democracy and Western values have become the only remaining ideological alternative for nations in the post-Cold War world (Fukuyama 1993). This view has been challenged by the controversial “Clash of Civilizations” theory popularized by Samuel P. Huntington (1996). Huntington’s thesis is 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 (Figure 4.3.3.-4). Huntington argues conflicts will be particularly prevalent between Islamic and non-Islamic civilizations. While the events of 9/11 and the Jyllands-Posten Muhammad cartoons controversy are often quoted as evidence for his predictions, his theory remains controversial, especially since he relies mostly on anecdotal evidence and plausibility arguments. More rigorous empirical studies, such as that of Tusicisny (2004), do not find evidence for a particular increase in the frequency of intercivilizational conflicts in the post-Cold War period. 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.

Goldstone et al. (2005) define instability as the incidence of revolutionary and ethnic wars, adverse regime changes, genocides or politicides (government targeting of specific communal or political groups for destruction). As Figure 4.3.3.-6 shows, the percentage of countries experiencing periods of instability increased until the early 1990s, reaching a peak of almost 30 %. Goldstone et al. (2005) develop a predictive model, which has essentially four variables: regime type, infant mortality, a “bad neighborhood” indicator (flagging cases with four or more bordering states embroiled in armed civil or ethnic conflict), and the presence or absence of state-led discrimination. Comparing models of different complexity, the authors found that a rather simple model based on these variables was over 80% accurate in distinguishing countries that experienced instability two years hence from those that remained stable. The study also shows 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 if the economic conditions are favorable.

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. Another conflict-related problem that affects agriculture is the threat of agroterrorism. While this threat is more relevant for industrialized countries, one should not neglect agroterrorism as a potential problem for developing countries, because they are far more vulnerable to attacks on their agricultural and food chains than industrialized countries (Linacre et al., 2005). 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 to due displacement of agricultural producers.

4.3.3.6 Socio-political factors in existing assessments

it is necessary to take political stability into account when formulating future scenarios, instability has far-reaching implications for agricultural and food systems and AKST. As for other socio-political drivers, however, predictions are difficult to make in view of the controversies on this topic. Still, predictive models—such as the one developed by Goldstone et al. (2005) quoted above—are available and can be used for formulating future scenarios. So-far, these factors have played nevertheless an important factor in developing storylines. An important example is formed in several studies that further specified the storylines of the IPCC-SRES study (MNP, 2005; MA, 2005). The possible development routes for political systems hypothesized earlier in this subchapter: 1) further global convergence towards Western style democracies (‘The End of History), 2) the re-emergence of regional emphasis (Clash of civilizations), 3) formation of global governance and 4) emphasis of local autocracy. Similar storylines were developed in the Millennium Ecoystem Assessment. As argued in this subchapter, the uncertainty in development of socio-economic drivers can have major consequences in AKST.

4.3.4. Science and technology

4.3.4.1 Introduction

Importance.

The growth of economies throughout the world since the industrial revolution began has been driven by continual technological innovation through the pursuit of scientific understanding and application of engineering solutions. Scientific breakthroughs and technological innovations in the 20th Century fueled substantial gains in agricultural productivity in many countries (USDA, 2003). Agricultural production technologies and practices have been developed to improve soil, water, nutrient, and pest management, which contributed to a steady increase in labor productivity, crop yields, yield stability, and sustainability in food production systems. These innovations have also improved the productivity of livestock systems and have expanded the variety, quality, and safety of foods, especially in developed and transitional economy countries. These innovations not only helped in meeting world food and fiber needs but, along with new transport and storage technologies, transformed much of agriculture from subsistence to commercial market-oriented farming, thus offering more opportunities for participating in global markets.

Clearly technology will impact other important indirect and direct drivers of change in agriculture, such as population, economic growth, labor, food consumption, energy, climate and natural resources. Although technology is frequently considered the core driver of both economic growth and global social and environmental change, it is difficult to incorporate its impacts into models of global change. This subchapter focuses first on reviewing the discussion of science and technology as a driver of global change in previous global assessments. This is followed by a review of future trends in important drivers of science and technology, including funding, performance, and adoption, and concludes with a discussion of the implication of these trends for agriculture systems in the future.

Previous assessments of role of science and technology in global change. The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (2000) contains a detailed discussion of approaches to and problems encountered in predicting the impact of science and technology on global change. There is general agreement that the adaptation of a new technology is predicated on new discoveries (research), the implementation of those discoveries for specific purposes (development), and the diffusion of the technology. As a particular technology ages, it may no longer be able to be improved upon or it may have undesirable features, thus creating the potential for new technologies to develop (Grubler 1998). The IPCC identifies five commonalities in the innovation process (Table 4.3.4.1). Although the IPCC is particularly concerned with how the innovation process may impact the energy sector, these five generalizations could reasonably be applied to the agricultural sector.

There appears to be widespread agreement that the innovation process is complex and difficult to model. Clearly, the commonalities listed in Table 4.3.4.1 cannot easily be incorporated into economic and environmental models. There is still not widespread agreement on what assumptions to make regarding 1) how government and industry investment in research and development (R&D) will impact the innovation process, 2) the motivation of producers of new technologies and 3) the role of consumers. For example, while public and private investment in R&D is vital at the beginning of the innovation process, “learning by doing” is also important. Producers may be driven to invest in new technologies not only to increase profits but also to hedge risks. Some technological innovations involve a change in consumer preferences while others give them more of what they already want. Although in the IPCC report these issues are discussed primarily from the perspective of the energy sector, they apply to the innovation process in the food system as well.

The Millennium Ecosystem Assessment (MA) (2005) recognizes science and technology as a major driver of change in ecosystems and their services. This assessment identifies two key concerns regarding technological trends. The importance and success of public institutions in the industrial world in fostering the research and development process is recognized but is coupled with a concern that such institutions are not yet well established in much of the developing world. There is also apprehension that the rate of spread of new technologies may be outpacing the time frame required to identify and address negative consequences.

In the Global Environment Outlook report (GEO 3) (2002), there is a focus on the distribution of the 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 with most power in the marketplace. In contrast, if in the future there is more caution on the part of governments and more power on the part of consumers, technological innovation could be slowed, but also result in more equitable distribution of benefits and fewer negative impacts.

Most global models treat technological change as an exogenous variable, aggregating technological changes into trend parameters. An example in agricultural macroeconomic models would be incorporating a factor (e.g. fertilizer, water) use efficiency parameter that could increase over time as the result of improved technologies. The limitation of this approach is that the future is constrained to being a more or less gradual extension of the past, whereas historically the innovation process has led to fundamental changes in global systems. However, models that pursue a microeconomic approach, in which the innovation process is endogenous and that include both uncertainty and learning, have been developed to explore energy technologies, and could be used to inform macroeconomic approaches to predicting global change (Grubler et al.1999).

4.3.4.2 Future trends

Trends in funding. Although the innovation process is complex, funding for research and development is considered a central driver of this process. As the innovation process in agriculture can be catalyzed by new discoveries in many different areas, it is appropriate to consider trends in all R&D funding. Typically, the ratio of R&D expenditures to GDP is used as an indicator of the intensity of R&D activity over time and in relation to other economies. Though the United States far outspends any other nation in R&D (it accounts for more than one third of the world's R&D expenditures), several countries maintain higher R&D to GDP ratios (Table 4.3.4.2).

China has recently more than doubled its spending on R&D, progressing from 0.6% of GDP in 1995 to 1.3% in 2005. This increase, coupled with the projected growth of the Chinese economy, means that by the end of 2006 China will be the second largest investor in R&D (Figure 4.3.4.1, OECD 2006). Many countries, including China, have explicit goals to increase their R&D spending over the next decade (Figure 4.x, OECD 2006). R&D as a fraction of GDP has been maintained at high levels for decades in the United States and Japan. Since 1956, the United States R&D share of the GDP has not been less than 2%, ranging to as much as 2.9% and averaging about 2.5%. Together this data strongly suggests that R&D spending will increase in the future both absolutely and as a percentage of total global economic activity.

It is clear from Table 4.3.4.2, that many countries outside North America, Western Europe and East Asia with small economies also have very low investments in R&D. In addition, there is concern that funding for agricultural R&D is declining in North America, Western Europe and East Asia. For example, in the United States federal research support for agriculture has been flat or declining over the last twenty years (AAAS website). This suggests that global R&D may have declining relevance to the agricultural sector of lesser developed countries, who will in turn have a declining share of global R&D. However, there are several trends in R&D funding that could to some degree moderate these problems. 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 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 2006). Thirdly and perhaps most importantly, China, with a very large, poor, rural population, is now the country with the second largest R&D expenditures. It is plausible that China will shortly become the major center for agricultural research, particularly research relevant to poor rural areas.

Trends in performing sector

a) Increased role of private sector

In the 20th Century, the key institutional innovators were national agricultural research systems that included universities, agricultural field stations, agricultural input companies, and extension services covering the chain from basic crop improvement research via field trials to disseminating information and new seed material to farmers (Ruttan 2001). For the agricultural technology advances of the Green Revolution, the contributions of the international agricultural research centers, in particular CIMMYT in Mexico and IRRI in the Philippines, were essential. Funding for these new institutions was mainly provided by the public sector in the first half of the century.

Though in labor-scarce countries, particularly the United States, the private sector has always played a central role in the development of agricultural machinery, the performance of agricultural research and development has generally shifted from the public to the private multinational sector. Three interrelated forces in this latter wave of globalization are transforming the system for supplying improved agricultural technologies to the world's farmers. The first is the evolving environment for protecting intellectual property in plant innovations. Private-sector research grew substantially in the last decades of the 20th century as the private sector gained legal rights to protect genetic modifications (Huffman and Evenson 1993).

The second force is the rapid pace of discovery and the growth in molecular biology and genetic engineering. The future potential of biotechnological will be driven by demands for specific traits and crops to address food security and environmental concerns. Particularly, the next generation of GM crops could be staple foods such as rice which is consumed by millions of people around the world (Loppacher and Kerr, 2004). Advances in this area are already on their way. For example, the recent release of genetically modified rice called "Golden Rice" which is rich in Vitamin A and could cover Vitamin A deficiency in 124 million children worldwide underscores the technology of the future (IICA 2002-2006). Value added output traits with consumer-oriented benefits, such as improved nutritional and other health-related characteristic would attain maximum attention of the private sector because these will turn many agricultural commodities into premium priced and quasi-specialty products (Shimoda, 2004). Internationally competitive biotechnology research and development systems are expected to emerge, accelerating the pace of biotechnology research. The number of biotechnology research laboratories may increase.

Although the investment in biotechnology is at rise in various countries, there are uncertainties about the political and economic costs associated with it. There are still unresolved international conflicts over environmental and public health safety. The opponents of GM products and environmentalists are resistant to GMO's due to the perceived environmental and health related risks associated with these products. The EU has imposed stringent regulatory requirements on foods containing or produced from GMOs - the exporting countries need to be listed by European Commission as complaint with EU food safety rules (Meijer and Stewart, 2004). On the other hand, various trade pressures are coming from the GMO exporting countries, like USA and Canada. The "GM cold war" caused by international conflict, legal uncertainty and fragmented and uncoordinated development assistance is leading to paralysis and/or difficulty in developing countries decision making regarding GMOs (Meijer and Stewart, 2004).

Finally, agricultural input and output trade is becoming more open in nearly all countries. These developments have created a powerful new set of incentives for private research investment, altering the structure of the public/private agricultural research endeavor, particularly with respect to crop improvement (Falcon and Fowler 2002; Pingali and Traxler 2002).

b) Participatory research/indigenous knowledge

In the decades of 1980s and 1990s the international research under CGIAR together with national agricultural research/extension systems launched On-farm Client Oriented or the so-called Farming Systems Research and Extension (FSR/E) approaches in developing countries to integrate local knowledge and local circumstances in modern science research and technology as part of the sustainable development agenda and with the goal of producing technologies relevant for resource poor farmers operating in diverse and often marginal agroecological conditions. As a result, local knowledge has become part of the policy documents in those years. In recent years as well local knowledge is being emphasized through advocacy and pressure from environmentalists who are now much more aware of environmental consequences of modern science application under local circumstances. Nevertheless, the debate of the indigenous knowledge and its harnessing into modern science and technology is currently limited only to social academic institutions and their scholars or environmental agencies.

The terms 'indigenous' and 'local knowledge' are used to refer to knowledge that is generated and transmitted by communities, over time, in an effort to cope with their own agroecological and socio-economic environments. This knowledge is generated and transformed through a systematic process of observing local conditions, experimenting with solutions, and readapting previously identified solutions to modified environmental, socio-economic and technological situations (Brouwers, 1993). This knowledge is learnt and acquired through a practical experience of centuries, transferred from generation to generation and stored in the form of local knowledge system specific to local conditions, needs and priorities. A better engendered understanding of local knowledge systems can contribute to effective development efforts that are equitable, and socially, environmentally and economically more sustainable.

Modern science and technology, despite the fact that it draws its biogenetic material from nature, is often developed in isolation from or with little attention given to socio- cultural contexts and existing knowledge systems. Perhaps the biggest reason this is the case is due to the complexities involved in collecting and harnessing local knowledge. All communities live with their unique cultural and social systems with geographic limitations that make up unique knowledge system only applicable to the particular community. Given the universal nature of its application and commercial nature of its development, modern science and technology cannot bear the capacity of absorbing local knowledge and technology. It has a natural aptitude of downstream flow which requires tremendous amount of energies for diversion.

Another complication for isolation is the number of problems related to the collection, analysis and then translation into adaptable packages of knowledge which is an arduous challenging and time consuming task for the agents of modern science and technology who are more driven by the fast economy growing factors and drivers. Harnessing of local knowledge is a multistakeholders’ task which requires involving NGOs, local line departments, informal institutions, and donors. To some extent it also requires support from the decision making bodies, enabling policies and an extensive research infrastructure not only at national level but also at local level which is highly expensive and incompatible in the fast growing economies. Most of the countries gaining larger benefits by the global trade of modern agricultural technology may discard the idea by saying it is infeasible. Some governments and multinational companies can initiate certain efforts but that may not be expected to be linked with broader modern science and technologies due to lack of profitability.

The programs and policies of most organizations tend to be the object of a sectoral rather than a holistic approach which ignores the real-life concerns, priorities, knowledge and experience of rural community systems. Areas such as gender, indigenous knowledge systems, and science and technology have been dealt with separately, thus continuing the marginalization and, in some cases, exploitation of peoples and their knowledge systems.

Since the World Summit on Sustainable Development (WSSD) held in Johannesburg in 2002, an increasing amount of research on indigenous knowledge systems is now coming to the fore. Non-governmental 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 indigenous knowledge systems of both men and women. This would be necessary to encourage the innovation processes of both local communities and researchers in the future. If indigenous knowledge systems are to continue to contribute to the quest for sustainable development, their capacity to focus on diversity and locality as well as to innovate on the basis of gendered-knowledge-generating processes must be recognized and respected.

Trends in Adoption

a) Underutilized technologies

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).

To get science and technology to contribute to increased agricultural production therefore goes considerably beyond identifying a limiting soil factor, introducing an insect-resistant gene in a crop, or developing a vaccine against a livestock disease. Little thought has been given to the so-called utility functions of poor farmers, what are bits of new science that they could adopt with little risk, and what is new and risky science that would require significant guarantees from the state (or insurance) companies to adopt, including the chances of getting fair, predictable prices in the marketplace. The low-risk bits may not always give high-productivity gains, and if that is what we are looking for to meet the Millennium Development Goals (MDGs), we may wish to suggest and guarantee high-risk science products. The corollary of these arguments is that many existing on-the-shelf technologies could become adopted if the perceived risks of using them were significantly lowered or if some of the other bottlenecks to hinder adoption, such as missing input supply chains, better marketing channels for surplus production, access to credit or new knowledge. However, there seems to be few advocates of existing goods. Even scientists tend to lose interest in established knowledge, since the award system encourages the development of new science, not necessarily the application of existing one.

For example, there are clearly major scientific breakthrough to come from genetic engineering of crops, animals, fish and soil micro-organisms. The unraveling of the genetic codes is the first step towards understanding the determining protein structures that may code for quantitative and qualitative improvements in agricultural productivity. But for this to be accepted in poor farmers' fields is a much more complicated matter, scientific environmental concerns apart. High costs of planting material, restrictions on the replanting of own seeds, uncertainty of market acceptability of a GMO crop – these are among many considerations a risk-averse farmer may have. If scientists and technologists fail to become part of a framework that addresses these real concerns farmers have, their technologies will almost invariably fail, or become socially divisive.

b) Information Technology

Rapid changes in information and communication technologies offer new challenges and opportunities for the agricultural sector. Computers, fiber optics, wireless, on line internets and satellites are now used by developed country farmers that provide easy and immediate access to information on markets, trade opportunities, consumer preferences, and competitors around the world (IICA 2002-2006). They also facilitate advertising, promotion and dissemination of information to potentially new clients and consumers. Farmers, agricultural researchers, cooperatives, suppliers and buyers use the internet to exchange ideas and information as well as to conduct business with each other.

To make information and communication technologies more effective to small-scale, resource poor farmers in rural areas, however, governments would have to increase investment in education and develop physical infrastructure such as roads and electricity in these areas (USDA, 2003). However, the use of information and communication technologies is already gaining importance in many developing countries. Already access to television, telephone and internet facilities are rapidly spreading to rural communities in developing countries. Public sector extension presently available to farmers has outlived its utility in these areas, replaced by farmers' cooperatives, specialized market-based organizations and private companies (Swaminathan, 2001). Farmers now have access to more information from the private sector, market intermediaries, input suppliers, integrated producers, cooperatives and less from the public sector.

4.3.4.3 Implications for agriculture

AKST has shaped agriculture in the 20th Century, increased agricultural productivity and created opportunities for reducing hunger and poverty. However, the innovation process is complex, making it difficult to predict the future impact of new technologies on agricultural systems. In addition, changes in agricultural systems are not solely, or in some cases even primarily, technologically driven.

It is known that resource-poor farmers are normally very risk-averse. The application of new technologies and methods inevitably carries inherent dangers of failures. Without financial and social safety nets failures may be devastating, and pose threats to social stability, health or even lives. Richer farmers and those with the guarantees offered by welfare states can be risk-loving. The promises of greater profits may be risks worth taking. Even a bankruptcy may not be life-threatening. Society has many safety nets and the risk-taking attitudes of such farmers encourage science and technology developments and implementation. The productivity successes of temperate agriculture have arisen in the context of farmer willingness to adapt new science-based technologies. The relative lack of productivity gains in developing countries may be understood as natural farmer reluctance to take the perceived risks involved with new things. Only when the risks are partly carried by others, as was the case with some of the implementation of the Green Revolution in Asia, do farmers come forward to capitalize on new science. Simplistically speaking, most developing country farmers lack or cannot afford crop insurance and livestock insurance, do not live in public welfare systems, and cannot risk taking risks. Simple game theory will support this conclusion.

If geared towards local farmers' needs (e.g., weather information for farmers, information on timing of operation and input use, input and product market information etc.), they can greatly benefit from the use of modern communication technologies. Disseminating and adapting information and communication technologies according to the requirements of resource poor and illiterate farmers could become a major future challenge in the developing economies.

Overwhelming evidence from both the developed and developing world demonstrates that agricultural knowledge, science, and technology (AKST) are important drivers of food systems, impacting both the quantity and quality of the services they provide. However, it may be unduly simplistic to consider agricultural progress as primarily science and technology-driven. Government policies and support, as well as the creation of functional markets, farmers cooperatives, preferential credit systems, and extension systems all represent elements of the AKST framework that have allowed science and technology achievements to have impact on production methods and productivity. For example, the Green Revolution strategy for food crop productivity growth was explicitly based on the premise that, given appropriate institutional mechanisms, technology spillovers across political and agroclimatic boundaries can be captured. In addition, high rates of investment in national crop research, infrastructure, and market development combined with appropriate policy support fueled the resulting growth in land productivity (Pingali and Heisey 2001).

4.3.5 Education, culture and ethics

This subchapter briefly addresses education, culture and ethics as indirect drivers of agriculture. Although it is clear these diverse and complex components of human society impact agriculture, it is very difficult, particularly in the cases of culture and ethics, to simplify, quantify and measure these impacts. This, in turn, makes projecting how education, culture and ethics are likely to change in the future, and how these changes may impact agricultural systems, problematic at best. Nevertheless, a few key trends within these drivers that could have important impacts on agriculture are addressed in this subchapter, including cost benefit analyses of educational spending, consumers' attitudes toward food, and sustainability concerns.

4.3.5.1 Education

Many international institutions 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 (CGIAR, 2004; FAO, 2006; World Bank, 1994; UNESCO, 2006). There also are programs implemented by institutions from developed countries (e.g. Noragric[1]) to help individual developing countries identify and address problems with their rural education systems (Noragric, 2004).

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 few assessments, scenarios or projections of plausible futures for educational policies directed toward this end. UNESCO's databases[2] shows 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. Forecasts to 2015 of the change in this population for different age-classes is presented in Table 4.3.5.1. Two features stand out from the data: (a) projected changes in school age population is highly variable among countries(as the values of the confidence intervals show); and (b) the change in the population aged 5-14 could be zero, because in some countries this age group decreased, whereas the opposite trend was predicted for other countries in this group.

[1] Department of International Environment and Development Studies Norwegian University of Life Sciences
[2] http://www.uis.unesco.org/ev_en.php?URL_ID=3753&URL_DO=DO_TOPIC&URL_SECTION=201

One important unknown is which proportion of the populations aged 15-19 and 20-29 would receive a rural (or agricultural) higher education or training or both. 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 the opposite–i.e. a decreasing share of the GDP–is likely to occur in those countries in transition to a larger-scale and/or more mechanized agriculture. While this agricultural transition will require less unskilled manpower, 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.

The reform and upgrading of educational systems are very likely to be expensive, and the more so when the existing systems are dysfunctional due to neglect, corruption, war or social unrest. There are many methods for estimating the costs and benefits of policies; the cost-benefit analysis (CBA) is possibly one of the most used. Rates-of-return (RRs) obtained from CBA provide policymakers a kind of foresight, because their estimation entails taking in some perception of the future, even if those rates are calculated from past values and assumptions. When education is the object of an economic study, the use of CBA is definitely difficult and frequently controversial, particularly in developing countries (Hough, 1993). A frequent criticism raised to some published values for rural education RRs is that they could have been different if non-economic benefits of education had been taken into account (e.g. the social benefits to society from agricultural research and education, to name a few). However, to be fair, the economic values of many of these omitted beneficial effects are very difficult to assess. Hough (1993) compiled and summarized the results of many CBA studies for developing countries in Africa, Asia and Latin America between 1960 and 1985. Major conclusions from this study were (i) private RRs[3]are always higher (27 %) than social RRs[4] (19 %); (ii) RRs are always highest (32 %) at the lowest, primary, level of education, but they varied 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); (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.

[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.

Cost-benefit analysis has many shortcomings, but these are no worse than other methodologies. Researchers still using CBA are presumably interested in improving and refining it in order to get better and more representative values for rates-of-return. Even if these might not be very precise, they would be useful to inform governments on how to invest public funds in policies with the highest rate-of-return (McGavin, 1991)

4.3.5.2 Culture

Culture has had–and continues to have–a profound influence in the creation of new agricultural systems, as well as on the continued management of existing agricultural systems.. On one extreme of an imaginary line connecting the human collective with the individual, agriculture is taken as part and parcel of a cultural cosmovision that binds individuals to particular worldviews, moral values and preferred ways of life (MEA, 2005). This is the case in traditional and indigenous agriculture, whose cultural richness should not be lost; on the contrary it should be the subject of interdisciplinary inquiry by research organizations and universities (Thaman, 2002; Rist and Dahdouh-Guebas, 2006). However, the future of traditional agricultural systems may be bleak if the materialist-rational paradigm fuelling economic development (Groenfeldt, 2003) leads to replacement of traditional production systems with others which can be more readily adapted to environmental shocks such as the changing climate caused by global warming (cf. Borron, 2006), natural resource depletion (e.g. irrigation water), and pollution. In the materialist-rational paradigm agriculture is viewed as a means of producing food. In this view, agriculture–also known as 'conventional' or 'industrial' agriculture–may be either an independent family-enterprise or one which is an integral part of some food chains[5]. These chains are created and operated for a profit, and the largest ones are more often than not owned by transnational companies, and not necessarily unsustainable (IFAP, 2006).

On the other extreme of that imaginary line connecting the human collective with the individual stand individuals with their feelings and beliefs, imbedded in their particular circumstances. These define a set of states of happiness and wellbeing, which partly materialize into consumers' demands for quantity, quality and kind of foods. Changes in diet seem to mostly follow closely changes in income, irrespective of cultural mores, religious beliefs or geographical location (FAO, 2002). At equivalent incomes, cultural differences become conspicuous drivers of food quality and type; e.g. Hindus abstain from beef or meat in general, Moslems and Jews from pork (FAO, 2002). Traditional and indigenous foods and meals are in demand by–besides those culturally

[5] A food chain for a particular food (e.g. milk) is a system composed of a sequence of subsystems, starting at the primary production subsystem and terminating at the final consumption subsystem. The food chain include variously skilled persons like farmers, fishermen, slaughterhouse operators, food processors, transport operators and distributors (wholesale and retail). From FAO (http://www.fao.org/ag/agn/food/quality_foodchain_en.stm)

bound to them–mostly urbanites of refined tastes or devotees of alternative medicinal therapies. However there are no general assessments of the importance of selective demands for special foods on their production.

Organic agriculture[6] is to some extent the Judeo-Christian counterpart of either indigenous or traditional forms of agriculture (IFOAM, 2006). It is possible that small farmers from LDC[7] countries could adapt to the likely impacts of climate change by increasing the resilience of their farming systems by adopting the practices of organic agriculture (Borron, 2006). Organic agriculture is also deemed the answer to avoiding the environmental maladies brought about–in the view of many of its advocates–by capitalism (Macilwain, 2004; La Vía Campesina, 2006). North America and Europe account for 97% of global organic food and drink sales (Willer and Yussefi, 2004). It is clear that the production and export of organic food might be a promising way (*pace* trade barriers) out of poverty for poor farmers in developing countries.

Concern for food quality and type are unlikely options for the poor and hungry when undernourishment and disease are everyday experiences. The fast and effective remedying of undernourishment and disease requires and will continue to require increasing staple food productivity or production or both; hence policymakers will be faced with a balancing act between producing sufficient food and the sustainability of that undertaking. Presently organic farming is an option to industrial agriculture from a productivity standpoint (Badgley et al., 2006), but organic produce is currently more expensive in the market because of the proliferation of standards, labels and farm subsidies (OECD, 2002; Cáceres, 2005). It is likely that these obstacles to organic farming will be progressively removed, as in the medium-term agricultural trade becomes freer, and more people become concerned with the care of the environment and the conservation of natural resources.

4.3.5.3 Ethics

Ethics cannot be neatly separated from Culture, because the latter sets the meanings of both 'right' and 'wrong' behavior, which Ethics is supposed to systematize and defend (IEP, 2006). Agriculture belongs to the province of ethics as a notion; i.e. the opposition between sustainable ('good') and unsustainable ('bad') agriculture. The latter is frequently judged to be the result of the

[6] "Organic agriculture is holistic production management systems which promotes and enhances agroecosystem health, including biodiversity, biological cycles, and soil biological activity... Organic production systems are based on specific and precise standards of production which aim at achieving optimal agroecosystems which are socially, ecologically and economically sustainable. Terms such as "biological" and "ecological" are also used in an effort to describe the organic system more clearly. Requirements for organically produced foods differ from those for other agricultural products in that production procedures are an intrinsic part of the identification and labelling of, and claim for, such products." From the *FAO/WHO Codex Alimentarius Commission Guidelines for the Production, Processing, Labelling and Marketing of Organically Produced Foods, 1999*

[7] Least Developed Countries.

‘productionist paradigm’, in which people’s relationship to land and food is reduced to the production and consumption of commodities (Campbell, 2000). However, sustainable agriculture should not be viewed as inimical to the use of technology (Korthals, 2001). Technology may be further qualified as either ‘good’ (for some) or ‘bad’ (for others), as the creation and use of GMOs, productivity intensifiers (i.e. chemical fertilizers, growth hormone, etc.), biocides (i.e. pesticides), organic farming, to name a few, illustrate. Some of these technologies pose ‘macroethical problems’ because they are embedded in, and adapted, to society (Allenby, 2006).

Ethical issues taken as either categorical imperatives or values of fairness may be some of the most important philosophical foundations for social movements’ intent on reforming the present utilitarian society mores (e.g. La Vía Campesina, 2006). However, there are no hard data demonstrating that ethical concerns of consumers have had any substantial impact on the what, the where or the how of food production. Consumers with such ethical concerns might well be well-nourished urbanites having some political clout to influence food production and processing and the scientific research and technological development related to them, or they might well be the poor and hungry, which generally lack a coherent, loud and efficacious voice.

The use of biotechnology for altering the genomes of animals and plants in order to reduce the production costs of commodities or adapt organisms to adverse climatic impacts (e.g. droughts, warm spells) brought about by a changing climate, to reclaim polluted lands (e.g. by arsenic), or to recover mismanaged lands (e.g. salinization) promises considerable benefits, but will likely raise ethical concerns about food and environmental safety (FAO, 2002). Therefore, it is likely that policymakers must become increasingly proficient in weighing the pros and cons of technological advancements against their externalities, in a context of strict international regulation of their use (Evans, 1999).

Presently there is an almost universal consensus among social networks, governments and international policy institutions on the urgent need to adapt current agricultural systems to sustainable production principles and improved nutritional and health standards. There also is some sense of urgency to create new and sustainable production systems in harmony with the landscape, biodiversity and rural populations. The UN System Network on Rural Development and Food Security[8] is a commendable endeavor in those directions.

Expediency will probably encourage policymakers to permit the production of food with a minimum tolerable compliance with sustainability principles. Diverse stakeholders will on their part press for various policies, ranging from those restricted to improving the sustainability

[8] www.rdfs.net/about/about_en.htm.

(viewed as an accounting of the balance in resource availability) of production systems to those addressing the social, political and economic renovation of society as a fundamental requirement for attaining sustainability. The way forward to assuaging macroethical concerns is emphasizing research to dispel them, in an increasingly multicultural society where actors recognize that their personal belief structures are contingent and limited, and also accept and respect other worldviews that may be not just different, but contrary to theirs (Allenby, 2006).

4.3.6 Biogeophysical environment

4.3.6.1 Biogephysical factors and agroecosystems

Dynamic interactions exists between biogeophysical processes and the agricultural system (Gregory et al., 2005). Given the importance of the biogeochemical cycles, somehow maintaining the integrity of these cycles forms an important element of any sustainable development strategy. Achieving these goals requires planning and action at local, regional, and global levels and specifying short- and long-term objectives that allow for the transition to sustainability.

Agriculture is a major contributor of the greenhouse gases methane (CH_4) and nitrous oxide (N_2O) (Gregory et al., 2005). Human activities including farming and industry have greatly increased the cycle of nitrogen through soils, water courses, and the atmosphere. By accumulating more nitrogen in a form that can be taken up by plants, the balance of ecosystems can be seriously upset (Figure 4.3.6.1). Also changes in the physical properties of the landscape modify the fluxes of energy and moisture between the surface and the atmosphere. Surface albedo depends on the vegetation cover, and is lower in a forested landscape than in open land because more solar radiation is trapped by multiple reflections within the forest canopy (Gregory et al., 2002). The quantification of potential future biogeophysical effects of agricultural intensification on climate and vise versa is difficult although attempts by Petoukhov et al. (2000) using a sensitivity experiment with a climate system model of intermediate complexity CLIMBER-2 (Petoukhov et al., 2000) gave useful insights. Agricultural intensification acts as both sources and sinks of several different greenhouse gases, chiefly CO_2, CH_4 and N_2O. The relative size of these fluxes can vary widely depending on the practices and the environment in which these occur. All the three gases are also emitted from burning increased crop residues and from fossil-fuel consumption associated with both off-farm production of inputs such as fertilizers (Izaurralde et al., 2000) and from on-farm fossil-fuel-based activities such as mechanized tillage. Carbon sinks can, however, be created by increased carbon input through increased yields (Paustian et al., 1997), changes in rotation management such as increased fallow length, agroforestry (Woomer et al., 2000), or inclusion of pasture leys (Grace et al., 1997). Addition of lime to offset acidification of soil can also increase the size of the carbon sink (Ridley et al., 1990), but this benefit can be negated by emissions of CO_2 during both the production and distribution process and subsequent breakdown in the soil. In the Subchapter on Climate Change (4.4.4) we go more into detail on the role of agriculture in climate change – and climate change mitigation.

4.3.6.2 Global nitrogen cycle

Human activities increasingly influence the global (and regional) nitrogen cycle (Galloway et al., 2004). The two human-influenced processes that influence the global nitrogen cycle mostly are fertilizer used for food production and fossil fuel combustion to produce energy. There is a direct link between the size of the (global) population and the use of nitrogen, because of the need of an increased food production and growing energy demand. A second link exists with welfare.

Nitrogen that is biological available, reactive N (Nr), includes nitrate ($NO_3^{-)}$ and ammonia (NH_4^+). Natural processes converting N_2 into Nr are lightning and biological nitrogen fixation (BNF) (figure 4.3.6.2). Cultivation-induced biological nitrogen fixation (C-BNF) and production of fertilizer, plastic and fibers (the Haber-Bosch process) are anthropogenic processes contributing to the conversion of N_2 into Nr. Besides, the combustion of fossil fuel mobilizes stored Nr and creates Nr by the oxidation of N_2. Other processes that play a role within the global nitrogen cycle are deposition, emission, leaching and riverine export. Denitrification of Nr into N_2 takes place due to microbiological processes.

Galloway et al. (2005) estimated the anthropogenic processes (C-BNF and fossil fuel combustion) accounted for 11% of total Nr creation in 1860. About 15 Tg N yr^{-1} of the 15,3 Tg anthropogenic created N yr^{-1} in total was converted by C-BNF. Due to the production of energy and invention of the Haber-Bosch process, the conversion of N_2 to Nr increases from 141 Tg N yr^{-1} to 268 Tg N yr^{-1} in the early 1990s, of which 55% has been converted by anthropogenic processes. C-BNF doubled to 31,5 Tg N yr^{-1}. Nr creation by the Haber-Bosch process increased from 0 to 100 Tg N yr^{-1} and fossil fuel combustion from 0,3 to 24,5 Tg N yr^{-1}. Natural biological Nitrogen fixation has been decreased (from 120 to 107 Tg N yr^{-1}), due to conversion of natural ecosystems in agricultural land (Galloway et al., 2005).

Within the nitrogen cycle two flows are difficult to define (Galloway et al., 2004). First, the proportion between Nr stored in the soil and denitrification is a large uncertainty. Secondly, the spatial distribution of natural BNF is relatively unknown. The current hypothesis is that the warmer regions like Asia and Africa do have more natural BNF (Galloway et al., 2004). Denitrification in agroecosystems can be a mechanism of important loss of fertilizer or soil nitrogen, but it can also convert potential harmful nitrate to N_2 (Mosier et al., 2002). However, the role of denitrification within these systems is still unknown according to the variation of denitrification rates in different studies (Galloway et al., 2004).

There is a large variability in N-budgets at the regional scale. Conversion of N_2 in Africa and Latin America mainly occurs by BNF, while fertilizer production dominates in North America, Europe and Asia. In Asia, the riverine transport of Nr to the coast is the highest (Galloway et al., 2004).

In the Millennium Ecosystem Assessment (2005), several projections are compared to the scenarios of the assessment. Use of fertilizer N has been estimated to grow from 85 Tg in 1990 to around 100 Tg in 2050 in the scenario emphasizing technology and to 140 Tg in the scenario emphasizing economic growth and globalization. Other scenarios project fertilizer N use in between those two extremes.

While increased agricultural productivity is a key step in reducing rural poverty (Von Braun et al. 2004), this may further increase the human impact on biogeochemical cycles. Over the last 50 years, farmers globally have doubled irrigated areas, have more than doubled the crop yields, and have increased the number of crops grown in a field per year. More understanding of how these changes relate to or feedback into biogeophysical systems is needed in order to project better the effects of future policy and management decisions as well as trends in AKST. Scenario analysis and simulations as well as the use of atmospheric general circulation models coupling the atmosphere, land and ocean/sea/ice may project interactions in the elements of the biogeophysical systems in relation to food systems. For instance, Lobell et al. (2006), shows that increased irrigation, reduced tillage, and higher yielding crops are projected to cool surface temperatures depending on land use type. The simulation study by Lobell et al. (2006) also revealed that reduced tillage is likely to have cooling effects by indirectly raising the planetary reflection of sunlight. The biogeophysical dynamics and their relationships with land cover changes have been modeled by Brovkin et al. (2006) indicating that in the future, reforestation might be chosen as an option for the enhancement of terrestrial carbon sequestration. Their study indicates that biogeophysical mechanisms need to be accounted for in the assessment of land management options for climate change mitigation. Anthropogenic change in land cover has been a substantial climate forcing during the last several centuries and is projected to continue to drive climate change.

4.3.6.3 Scenarios of biogeophysical factors in agriculture

Different scenario processes have projected changes in biogeophysical factors to take different states in the next decades. Most of this work concentrates on the role of natural and man-made ecosystem in climate change, something that is discussed further in this chapter. The IPCC predictions and dynamical representations of future greenhouse gas emissions and their impacts on climate provide a clear understanding of this linkage while the MA scenarios (MA, 2005) model the link between vegetation and biotic responses that in turn feed back on the greenhouse gas scenarios.

The use of both mineral and organic fertilizers in agriculture including livestock occasions changes in the biogeophysical system though the future use of fertilizers is difficult to predict due to need to integrate many assumptions. The future fertilizer use will most certainly affect the global food production and its relationship with the biogeophysical factors which will hinge on the efficiency of fertilizer use. FAO estimates that the global fertilizer consumption will increase from 138 million tonnes in 1997/99 to 188 million tonnes in 2030. Wood et al. (2004), basing their projection on results of the IFPRI-model IMPACT, calculate an N fertilizer consumption of 96-111 million tonnes in 2020, compared to a slightly lower projection by FAO AT 2030 for 2020 (91-106 million tones). For the year 2050 (Wood et al., 2004) project an N use of 106-121 million tonnes, or even up to 170 million tonnes following different assumptions.

The future use of fertilizers in agriculture will dictate the role of biogeophysical factors in sustainability of food systems and have been assessed in many scenarios exercises. The MA scenarios, for instance, make estimations for the historical and future (based on the AT2030 study) river nitrogen export to oceans and seas. The export is expected to reach 50 million tonnes per year by the year 2030 with the Pacific Ocean experiencing the greatest increase. Past approaches to scenarios on future fertilizer use, fertilizer consumption has been viewed as a factor of changes in crop and livestock production. Fertilizer use is also driver of crop and livestock production. A better targeted fertilizer use policy framework and AKST can shape future fertilizer use and its relationship with biogeophysical environment.

4.4 Assessment of direct drivers: how have direct drivers changed over time and what is the likely range of change to 2050?

4.4.1. Food consumption patterns

4.4.1.1. Introduction.

Changes in food consumption patterns are a direct driver in the IAASTD conceptual framework. Changes in dietary patterns influence food systems and agricultural products and services, including both food and non-food products, and other ecosystem services. While changes in food demand directly impact upon the types and quantity of food being produced, and thus on AKST used in producing this food, changes in AKST driving food supply can also impact food consumption patterns indirectly.

Fundamental changes are occurring in the global structure of food demand, driven in large part by economic growth in the developing countries. Rising incomes and rapid urbanization, particularly in Asia, are changing the composition of food demand. Direct per capita food consumption of maize and coarse grains is declining as consumers shift to wheat and rice with increasing incomes. When incomes rise further and lifestyles change with urbanization, a secondary shift from rice to wheat takes place. Growth in incomes in developing countries is driving strong growth in per capita and total meat consumption, which in turn induces strong growth in feed consumption of cereals, particularly maize. As incomes and urbanization continue, dietary shift towards increased consumption of fruits, vegetables, and milk and milk products increases. With yet further changes, diets will change to more consumer-ready, processed, sugary, and fatty foods, increasingly procured in (international) supermarket chains, and fast food establishments. At the same time, growth in per capita meat and cereal consumption in developed countries has slowed dramatically as these countries have reached very high levels of meat consumption in the past decades. These trends will lead to an extraordinary increase in the importance of developing countries in global food markets (Rosegrant et al., 2001; Cranfield et al., 1998; Schmidhuber, 2003).

Intensification of production practices is also responsible for some of the changing dietary preferences. Science and technological advances in mechanization and development in fertilizers, pesticides, and genetic improvements have contributed to tremendous growth in food production. With production of staples exceeding demand in several countries, real prices of agricultural produce declined, supporting increased dietary diversification (Schmidhuber, 2003).

There is a complex interaction between changing food consumption patterns and changing production practices. On the one hand increased intensification of agriculture has let to diversification of dietary preferences, while on the other hand changes in demand for food products due to rising incomes and urbanization drives AKST to increase supply of food commodities demanded, by changing production processes.

4.4.1.2. Nutritional transformation.

Rapid gains in purchasing power of food, driven by agricultural productivity growth, which resulted in higher overall economic growth as well as declining food prices, together with shifts in demographic patterns, growing urbanization, changes in women’s roles, an enhanced understanding of the impact of diets on health, and government interventions towards certain food crops or livestock products, influence exerted by the food industry, growing international trade, and an increasing globalization of tastes all contribute to nutrition transitions (Schmidhuber, 2003). The nutritional transformation reached many industrialized countries in the 19th century, and advanced to many developing countries in the last 50 years or so, including some of the larger ones, such as parts of Brazil, China, India, and Indonesia, and Mexico, but left yet other countries, mostly in Sub-Saharan Africa, largely untouched (Popkin, 2003; Smil, 2000; Schmidhuber, 2003). An overview of the stages involved in the nutritional transformation can be seen in Box 4.4.1.1. Urbanization and income growth are key drivers for changes in food demand.

Urbanization has and will continue to cause changes on several fronts. Urbanization is generally associated with 1) It higher incomes and a higher level of education for the household; 2) more opportunities for women to enter the paid-work sector; 3) and a major boost in the amount of information, goods and services, as a result of better infrastructure, which can be accessed by the household. 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 physical-intensive activities requiring less food energy, and a preference of pre-cooked, convenience foods, causing a shift from fresh fruits and vegetables, pulses, potatoes, towards more sugary, salty, and fatty diets; and from diets rich in fiber, minerals, and vitamins towards diets rich in energy, saturated fats, and cholesterol. Moreover, urbanization entails a physical separation of the agricultural sector from the post-harvest sector (in charge of processing, packaging and distributing the food produced) and the final consumption sector (in charge for the preparation and consumption of meals) (Giampietro, 2003; Schmidhuber, 2003; Smil, 2000; see also the sub-chapter on demographics).

The relationship between the level of household income and expenditures on food item is well known. As Engel's law of 1857 suggests, as people become wealthier, the share of food expenditures in total expenditures declines. However, in absolute terms, more affluent consumers tend to spend more money on their diets (Houthakker 1957 for 30 surveys from various countries; Huang and Bouis, 1996 for China and Taiwan, Theil et al. 1989 and hundreds of other studies). Moreover, the composition of food demand changes as well. Table 4.4.1.1 shows food expenditure shares of poorer and more affluent developing countries, as well as the share of energy obtained from basic staple crops. People living in urban areas tend to spend both less on food and less on basic staple crops; and overall diet quality tends to be better in urban areas. Smith and Subandoro (2005) also find that food energy deficiency prevalence is close in the South Asian and sub-Saharan African samples at 51.2 percent and 56.9 percent, respectively, while diet quality is a much greater problem in sub-Saharan Africa.

With growing affluence, consumers tend to spend more on food, food prices are less important in food consumption decisions, whereas other factors, such as convenience or health-related concerns increase in determining consumers' choices (Giampietro, 2003).

Box 4.4.1.1. Stages in the nutritional transformation;

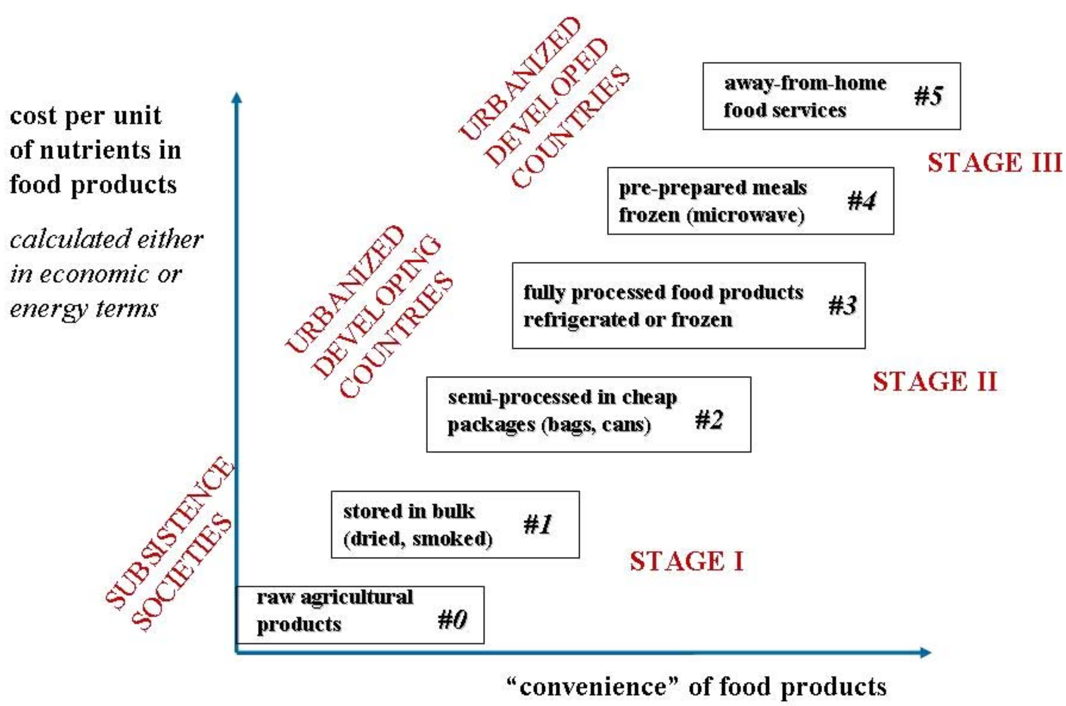
We can identify three distinct stages in the evolution of food systems :

STAGE I – *subsistence societies and rural areas of developing countries*. In these societies the interpretation of food

security and poverty alleviation is done by adopting the traditional patterns of production and consumption of food (in relation to food security) and goods and services (in relation to poverty alleviation).
STAGE II – *urban population of developing countries and medium/low class of developed countries*. In this stage, the interpretation of the term “food security” and the task of “reducing poverty” implies a re-definition of the traditional patterns of production and consumption of food and the traditional patterns of production and consumption of goods and services. New food products and new economic activities are introduced in the universe of discourse of the society. Dietary changes entail the abandonment of a monotonous diet based on a single staple food and a major increase in the presence of animal products as source of protein and vegetal oil as source of calories. Beside this move, the convenience of food products gains an increasing relevance as criterion of choice.

STAGE III – *medium/high income in post-industrial economies*. In the last stage of economic development the two criteria of “healthy diet” and “convenience” become more dominant in determining the choice of the consumers. The relative changes in the diet imply a move to: (i) less and leaner meat; (ii) less saturated fat; (iii) less sweeteners; (iv) more fresh vegetables and fruits. There is a growing reliance on pre-prepared food either in restaurants or to be warmed up in microwave ovens or delivered meals prepared by commercial food services. (Giampietro, 2003).

Box 4.4.1.1 Figure: Stages in the nutritional transformation



Shifts in food expenditures. Food purchase decisions are related to other household expenditure choices, including housing, clothing, education, health costs, among others. The overall budget available for food therefore depends on the amount of total household budget spent on other goods and services as well. Seale et al. (2003) analyze total and food expenditures for 114 countries by income group and confirm that 1) Low-income countries spend a greater portion of their budget on basic necessities, including food, while more affluent countries tend to spend larger shares of their income on luxury goods, such as recreation; 2) Among food items, low-value staples account for the largest share of food budgets in low-income countries, while high-value food items, such as dairy and meat, take up larger shares of food budgets in rich countries; 3) Poorer countries are more responsive to changes in income and prices and adjust food expenditures accordingly; but staple food consumption changes the least, while consumption of higher-value food items such as dairy and meat responds most to changes in income and prices; 4) Finally, when price changes are accompanied by equivalent income changes, wealthier low-income countries and middle-income countries adjust their food demand most rapidly (see also Ragmi et al. 2001). Studies projecting such shifts out into the future make use of these trends. An example is Cranfield et al. (1998) who project shifts in food expenditures for selected countries (see Table 4.4.1.2) with expected slow declines in food budget shares as well as slow declines in expenditures on grains.

Trends in obesity. A growing health concern in several high income countries is the incidence of obesity – largely because of a large portion of the population is overfed, yet under nourished. 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. Some factors that are responsible for the 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).

The World Health Organization has reported a rise in obesity in both developed and developing countries (WHO, 1998). It is estimated that by 2020, 60 percent of the disease burden in developing countries will result from non-communicable diseases, further exacerbated because of obesity (Caballero, 2001). Grummer et al. (2000) decipher definite trends between obesity and development. They compared overweight and obesity rates in women from 38 developing countries with rates in the United States and found that South Asia had very low levels of obesity (Figure 4.4.1.5). In Sub-Saharan Africa, obesity though low, was concentrated among urban and educated women. Latin America and Central Eastern Europe exhibit obesity rates that are more distributed across the population and are at a higher level. These are also regions that are slightly more developed. They also found that in Mexico, as in developed countries – it is the subchapter that belongs to the lower socioeconomic strata that is markedly more obese. In the Eastern Mediterranean region the prevalence of obesity among women is among the highest, ranging from 35 to 75 percent (Musaiger, 2004).

Research on obesity in developing countries is still limited by the lack of nationally representative, reliable longitudinal surveys and several estimates may be biased as it covers only urban areas or small population samples (Caballero, 2001). Martorell (2001) also emphasizes the difficulty in identifying trends with limited data. The repeat surveys in sub-Saharan Africa do not necessarily indicate increasing obesity. The surveys in Latin America, however, do suggest an increase over time.

Changes in agricultural production systems. Changes in the dietary composition induce changes in the mix of crop production. Increased consumption of livestock products, for example, has already led to a rapid increase in the area planted to corn as animal feed. According to Smil (2000), an annual increase of 1.3 percent in food production is necessary at the present time to feed the growing population, if diets do not change. Given that diets are set to continue to change with rising incomes and urbanization, a doubling of cereal yields may instead be necessary.

Because of the high rate of conversion of grains to meat, some analysts have argued that a reduction in meat consumption in developed countries, either through voluntary changes in dietary patterns, or through policies such as taxes on livestock, would release cereals from livestock feed to food for poor people in developing countries (e.g., Brown, 1995). Rosegrant et al. (1999) show that 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 developed countries are not an effective route to improvement in food security in developing countries.

The role of food processing and transportation industries is rapidly increasing to satisfy more complex, urban diets. With globalization, industrialization and intensification of the food production process, food retailing is making inroads into both the urban and rural sectors of developing countries. Retailing through supermarkets is growing at 20 percent per annum in some countries, along with food manufacturing and processing that are on the rise, as urban consumers demand more processed foods, shifting agricultural production systems from a focus on on-farm production towards agribusiness chains. As Figure 4.4.1.4 shows, the food retailing sector serves as the primary interface between consumers and the rest of the agricultural sector. The top 10 food retailing companies generated sales reaching almost 800 billion in 2005 (von Braun, 2005). While food processing industries and supermarkets will likely contribute to food safety outcomes, and can make more nutritional foods available to the poor, they sometimes also produce less healthy foods, such as refined white flour with reduced levels of fibers, minerals, and vitamins, or through the application of hydrogenation processes.

The role of supermarkets in determining food consumption patterns. The nutrition transition has led and will continue to lead to fundamental changes in the food marketing and distribution system. The rapid emergence of supermarkets in developing countries is the major outward sign of these changes. In Latin America and Mexico, supermarkets in 2000 controlled about 60 percent of the total retail sector, up from about 15 percent in 1990—thus, structural changes that took 50 years in developed countries can take as little as 10 years in developing regions (Reardon and Berdequé, 2002). International supermarket chains directly themselves accelerate the nutritional transformation—the increase in the availability of yogurt and pasteurized milk has lead to increases in consumption of dairy products in Brazil, for example. Consumption of Ultra High Temperature Milk went from zero in 1988 to 92 percent of the fluid milk formal market in 2000 (Reardon and Berdequé, 2002). Similar changes have started to take place in Asia. In China, supermarkets have taken over 30 percent of the urban food market and are growing at rates of 30-40 percent annually, and accounted for about US$71 billion in sales in 2003 (Gale and Reardon, 2005). Supermarkets are emerging in most other Asian developing countries, and more slowly in Sub-Saharan Africa over the next three to five decades. Traill (2006) estimated the penetration of supermarkets for 42 countries, with supermarket shares ranging from 1-90 percent 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, explaining 90 percent of the variation in supermarket shares. He also projected the share of supermarkets out to 2015, based on projections of GDP and urbanization, and opening to trade. While 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. Overall, the analysis suggests significant but not explosive further penetration and increased openness and GDP growth as the most important drivers of further penetration.

4.3.1.3 Changing food consumption patterns in global assessments

Studies focusing on food and agriculture have seldom projected changes in food consumption patterns out to 2050 at the global level and most projections in this area focus at the national level (f.ex. Bhalla et al. 1999 for India). Only two food/agriculture focused studies have done so: the FAO World Agriculture Outlook towards 2030/2050, interim report (FAO 2006) and Von Braun et al. (2005) using the IFPRI IMPACT model. An overview of global assessments that explicitly or implicitly relate to changing food demand patterns is presented in Table 4.4.1.3. 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/capita. Tables 4.4.1.4 and 4.4.1.5 present results from the FAO intermediate report outlook to 2050 (FAO, 2006), and Figures 4.4.1.1-4.4.1.3 present results for the IPCC SRES scenarios and the GEO-3 scenarios, and the Millennium Ecosystem Scenarios, respectively. Future outlooks tend to agree

- that the consumption of meats and milk, fats, and sugars increases considerably, globally, 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 still in 2050 the average food intake is 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 larger 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 kcal/day 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 an 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 rise towards OECD levels.

4.3.1.4 Implications for agriculture

Changes in food demand out to 2050 are expected to contribute to increased nutrition and human health. Dietary diversification will likely increase if urbanization and income growth proceeds apace. On the other hand, obesity rates and associated diseases are expected to increase. Changing consumption patterns are expected to increase the need for high-value food production, including livestock products and fish, as well as for oil and sugar crops. Demand for fruits and vegetable production is also expected to grow.

4.4.2 Direct drivers of agricultural development: natural resources

4.4.2.1 Water

Introduction. Water is a prime natural resource and a precious asset. Less than one percent of all the fresh water on earth is technologically and economically accessible for human use. More people mean increased water use and less available on a per capita basis. In 1989 there was some 9,000 cubic metres of freshwater per person available for human use. By 2000, that figure had dropped to 7,800 cubic metres and is expected to plummet to 5,100 cubic metres per person by 2025, when the global population is projected to reach 8 billion.

Past trends in water and agriculture. The last 50 years have seen massive 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 the World Bank spending was devoted to irrigation (Molden et al., 2006). Spending reached a peak of over US$1 billion per year in the late 70s (in constant 1980 US dollars) but fell to less than half that level by the late 1980s (Rosegrant and Svendsen, 1994). The irrigated area roughly doubled from 140 million hectares in the 60s to 280 million hectares in 2003, primarily in Asia (FAO stat). By contrast, irrigation in Sub-Saharan Africa consists of less than 4% of the total cultivated area. Agriculture is expected to remain the major water user, accounting for 69% of the withdrawals and 84% of the consumptive uses (Figure 4.4.2-2)

Groundwater. Groundwater is an important source of agricultural water, particularly in India, China, North Africa, US and Mexico. In India and Bangladesh, low cost technologies such as treadle pumps fueled the groundwater boom and boosted the income of millions of poor farmers (Shah 2000). Molden (2004) estimates that farmers in India have invested around US$ 12 billion in groundwater pump structures. Groundwater provides now more than 55% of total water use in India. But many of the world's most important grain lands are consuming groundwater at unsustainable rates. Collectively, annual water depletion in India, China, the United States, North Africa and the Arabian Peninsula adds up to 160 billion cubic metres a year - an amount equal to the total annual flow of two Nile Rivers (http://www.ozh2o.com/h2use.html)

Water scarcity. 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. The problem is becoming more urgent due to the growing share of food produced on irrigated areas; the rapid increase of water use in industry and households and increasing water reservation for environmental and ecological purposes; and water quality deterioration that reduces the effective availability of water

(Rosegrant 2002). Despite impressive achievements, past experiences also indicate problems and failures of irrigated agriculture, often related to poor performance and environmental issues, including excessive water depletion, groundwater level decline, water quality reduction, water logging, salinization and adverse social impacts of big dam projects (Rosegrant 2002). Poor drainage and irrigation practices have led to waterlogging and salinization of approximately 10 percent of the world's irrigated lands (30 million hectares of the world's 255 million hectares of irrigated land) according to the UN Food and Agricultural Organization (FAO). A combination of salinisation and waterlogging has degraded another 80 millions hectares (http://www.ozh2o.com/h2use.html). Agriculture is responsible for most of the depletion of groundwater, along with up to 70 per cent of the pollution. Both are accelerating (http://www.ozh2o.com/h2use.html). Further, although water development helped preventing famines and contributed to rural development, rural poverty persists, particularly in South Asia and sub-Saharan Africa (Namara et al 2006).

Figure 4.4.2-4 illustrates global water scarcity (CA 2007). River basins depicted in red face physical water scarcity where all water resources are allocated – or rather over-allocated. The basins in orange will face water shortages very soon, while areas shown in yellow face economic constraints to make necessary water investment to increase access to water. In 2000 an estimated 2.4 billion people (40%) lived in basins affected by water scarcity problems. Many areas in Sub Saharan Africa where malnourishment exists have ample water resources but infrastructure to tap them is lacking for economic reasons. Hence, promotion of irrigation development in SSA is considered important (NEPAD, 2006).

Future water scarcity assessment. The rapid expansion of the irrigation and associated water use and scarcity raise a few pertinent questions for the future of agricultural water: 1) Are available water resources sufficient to produce food for the growing world population while at the same time meet increasing municipal, industrial and environmental requirements? 2) What are the consequences of increased agricultural water use for the environment? 3) What is the potential role of agricultural water in meeting the MDG’s to halve hunger by 2015? A variety of assessments come to different conclusions.

Recent forecasts agree that water will be a key constraint in food production in many developing countries, calling for the need to improve water management and increase water use efficiency (Seckler et al., 1998; Seckler et al., 2000; Alcamo et al., 1997; Rosegrant, Cai and Cline, 2002; Shiklomanov, 2000; Vörösmarty et al., 2000; FAO, 2003; Wallace, 2000; World Water Assessment Program, 2006). However, the concern that water is a finite resource and overuse may lead to environmental disasters, is by no means new, and earlier predictions proved too alarmist. Over the last four decades, several research groups estimated actual and future global water diversions and depletion by human purposes. The studies conducted during the 1960s and 1970s forecasted that, by the year 2000, global water diversions would climb to 6,000 to 8,000 km^3, out of the 12,500 km^3 accessible resources, with devastating consequences for the health of world's water resources (Nikitopoulos, 1967; L'vovich, 1974; Falkenmark and Lindh, 1974; De Mare, 1976), all cited in Gleick (1999)[9]. Recent assessments put the current global water depletion between 3300 and 3900 km^3 annually. The earlier forecasts exceed the water demands that actually materialized, by a factor two, suggesting that the earlier water scenario developers missed some critically important real world dynamics (Gleick, 1999).

Whereas earlier projections were based on rather crude estimates of per capita water diversions for domestic, industrial and agricultural purposes, multiplied by expected population for the forecast year, recent modeling techniques have improved considerably in a number of ways. Firstly, they use spatially distributed GIS-based techniques and remote sensing to characterize water movement over the land surface, estimate crop evaporation by region and to locate irrigated areas (Maidment, 1999; Thenkabail et al., 2000; Alcamo et al., 1997; Bastiaanssen, xx). Secondly, explicit provision is made for improvements in water use efficiency at local and basin level and agricultural productivity gains (Seckler et al., 1998). Thirdly, models integrate economic processes and variables, such as crop prices, production functions and trade, with hydrological processes at global (Rosegrant, Cai and Cline, 2002) and basin scale (Cai and McKinney , 2001).

The major constraint to future improvements in water forecasts comes from limitations on the quality, availability and regional resolution of water demand data (Seckler et al., 1998; Gleick, 1999; Vörösmarty et al., 2000). Since agriculture is the biggest water user, forecasts critically depend on scenarios related to developments in agriculture.

Several factors explain the major differences in water use and water scarcity forecasts: the potential of rain fed agriculture, the potential of water productivity improvement in irrigated areas and agricultural trade. Trade can help mitigate water scarcity if water-short countries import food from water abundant countries (Hoekstra, 2002), although political and economic factors may prove stronger drivers than water (Fraiture, 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, Sakthivadivel and Habib 2000; Rosegrant et al., 2002). Rockstrom et al. (2005) argue that yields in semi-arid regions can be doubled by water harvesting techniques. However, referring to past efforts to enhance productivity in rain fed areas –with

[9] The estimate of 12,500 km^3 accessible and renewable surface water resources comes from Rockstrom et al. (1999). Alcamo et al. (1997) argue that diverting more than 40% of renewable water resources leads to environmental problems.

mixed results-, Seckler et al. (2000) are less optimistic concerning the potential of rain fed areas. Also, the potential to improve water productivity in irrigated areas is subject to debate (Kijne et al., 2005).

Existing forecasts reflect these differences in the assessment of potential: Seckler et al. (2000) foresee that only 5% of increases in future grain production will come from rain fed agriculture. Rosegrant et al. (2002) project that over 50% of all additional grains will come from rain fed areas, particularly in developed countries, while developing countries increasingly import. The FAO (2003) foresees that the contribution to total global food supply from rain fed areas declines from 65% now to 48% in 2030. Seckler foresees a growth in irrigated areas by 29% and FAO by 24%, IFPRI by 12% (Table 4.3.3-1). Forecasts of water diversions to agriculture vary from 4% to 24%. Scenario analysis conducted as part of the Comprehensive Assessment indicates that growth in global water diversions to agriculture varies anywhere between 0% to 37% by 2050 depending on assumptions on trade, water use efficiency, area expansion and productivity growth in rainfed and irrigated agriculture (Fraiture et al., 2006).

Irrigation-poverty alleviation. Hussain, (2005) explained impacts irrigation on poverty positively through irrigation-induced crop intensification and diversification towards high value crops leading to increased crop productivity and overall crop production; benefits derived through non-crop farm and non-farm uses of water including non consumptive uses of water supplied by irrigation infrastructure; benefits arising from improved employment opportunities and higher wage rates; benefits through improved incomes and consumption expenditures, and enhanced food security; social benefits such as improved health and education; and benefits from expansion in economic activities in related sectors resulting in overall improved growth of regional and national economies, that in turn, contributes to overall poverty reduction.

But there are significant inter- and intra-country differences in poverty incidence in irrigation systems (Hussain 2005). Poverty is much higher in South Asian systems (particularly in Pakistani systems) than in Southeast Asian and Chinese systems. Further, poverty-reducing impacts of irrigation-related interventions are larger when they are implemented in an integrated framework (e.g., integrated approaches for managing surface water and groundwater; developing systems that allow multiple uses of irrigation water, and for new investments in improving irrigation infrastructure, irrigation management, and service provision in agriculture (provision of inputs, technologies, information, finance, marketing)).

Water and climate change. Aren't warming itself, shift of precipitation patterns, more extreme events and the (potentially rapid) rising of the sea level (endangering fertile delta areas) bigger risks? The melting of glaciers is a quite local effect, the description below is quite specific for one region. Potentially the biggest threat of climate change for agricultural water lies in the melting of glaciers that feed major rivers that are used for irrigation. This may affect millions of hectare irrigated area in the Indo-Gangetic plain and the livelihoods of millions mostly small farmers. Millions of cubic meters of water are stored during the winter months in the form of ice and gradually released as spring melt. The warmer spring weather coincides with the start of the growing season. The disappearance of ice caps changes this flow regime, leading to higher summer runoff. Without additional storage to capture increased summer runoff much water will flow unused to the ocean leading to water scarcity in the drier months (Barnett, 2005).

One way to mitigate impacts of climate change in agricultural water management consists of including the 'risk' notion as much as possible at the different decision levels of: there are more decisions levels possible and not in all regions farmer corporations play an important rolefarmers, farmer corporations and countries or associations of countries. These three decision levels will be analysed both for rainfed and irrigated agriculture. The poorest countries are those most subject to climate risks, the main risks in developing countries, because they too rarely possess the means to combat excesses or shortages of water during the plant growing period (irrigation schemes) and they cannot rely on crop insurance or other kinds of support to maintain their income in bad years. Consequently, in order to ensure a minimum level of income, farmers will prefer low input practices that provide a low but stable production without involving too much investment or cash. Where possible they will diversify their production.

Water, energy prices and biofuels. The potential impact of energy prices on agricultural water use is fourfold (Fraiture et al 2007): First, the demand for cheaper and cleaner energy sources –such as hydropower and biofuels- will increase requiring large quantities of water. Second, groundwater pumping will become more expensive. Third, if energy prices go down again, desalinization may become a viable option. Fourth, fertilizer prices and prices of other inputs are highly related to oil prices. Fertilizer use impacts water productivity and water quality (Molden et al 2007).

At present the role of hydropower and biomass in meeting energy demand is relatively modest: 2% of global energy needs are derived from hydropower and 12% from biomass (i.e. woody biomass, crop residues and dung). One of the MA scenarios (TechnoGarden) assumes that by 2050 the contribution of biomass to total energy needs will double to 25% (or 150 EJ out of 600 EJ demand in 2050). Requiring 8000 million tons of woody biomass, implications for land and water resources are enormous. This is 5500 km3 of additional crop water use, being an increase of x% relative to the level in 2000 and 400 million hectares of land. For comparison, actual crop water depletion for food production is 7100 km3 and crop land is 1500 million hectares (ref from SEI-Boston). At a global the production of biofuels plays a relatively minor role in land and water use. But for individual countries like India and China, where water is already short, additional pressure on water resources may prevent government to pursue large scale biofuel programs (Fraiture 2007).

Water as driver of AKST. Different assessments of potential and desirability of measures in agricultural water management imply different demands for AKST. The description below is quite technical, shouldn't one start with how pressure on water will influence the generation of AKST including institutional aspects. Some promote techniques or measures to improve irrigation efficiency (Gleick et al.). AKST should be geared towards development of techniques to enhance water use efficiency. However, others claim that the water saving potential at the basin level is small because of water reuse and recycling (Molden. Seckler). Molden (2000) promote the idea of water productivity improvement ("more crop per drop"). AKST should be geared towards better on-farm water management, crop varieties with better harvest index, soil improvements, higher value crops with higher output per unit of water etc. But others are questioning the potential of water productivity on plant-physiologic grounds (Seckler, Keller et al.).

Rockstrom et al.(**) suggest that upgrading rainfed agriculture is key to ensure global food supply instead of building more irrigation schemes that damage the environment. AKST should be geared towards water harvesting techniques and development of drought resistant crops. But others (FAO, IFAD, Nepad) argue that the lack of reliable rainfall seriously limit the potential and that more irrigation is essential for rural development and food security. Also where ever surface irrigation are inadequate, groundwater supplementation should be encouraged. Others (Polak et al, **) favor irrigation to alleviate poverty (AKST should be geared towards development of low-cost small scale irrigation techniques such as treadle pumps and drip kits).

4.4.2.2. Soils

Soil and water are important natural resources essential to the survival of the human race. Overexploitation and mismanagement of these natural resources due to increasing population, especially in the developing world, have made these natural resources critical for long-term food security. Without addressing the issues relating to soil quality and management, a major problem could emerge which may threaten the food security and quality of life of the future generations. Thus, present needs and future demands of these resources to match the expected increase in population should be taken into consideration for effective conservation and utilization methods of these natural resources.

Many driving forces affect the way soil is being used and will be used in the future. Among these driving forces are population growth, land use planning and policies, land development and growth and demands for agricultural products (Blum, 2001). All these driving factors operate directly and interact in different ways to produce either a positive effect (sustainability) or a negative effect (degradation) on soil. Sustainable management of soil is vital to agricultural productivity and food security. Soil degradation due to improper farming practices has had more devastating effects on soil quality in many developing countries than the developed world. While the food requirement has kept on rising with an increasing population, the present productivity from the arable land of the developing world has not been able to support its population. (this info will already be in the subchapter on indirect drivers. At the global level, out of the total ice-free land area of 13.4 billion ha, only 4.9 billion ha are agricultural lands. Out of the agricultural lands, 3.2 billion ha are in the developing countries, while 1.8 billion ha are in the developed world (FAO, 1996) refetence to FAO, 2003 (AT 2030). 1.3 billion ha have been classified as low productive lands. 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 the ever-growing population remains challenging, particularly as per capita land availability may decrease and soil degradation continues at present rate.

Population pressure and improper land use practices has given rise to soil degradation, manifest through processes such as erosion, desertification, salinisation and other undesirable soil conditions. Many lands are already seriously degraded through accelerated erosion, desertification, compaction and hard setting, acidification, decline in soil organic matter content and biodiversity and depletion of soil fertility (Lal, 1994). Desertification, which is mostly human-induced land degradation occurring in arid, semi-arid and dry sub-humid regions, has led to loss of soil productivity in the affected regions. The total degraded land in the world is estimated at about 2 billion ha, while the annual loss of arable land has been estimated to be 5-7 million ha. Land degradation continues to spread at an average rate of 6 million ha per annum (FAO/UNEP, 1984). Conversion of forest land to arable land use has also contributed significantly to soil degradation. Gates (1999) reported that during the last 50 years, 33% of the forest cover was lost worldwide. This conversion of forest land was accompanied by the removal of 25% of topsoil through erosion. Erosion of this magnitude corresponds to enormous losses in soil fertility.

Soil degradation. Land degradation has attracted much attention in the recent times, since this is pivotal to agronomic productivity, the environment, food security and quality of life (Eswaran et al., 2001). Soil, an essential component of the land, is affected both by its inherent and dynamic quality. Inherent soil quality relates to the natural (genetic) characteristics of the soil which are the result of soil-forming factors. The inherent soil quality is described by soil capability classes. The dynamic soil quality is readily affected by human management practices. The inherent and dynamic soil quality components do interact, however, as some soils are much more sensitive to degradation than others. Soils from different parts of the world differ in their capabilities. The Food and Agriculture Organization Database (FAO, 1997; WRI, 1997) has provided individual country assessments on quantity of arable land and other indicators for national and global assessments.

Soil degrading factors. This subchapter is describing technical measures. Shouldn't it focus more on what land degradation might mean for the development for AKST. Soil erosion, which is the physical removal of soil in horizontal and or/vertical direction (Lal, 2001) is a major soil degradation factor worldwide. Once the topsoil is removed, it takes a long time before they can be formed again through natural pedogenic factors. It has been estimated that it takes between 100 and 1000 years for an inch of soil to form through natural processes (Pimental *et al.,* 1976). This soil forming rate corresponds quantitatively to 0.4 to 4 Mg/ha/yr.

Land degradation due to erosion has been estimated at 1100 Mha by water erosion and 550 Mha by wind erosion (Oldeman et al., 1991). Areas with significant soil erosion problems fall mostly in developing regions of the world. Important areas include south Asia, sub-saharan Africa, Central America and the Caribbean. About 663 Mha and 413 Mha hectares of soil have already been degraded by erosion in Asia and Africa respectively (Lal, 2001). In both regions (Asia & Africa), degradation caused by soil erosion accounts for more than 80% of human-induced degradation (Oldeman et al., 1991).

Soil erosion rates in India has been estimated between 4 and 10 t/ha/yr in red soils, 17-43 t/ha/yr in black soils and soil 4-14t/ha/yr in alluvial soils. Higher soil losses in Indonesia and Thailand have been reported with erosion rates as high as 500t/ha/yr under some cropping practices corresponding to a loss of 1 cm topsoil each year. At such high rates of soil loss, crop production from such lands may cease after 15 years with total denudation of the surface soil (Sajjapongse, 1997). The salt affected soils are widespread in about 120 countries encompassing all continents and cover a total area of 953 M ha, reducing productive capacity of 7 to 8% of land surface in the world. More than 50% of the salt affected soils are sodic with largest area in Australia (Yadav, 2003).

The fast increasing trend of urbanization and industrialization in the world is having a pronounced detrimental impact on soil quality. Mismanagement of municipal wastes, sewage sludge, sewage water, industrial effluents, agricultural chemicals etc, has led to severe degradation of peri-urban soils. Accumulation of toxic heavy metals like cadmium, lead and arsenic in many river valley soils of peri-urban areas has also been found to be an important soil degrading factor.

In order to achieve the long-term stability of soil quality, it is important to develop scientific approaches to soil management as it affects agriculture. Soil management research covering issues such as tillage, soil and water conservation, residue management and carbon sequestrating need to be expanded to provide appropriate management practices to enhance sustainable soil use. The current intensive farming practices which support high productivity have proven unsustainable. The following problems have been recurrent in the use of land resource (Katyal, 2003).

- Irrigation-mediated rise in water logging and salinity
- Over exploitation of underground water (more extraction than replenishment)
- Unbalance fertilizer use and development of micro and secondary nutrient deficiencies
- Inefficient use of fertilizers promoting environmental pollution
- Inappropriate and excessive tillage leading to accelerated soil erosion and loss of organic matter

Some important strategies to maintain soil resource for sustainable agriculture are (Yadav, 2003):

- Prevention of degradation and pollution of the soil resource through technically sound, ecologically friendly and cost effective technologies
- Amelioration of the already degraded and polluted soils to restore their biological productivity
- Proper understanding of soil water-nutrient-plant relationship and enhancing soil productivity
- Judicious integrated nutrient management technology including the use of chemical fertilizers, organic manures, green manures, crop residues, organic wastes and biofertilizers
- Selection of suitable crops and cropping system according to soil capability class and inclusion legume crops in the cropping systems
- Efficient water management to arrest water-logging, salinisation and soil sodification
- Increasing use efficiency of key inputs such as plant nutrients and water
- Use of sound cultivation methods on sloping, marginal and other fragile lands
- Regular monitoring of soil health
- Suitable models to predict the likely changes in soil quality consequent to varying land use and management practices
- Mass awareness among the farmers and other stakeholders about importance of soil health

Economic implications of land degradation and its relation to future crop production. A lot of efforts have been made to estimate the impact of soil degradation on crop production. While significant crop losses from land degradation have been recorded globally, there has also been increased crop productivity due to technological advancement (crop improvement and land improvement) (Scherr & Yadav, 1996). Several arguments have been proposed on how land degradation will affect the future food security. Some authors feel that land degradation will not be a major issue in food security for the future generations (Crosson, 1994; Rosengrant & Sombilla, 1997), while other have argued that it will be a major constraining factor for food production in the future (Brown & Kane, 1994; Hinrichsen, 1998).

An estimated 5 to 10 million hectares of land are being lost annually to degradation (Scherr & Yadav, 1996). If this continues, an estimated 4.9 to 10 percent of agricultural lands would have been lost to degradation by the year 2050. Most of these losses due to soil degradation will take place in the developing nations of the tropical belt. Projecting from the current trends, the hotspots for food insecurity arising from degradation may be mostly densely populated sub-Saharan Africa and South Asia (Rosengrant & Sombilla, 1997). Therefore, the effects of land degradation on future food production may have only regional or national impact especially on the poor nations of the tropics.

Crop productivity losses due to land degradation in drylands are estimated to be between \$13 and \$28 billion annually (Yadav & Scherr, 1995). The global losses due to soil erosion have been put at about \$26 billion annually out of which \$12 billion losses occur in developing countries (UNEP, 1986). The productivity of some lands in Africa (Dregne, 1990) has declined by 50% as a result of soil erosion and desertification. Yield reductions due to past soil erosion in Africa range from 2 to 40%. This corresponds to a loss of 8.2% for the continent (Lal, 1995). Annual reduction in total production for 1989 due to accelerated erosion was 8.2 million tons for cereals, 9.2 million tons for roots and tubers, and 0.6 million tons for pulses (Lal, 1995). If accelerated erosion continues unabated, yield reductions by 2020 may be 16.5% for the continent of Africa (Scherr and Yadav, 1996).

Up to 20% losses in crop productivity due to erosion has been reported for Asia, especially India, China, Iran, Israel, Jordan, Lebanon, Nepal, and Pakistan (Dregne, 1992). In South Asia, annual loss in crop productivity due to water erosion was estimated at 36 million tons of cereal equivalent valued at US\$5,400 million and losses of up to US\$1,800 million due to wind erosion (UNEP, 1994). Soil compaction affects about 68 million hectares of land worldwide (Oldeman et al. 1991), with about half of the affected area concentrated in Europe. Severe limitations of crop growth and yields have been observed in soils affected by compaction. Yield reductions of up to 50% were observed in parts of Europe (Ericksson et al., 1974) and North America. Yield losses ranging from 40% to 90% was observed in West African countries (Charreau, 1972; Kayombo and Lal, 1994). On-farm losses through land compaction in the USA were estimated at US$1.2 billion per year (Gill, 1971).

An estimated 950 million ha of salt-affected lands are in arid and semi-arid regions. This represents nearly 33% of the potentially arable land area of the world. Productivity of irrigated lands is severely threatened by build up of salt in the root zone. In South Asia, annual economic loss is estimated at US$500 million from water-logging, and US$1,500 million due to salinization (UNEP, 1994). Potential and actual economic impact of salinization is not yet known globally (Eswaran et al., 2001).

Appropriate and judicious use of soil resource is essential if the food need of the future is to be met. Projecting into the future from the present state suggests that soil degradation will continue and the food needs will increase due to increasing population. This will constitute a serious threat to food security and human well-being especially in poor nations in the tropics. Appropriate technologies are needed to reduce the rate and extent of soil degradation. Soil degradation problems need to be addressed both at stakeholder and at institutional levels. Research efforts should focus on quantification and monitoring of soil quality in such a way that sustainability of cropping and land use systems can be measured. Restoration of degraded lands should also receive important consideration especially in the developing world where natural resources are already under a great stress.

4.4.2.3 Fertilizers

Crops are highly depended on an adequate supply of nutrients, notably nitrogen, phosphorus and potassium. This supply might come from organic fertilizers alone, but to realize adequate crop yields the input of mineral fertilizers is usually necessary to compensate for the export of nutrient by crops and for losses of nutrient through erosion and leaching. 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). The use of nitrogen did almost triplicate in the period 1970-2005 (Figure 4.4.2.6). The global demand for N fertilizer is largely dictated by cereal grain production (Cassman et al., 2002). About two third of the global N fertilizer is being used cereal production. Especially in Asia the nitrogen use did increase rapidly. This increase was one of the major factors of the tremendous increase in agricultural output in Asia during the Green revolution. The use of N-fertilizer in North America and Europe stagnated after 1986 (Figure 4.4.2.6). This was partly caused by a higher environmental concerning. While sustaining crop yield, the input of N fertilizer was decreased, leading to an increase in the nitrogen use efficiency

(NUE). Although N fertilizer use in SSA also increased over the last decades, it remains at a very low level, both expressed in kg fertilizer per ha and per capita. On a per capita basis, the N fertilizer consumption was 38 kg in the USA, 11 kg in India, but only 1,1 kg per person in SSA (Mosier et al., 2004). The price of fertilizers is one of the major factors of the low use in SSA. A metric ton of urea costs $90 in Europe, $120 kg in the harbor of Mombassa, $400 in Western Kenya and $770 in Malawi (Sanchez, 2002). The use of fertilizers in South America did also increase over the last 30 years, but at a much lower pace than in Asia.

Soil nutrient budgets. The (combined) use of mineral and organic fertilizers differs considerably between countries, as does the nutrient surplus (the difference between input and output). A too high surplus indicates the risk of nitrogen and phosphorus leaching. Very low or even negative surpluses indicate depletion and loss of soil fertility. Among the countries with high nitrogen surpluses per ha are the Netherlands, Belgium and Japan (OECD, 2001). On the other side, the soil nutrient balance of Sub-Saharan Africa shows an annual loss of 22 kg N ha-1, 2,5 kg P ha-1 and 15 kg K ha-1 (Stoorvogel et al., 1993). However, both observation needs to be put in perspective. In large industrialized countries, like the USA, Canada, Germany and France a moderate surplus is probably the result of regions with higher and lower (sometimes even negative) surpluses (Daberkow et al., 2000; EEA, 2005a; Lefebvre et al., 2005). The opposite is true in regions with negative nutrient balance. Not all fields are continuously mined. Some fields have very positive balances, usually through concentration of nutrients from other parts of the farm (Vanlauwe and Giller, 2006). This ensures good crop yields on those fields, and saves labor in terms of the distance the nutrients are transported.

Fertilizers and livestock production. Livestock plays an essential role in local and global nutrient management. The increase in consumption of animal products is, next to population growth, is one of the major causes of the increase of global fertilizer use. The protein conversion efficiency for meat production ranges from 8% for beef to 30% for chicken (Smil, 2000). Large quantities of cereals and soybeans are being used as animal feed, and most minerals (N,P etc.) in these products are being excreted in the form of manure. In many regions, this manure is not efficiently used again as a valuable source of nutrients, and thus leading to large losses of N (and P) to the environment.

Environmental effects. Losses of nutrients by overfertilization may cause environmental damage in several ways. Losses of N might be in the form of ammonia (NH3) to the air, mainly from animal manure, but also from mineral fertilizers. This ammonia is deposited elsewhere, leading to undesired enrichment of ecosystems and in some cases to acidification. N losses to groundwater might lead to too high nitrate (NO3-) concentrations, making it unsuitable for human consumption (van Grinsven et al., 2006). N and P losses to surface waters might lead to eutrophication of both fresh and saltwater ecosystems (see e.g. (Rabalais, 2002)). Due to microbiological transformation of nitrogen in the moist or wet soil, nitrous oxide (N2O) might be formed. In 2000, nitrous oxides stemming from agriculture were responsible for more than 6% of the global greenhouse gas emissions (EPA, 2006).

Soil depletion and soil degradation Depletion of soil fertility is, together with other factors, a major biophysical cause of low per capita food production (Sanchez, 2002). Therefore, in many plans to enhance food production in poorer regions, the stimulation of the use of fertilizer plays an important role (UNMilleniumProject, 2005). Loss of soil fertility is not only caused by removal of nutrients by crops, but also because of erosion. Erosion selectively removes the finer and more fertile fraction (Stocking, 2003).

Mineral or organic fertilizers. Minerals can be applied to the soil (and the plant) in the form of mineral or organic fertilizers. Agronomist know that the plant does not care whether the nutrients come from a mineral or organic fertilizer (Sanchez, 2002). Mineral fertilizers can be mined, as for phosphorus and potassium and treated to purify them or make the nutrient better available for crops. Nitrogen fertilizer is mainly produced in the petrochemical industry. Organic fertilizers include livestock manure, compost, green manure and fertilizer trees. Typically, mineral fertilizers only supply 1-3 nutrients, while organic fertilizers supply the whole spectrum of essential nutrients. Since organic fertilizers supply organic C, they improve the soil’s water-holding capacity and other soil properties. The currently adapted paradigm for tropical soil fertility management is Integrated Soil Fertility Management (ISFM). ISFM is a holistic approach to soil fertility research that embraces the full range of driving factors and consequences of soil degradation (TSBF-CIAT, 2006). ISFM advocates the integration of mineral and organic sources of nutrients, thereby using locally available sources of inputs and maximizing their use efficiency.

Future use of fertilizers. Like many other factors, the future use of fertilizers is hard to predict. “Long term projections of international agricultural production and/or resource requirements are fraught with assumptions, data limitations, and ill-understood economic and physical relationships” (FAO, 2004). The use of fertilizer basically demands on two factors, being the global food production and the efficiency of fertilizer use. But, the global food production itself, is depending on the use of fertilizers, especially in regions were the present use of fertilizers is quite low.

The approach to calculate the future use of fertilizer from estimates (or model results) of global food production is followed in the FAO Agriculture Towards 2030 study (Bruinsma, 2003; FAO, 2000). Projections for fertilizer consumption in the FAO-study have been derived on the basis of the relationship between yields and fertilizer application rates that existed during 1995/1997. FAO estimates that the global fertilizer consumption will increase from 138 million tonnes in 1997/99 to 188 million tonnes in 2030. The aggregated growth rate for fertilizer of 1.0% p.a. is much slower than in the past, mainly because of the saturated markets or higher efficiency use in the industrial countries and South and East China. Since the FAO AT2030 assumes a low yield increase in SSA, also the growth in use of fertilizer is also very limited: from 7 to 9 kg/ha of arable land. This is despite the significant potential of SSA to raise crop yields by making more (and more efficient) use of nitrogen. About 60% of the total fertilizer use is nitrogen, and this ratio in not expected to change much in the future (FAO, 2000).

A different approach to calculate future fertilizer use is followed by (Wood et al., 2004), who base their projection on results of the IFPRI-model IMPACT. They calculate N fertilizer from IFPRI"s food production projections, using different scenarios for nutrient use efficiency. They calculate an N fertilizer consumption of 96-111 million tonnes in 2020, compared to a slightly lower projection by FAO AT 2030 for 2020 (91-106 million tonnes, as interpolated by (Wood et al., 2004)). For the year 2050 (Wood et al., 2004) project an use of 106-121 million tonnes, or even up to 170 million tonnes following different assumptions. The MA gives no new projections, but draws on projections as summarized above.

Increased animal production World meat consumption (and production) is expected to growth with 70% in the period 2000-2030 and with 120% in the period 2000-2050 (FAO, 2006). This is even slightly higher than previously predicted by the FAO (Bruinsma, 2003). 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 are depending on protein-rich feeds. They lead to concentration of manure in certain regions. When this manure is not properly processed or disposed off, concentrated spreading manure can lead to significant emissions, both to air as to soil and water.

Fertizers and manure. Following crop and livestock production growth of the FAO AT2030 study, (Bouwman et al., 2005) calculated not only the fertilizer use, but the use of manure as well. The largest absolute increase can be seen in East Asia, whereas in SSA the combined use of manure and fertilizer only marginally increases (Figure 4.4.2.7). The results indicate and present problems regarding overfertilization on one hand (notably in Asia, North America and Europe) increase, while on the other hand soil depletion in SSA continues as well.

Emissions. Runoff and leaching of excess nitrogen ends up in rivers and finally in seas and oceans where it can cause eutrophication and disruption of ecosystems. In the MA estimations have been made for the historical and future (based on the AT2030 study) river nitrogen export to oceans and seas. Already between 1970 and 1995 the total nitrogen export increased with 30% (from 34 to 44 million tonnes per year). By the year 2030, the export is expected to have increased to 50 million tonnes per year. The Pacific Ocean will experience the strongest increase, with almost a doubling of the river nitrogen export between 1970 and 2030. The MA-Global orchestration scenario the nitrogen export is somewhat higher than in the AT 2030 projection, where the TechnoGarden scenario even shows a decrease between 2000 and 2030

Fertilizer as a driver. In the approach above, fertilizer consumption was seen as a result of changes in crop and livestock production. Fertilizer use can however also be seen as a direct driver for crop (and livestock) production, whether influenced by autonomous developments or direct policies impacting fertilizer use. Since the production of N fertilizer is an energy intensive process, energy prices will have a direct influence on N fertilizer prices. Higher energy prices will lead to higher fertilizers prices and thus to a lower use. The price of fertilizers might also be influenced by climate change mitigation policies, leading to higher production costs or to taxes on fertilizers, given emissions of nitrous oxides directly or indirectly resulting from fertilizer use.
As demonstrated above, in regions with poor infrastructure the price of fertilizers is much higher than world market prices. Improvement of infrastructure (and removal of other trade barriers) will lead to lower market prices and probably thus to higher fertilizer use. Direct policies regarding the use of fertilizers can be aimed at a lower (or more efficient) use in areas where emissions are too high. In a number of OECD countries of regions, like the European Union, USA and Japan, policies are already in place to reduce emissions of nutrients (see e.g. (EEA, 2005b)). Especially in a number of countries in Asia, fertilizers are still being subsidized. Removal of these subsidies could result in a lower, more efficient use of N fertilizer. In regions with persistent depletion of soils the introduction of some kind of subsidy could be considered, especially for poor farmers, resulting in a higher use. But, as stated in the Declaration adopted by the Africa Fertilizer Summit 2006, emphasis should also be put on capacity building, and measures to improve output markets incentives. The aim is to dramatically increase to use of fertilizers to a level of at least 50 kg per hectare by 2015. In the same regions other policy interventions might be possible, like loan facilities, changes in land tenure systems etc. to promote a more sustainable land use. And, last but not least, through AKST the use of fertilizers could be influenced again in different directions. Of course, in all regions a more efficient use of mineral and organic fertilizer could be promoted, leading to a lower fertilizer inputs. But in regions where poverty prevails and crop production is low, AKST might lead to a higher use of mineral and organic fertilizers.

Fertilizer management as driver of AKST. The need for a better targeted fertilizer management is a key driver for AKST, both in regions with a too low use of fertilizers, as in regions with overfertilization and environmental problems. One of the examples of extended research and outreach programs of improving nutrient availability in developing regions is the strategy of CIAT for Integrated Soil Fertility Management (TSBF-CIAT, 2005), with a budget of approx. 30 million dollars in the period 2005-2010. In developing countries, much research, outreaches programs but also farmers initiatives are committed to increase nutrient efficiency over the whole agricultural production chain and the reduce emissions to the environment.

4.4.3 Land use and land cover change

4.4.3.1 Introduction

Land is used to meet a multiplicity of human needs and to serve numerous, diverse purposes. 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, or both. 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 that 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 the balance of human well-being needs and preferences evolves in different societies, so too will the goals and priorities for the development of new AKST. For example, in their work on “induced innovation” Hayami and Ruttan (1971) demonstrated how the relative scarcities of land in Japan and labor in the USA shaped the agricultural research priorities of those two countries. And 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 (US dust bowl, China loess plateau, Machakos refs) has driven the search for new knowledge on sustainable farming technologies and land management practices. But land use/cover change is a complex process best explained by multiple factors and drivers acting synergistically rather than by single-factor causation. In the tropics, for instance, Geist and Lambin (2004; see Figure 4.4.3-1) suggest that in more than one third of a set of case studies, deforestation was driven by an interplay of economic, institutional, technological, cultural, and demographic factors.

In this subchapter we focus on the potential AKST implications of land use/cover change in just three land systems: forest, urban, and cultivated systems. Many of the important drivers of land-use change have been discussed elsewhere in this Chapter; here we provide an overview of how land use/cover change contributes to global scenarios of the evolving conditions to which AKST development must respond. We also add some regional and local specifics.

4.4.3.2 Global land cover and land use change

Historical change. Humans have, for millennia, deliberately managed and converted the landscape to improve their food security and meet their needs for other specialized biological products (Klein et al. 2004). Klein et al. estimated that cropland expanded from 3-4 million km^2 in 1700 to 15-18 million km^2 in 1990 (mostly at the expense of forests), while grazing land expanded from 5 million km^2 in 1700 to 31 million km^2 in 1990 (mostly at the expense of natural grasslands). Since the beginning of the industrial era, global forest area has been reduced by 40 percent, with three-quarters of this loss occurring during the past two centuries (MA 2005).

Figure 4.4.3-2 depicts the evolution of cropland distribution during the 20th century. Box 4.4.3-1 elaborates on the trade-offs that are faced when bringing more land into production. 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 harvested area increases 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.

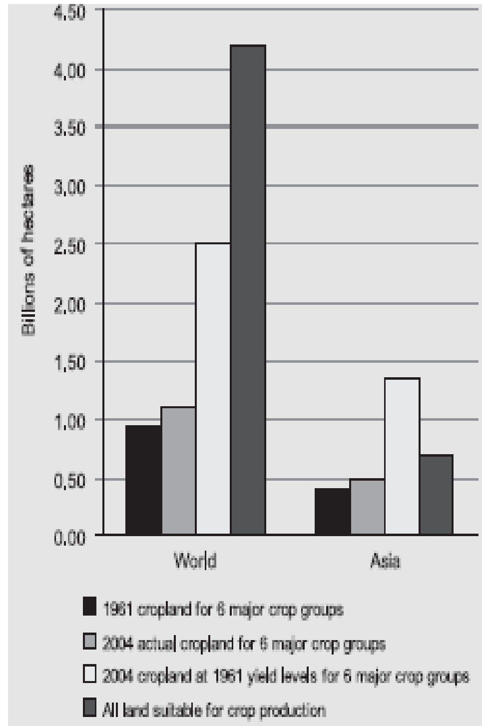
Current state. Forests have completely disappeared in 25 countries, and another 29 have lost more than 90%. Although forest cover and biomass in Europe and North America is currently increasing following radical declines in the past, deforestation of natural forests in the tropics continues at an annual rate of over 10 million hectares a year. Deforestation and forest degradation affect 8.5% of the world's remaining forests, nearly half of which are in South America. Deforestation and forest degradation have been more extensive in the tropics over the past few decades than in the rest of the world. Data on boreal forests are especially limited and the extent of change there is less well known. Approximately 10% of the drylands and hyper-arid zones of the world are considered degraded, with the majority of these areas in Asia. Cultivated systems currently comprise about 40% of the Earth's terrestrial surface (Cassman et al, 2005).

Projected global land cover and land use changes. There are only a few global studies that have produced long-term (century) land cover and land use projections. According to Alcamo et al. (2006; see Figure 4.4.3-3), the most comprehensive studies, in terms of sector and land type coverage, are the IPCC Special Report on Emissions Scenarios (SRES; Nakicenovic et al., 2000; number 1-4), the scenarios from the Global Scenarios Group (Raskin et al., 2002; number 5-8), UNEP's Global Environment Outlook (UNEP, 2002; number 9-10), and most recently the Millennium Ecosystem Assessment (MA, 2005). The projections of agricultural land, forest land, and urban land (1990-2050) are illustrated in Figure 4.4.3-3, and show a high variability in their expected future evolution. The IPCC outlook for agriculture for example, differs between a 20% reduction (line 2; A2 scenario) and a 40% increase (line 3; B1 scenario). The developments in forest land largely mirror those of agriculture. 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. Scenarios that project strongest increases do not account for changing spatial requirements of settlement areas.

Box 4.4.3-1 Aggregate impacts of trade-offs in cultivated systems.
Source: Cassman et al 2005

Aggregate Impacts of Trade-offs in Cultivate Systems: Land Use Perspective

At a regional or global scale, one measure of the trade-off is the amount of land that needs to be brought into production according to different levels of food productivity. The "land-sparling" impact of modern farming practices has largely been achieved through yield increases brought about by the use of crop monocultures with improved crop varieties, fertilizer inputs and irrigation where farmers have access to supplemental water. For example, if yields of the six major crop groups that are cultivated on 80% of the total cultivated land area had remained at yield levels farmers achieved in 1961, it would require an additional 1.4 billion hectares of land to meet global food demand in 2004 (See Figure). This represents 34% of total land area suitable for crop cultivation and would have required convention of large areas of uncultivated land that currently support rain forests, grassland savannas, and wetlands. In Asia alone, it would require an additional 600 million hectares, which represents 25% more land area than is suitable for cultivation on this continent. Asia would have had to be heavily dependent on food imports if crop yields had remained at 1961 yield levels.



Land used to produce major crops in 1961 and 2004 and land that would be needed to produce them in 2004 at 1961 yield levels. The six major crop groups included in this analysis are cereals, oil crops, pulses, root and tuber crops, sugar crops, and fiber crops. They accounted for 87% of all cropland in 1961 and 8-% in 2004.

The key ecological question is therefore whether environmental services other than food production at regional and global scales would be enhanced by focusing food production on less land under intensive management with high yields versus expanding cultivated area in lower-yield systems that use farming practices that seek to preserve environmental services at the field and local levels. Few studies have addressed this issue using sound, ecological analytical methods. One recent study found that farming is already the greatest extinction threat to birds and evaluated the impact of land-sparling high-yield systems with "wildlife-friendly" farming practices on bird species persistence using ecological models (Green et al,, 2005. The results suggest that high-yield farming may allow more bird species from a range of taxa to persist in developing countries. More such studies with other threatened

The wide divergence in the scenarios reflects major uncertainties in the assumed nature and rate of change in agricultural expansion, intensification, and world food trade. The MA scenarios implement a complex representation of yield growth projections that, in addition to autonomous technological change, reflect changes in production practices, public investment, technological transfer, environmental degradation, and climate change. The net effect is declining productivity growth over time for some commodities due in large part to diminishing marginal technical productivity gains and environmental degradation. Eickhout et al. (2006) observe that in four scenarios based on the IPCC storylines, the highest crop and livestock production growth is projected for the developing regions Africa, Asia and Latin America. Because of the high economic growth in these regions in the liberalizing scenarios, the largest increases in production are projected in Global Economy (GE) and Global Co-operation (GC). Subchapter 4.2.1 provides a more detailed elaboration of the underlying drivers in these global scenario exercises. An important additional reason for the difference between the various scenario studies is related to differences in input data. Although not visible in the normalized graphs in Figure 4.4.3-6, there are considerable differences in historical forest, grassland, and other land acreage, which can be attributed to differences in definitions. For example, some models consider only managed forests, while others consider both managed and unmanaged forests. This has consequences for the projected rates of change.

Changes in agricultural land are caused primarily by changes in food demand and the structure of supply as moderated by international trade. Scenarios with a greater extent of agricultural acreage result from assumptions about 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 sizeable expansion (up to 40%) 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 (as much as 20% less global agricultural acreage) by the end of the century. In the near-term, almost all scenarios suggest an increase in agricultural acreage to meet projected increases in food demands over the next few decades. The global forest scenarios largely mirror the agricultural scenarios; thereby, illustrating both the positive and negative aspects of some existing scenario modeling. Sands and Leimbach (2003) provide a very informative sensitivity analysis of global scenarios for population growth, yield improvements in crops over time, and changes in diet. Global integrated assessment and computable general equilibrium scenario approaches broadly are beginning to model the competing driving forces of land use/cover change more directly and realistically.

4.4.3.3. Regional and local changes

Interdisciplinary complexity. As pointed out earlier, drivers of land use change are many and highly interrelated. Specifically when adding regional and local detail to the global scenarios, a highly heterogeneous picture emerges. Combinations of drivers that work across different temporal and spatial scales and also occur intermittently, such as droughts, armed conflict, and economic crises, drive land use change. Moreover, it is ultimately the farmer who makes decisions about the nature and management of cultivated systems, decisions that affect the delivery of both cultivated products and ecosystem services. The cultural, socioeconomic, and educational background as well as the expectations, perceptions, preferences, and risk attitudes of farmers and farm households can all be of overrriding importance in shaping land-use options. An example of stakeholder perception comes from a study in Spain (Kok et al., 2006) where it is shown that contrary to the definition provided by the UNCCD, local stakeholders refer to the social, economic and institutional aspects in their perception of desertification. When asked for a single definition, most local stakeholders define desertification as *human desertification*. Thus, local farmers are relatively unconcerned with processes of land degradation, and more with social processes such as rural outmigration. Yet, in addressing drivers of ecosystem changes, the MA (2005) noted that the interactions among drivers create new opportunities and constraints on land use, induce institutional changes in response to perceived and anticipated resource degradation, and give rise to social effects such as changes in income inequality (as there are winners and losers in environmental change).

An illustrative example of the connectedness of many drivers is the generally well-understood process of tropical deforestation. In all regions of 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. However, many regional variations on this general pattern are found. Deforestation driven by swidden agriculture 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, especially in the Amazon Basin. Pasture creation for cattle ranching is causing deforestation almost exclusively in the humid lowland regions of mainland South America. And expansion of smallholder agriculture and fuelwood extraction for domestic uses are important causes of deforestation in Africa. Box 4.4.3-2 illustrates the role of AKST in the expansion of soybean in Latin America.

However, according to Reid et al. (2006) single-factor causes are rare, but the range of combinations is not infinite. Specific combinations account for a significant share of land-use change including lifestyle choices and shifting consumption patterns; governance; global markets and policies; that underlying causes often have a strong influence on local land use and cover changes; and that drivers can work together to create rapid land use and land cover change. In the same way land use alters, in multiple ways agricultural production and AKST.

Box 4.4.3-2 Genetically modified soybeans in Latin America
At the global scale, soybean is one of the fastest expanding crops; in the past 30 years, with planted area more than doubling (FAO, 2002). Of the world's approximately 80 million hectares of soybean, 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 hectares in 1970 to more than 13 million hectares 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, for example, 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 endeavour (Kaimowitz and Smith, 2001). Although until recently, Brazil was a key global supplier of non-GM soya, planting of GM soy has been legalised in both Brazil and Bolivia. Fearnside (2001) furthermore documented how soybean expansion in Brazil increased; research on soybean agronomy, infrastructure development, and policies aimed at risk-reduction such as inexpensive credits during years of low production or profitability. In Brazil alone, about 100 million hectares are considered to be suitable for soy production. If Argentina, Brazil and Paraguay expand their acreage according to, an overproduction of 150 million tonnes will be reached in 2020 (AIDE, 2005)

Scale-related complexity. According to Lambin et al. (2001), global forces are the main determinants of land use change, as they amplify or attenuate local factors. Even so, the myriads of land use changes which occur continuously on the earth's surface are evaluated differently at different scales. Less visible but of no lesser importance is the buildup of small impacts at lower levels of the spatial and temporal scales to generate impacts on higher levels of these scales; this is the case of cumulative impacts which 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. Temporally, cumulative impacts appear as lagged effects of land use change. Salinization, acidification, desertification are caused usually by the buildup of smaller, short run changes in the use of land. Another class of impacts are the non-point source impacts; those caused in a place by land use changes in another place (or places). The development of exurban space results from changes of land use, among others, in urban areas. Water shortages in a region may be due to excessive water abstraction to serve a fast growing tourist area. The issue of scale is implicated in all these and similar instances and makes the use of "scale-sensitive" analytical approaches imperative. The MA (2005) is a good example of a multiscale effort, in which global, regional, and local studies are brought together.

Conclusions. 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, mostly because of lack of data, a rather limited subset of these drivers are actually 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 Subchapter 4.2), but poorly presented 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; or urban-rural connections, to name a few. Once these are incorporated in a more comprehensive way, the link with AKST will become easy, almost self-evident.

4.4.4 Climate change and air pollution

4.4.4.1 Introduction

Climate change and air pollution are clearly important driver of future agriculture and needs for research and knowledge development. On climate change, the Intergovernmental Panel on Climate Change concluded in its latest assessment that it is very likely that humans have caused most of the warming observed over the twentieth century (IPCC 2007). 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). An important question is what this would mean for agriculture.

4.4.4.2 Climate change

Driving forces of climate change. Increasing greenhouse gas concentrations play a dominant role in the recent and future increase of global mean temperature (IPCC 2007). The contribution of direct land use change impacts are assessed to be much small compared at the global level. At the local scale, however, changes in biophysical factors (surface roughness, albedo) related to land use change can be as important as changes in greenhouse gas concentrations. Moreover, under particular circumstances (for instance, in the case of a large-scale dieback of the Amazon), changes in land cover could also have a large contribution globally (e.g. Cox et al. 2000).

To assess the potential impact of climate change, Nakicenovic et al. (2000) developed a set of scenarios (the IPCC SRES scenarios) depicting possible emission trends under a wide range of different assumptions. Subsequent calculation showed that these scenarios result in atmospheric concentrations of CO_2 of 540–970 parts per million in 2100. This range of projected concentrations is primarily due to differences among the emissions scenarios: the scenarios show a range of 5–28 GtC per year in 2100, compared with 7.1 GtC in 1990. Model projections of the emissions of other greenhouse gasses (mainly CH_4 and N_2O) also vary considerably by 2100 across the IPCC-SRES emissions scenarios. Recent work by Van Vuuren and O’Neill showed that the IPCC scenarios are still roughly consistent with current literature – with the majority of the scenarios leading to 2100 emissions of around 10-22 GtC (as shown also in Figure 4.4.4.1). The projection of the IEA-2006 World Energy Outlook lies in the middle of this range. The environmental assessments follow the ranges depicted by the SRES scenarios as indicated in Table 4.4.4.1.

The IPCC scenarios do not explicitly include climate policies. Stabilization scenarios explore the type of action required to stabilize greenhouse gas concentrations. In Figure 4.4.4.2, ranges of stabilization scenarios going to 650, 550, and 450 ppm CO_2-eq (Den Elzen et al., 2007) are compared to IPCC-SRES scenarios and the WEO-2006 scenarios. The ranges in emission pathways result from uncertainty in the land-use emissions, other baseline emissions and timing in reduction rates (the latter implies that being low in the range early in the scenario period, allows being high in the range later on and visa-versa).

Figure 4.4.4.2 shows that the B1 scenarios more-or-less corresponds to a 650-700 ppm CO_2-eq stabilization scenario. The B1 scenario is the lowest scenario that has been compared in climate model calculations in the recent IPCC-WG1 report (AR4) (have not scanned the report for individual model studies yet). The WEO-2006 AP scenario can be considered as a real 650 ppm CO_2-eq scenario, while the BAPS scenario possibly corresponds to a 500 ppm CO_2-eq scenario.

Temperature projections. IPCC calculations show that these scenarios are expected to lead to considerable climate change. The globally averaged surface air temperature is expected to increase from 1990 to 2100 for the range of IPCC-SRES scenarios from 1.4 to 6.4 Celsius (IPCC, 2007) (see also Figure 4.4.4.4). This increase would be without precedent during the last thousand years. The total range given above is partly a consequence of differences in emissions, but also partly an impact of uncertainty in the so-called climate sensitivity, i.e. the relationship between greenhouse gas concentration and the increase in global mean temperate (after equilibrium is reached).

In the last years, there has been a shift to express the temperature consequences of stabilization scenarios more in term of probabilistic expressions than single values and/or ranges (Figure 4.4.4.3). As a (somewhat arbitrary) example below the probability for equilibrium temperature for 2^oC and 2.5^oC are shown as a function of the CO_2-eq concentration. The figure shows that 50% probability for 2^oC more-or-less corresponds to 450 ppm CO_2-eq, for 2.5^oC the corresponding concentration is around 525 ppm CO_2-eq. As a result, a scenario (based on it emissions) that would lead to 2^oC warming as most likely outcome could also lead to a 0.9 ^oC-3.9 ^oC warming (95% certainty range). Similarly, a scenario with a medium outcome of 3.6 ^oC could lead to a range of outcomes from 2.1 ^oC-6.1 ^oC. Handling uncertainty therefore represents an important aspect of future climate change policy. What to avoid – and with how much certainty? How much risk is society willing to take?

Obviously, assuming climate policy may lead to lower degrees of warming. Current insights indicate that the temperature increase associated with climate policy scenarios currently would decrease the lower bound of the range for the SRES scenarios to about 0.5-1.0 degree Celsius above 1990 level (i.e. based on an insensitive climate system and using a strong climate policy scenario). This implies that although these values may be uncertain, climate change is expected to be very likely. High rates of temperature change are in fact most likely to occur in the first half of the century as result of the fact that even if climate policies are adopted, their action will also result in lower sulfur emissions. The latter are currently having a cooling effect on the atmosphere. While the computation of global mean temperature is uncertain, the patterns of local temperature change are even more uncertain (Figure 4.4.4.5). In its comparison of temperature calculations from different climate models, IPCC (2007) noted some areas of agreement (such as temperature increase likely being higher at higher latitudes than near the equator) but also many areas of disagreement. Disagreements, for example, typically occur in areas with complex weather patterns.

Finally, as noted, land use changes can affect various biophysical factors that have a major impact on climate (and that form a direct linkage between ecosystems and climate change). While impacts in tropical zones via albedo changes are relatively small, other influences of large-scale deforestation of tropical rain forests on (local) climate are highly uncertain but may be significant. Reforestation in temperate zones may have impacts too (possibly driven by climate policy for sequestrating CO_2). As indicated by Betts (2000), this actually could lead to increased warming as a result of reduced albedo. Again, these effects are still highly uncertain.

While future regional temperature is uncertain, still more uncertain are the computations of precipitation patterns within regions. Climate models can provide insight into overall global and regional trends but cannot provide accurate estimates of future precipitation patterns when the landscape plays an important role (as in the case of 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, the northeast of Brazil, and west of the Andes in Latin America. This will increase water stress in these areas, as described later.
Although climate models do not agree on the spatial patterns of changes in precipitation, they do agree that global average precipitation will increase over the twenty-first 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. In general, climate models give a more consistent picture for temperature change than for precipitation.

The potential impact of climate change on future agricultural yields. One of the great human achievements of the 20th century was the successful expansion of global agricultural capacity apace with growing agricultural demand (see also elsewhere in this chapter). Between 1960 and 2000 the population of the Earth doubled while the agricultural system has been able to expand its production to feed this increasing population (production grew by 2.2% annually). For the future, further production increases are required. Food production must expand to meet this increase, with or without climate change.

The impacts of climate change on agriculture have been assessed by IPCC (2001) in its Third Assessment Report and new work is underway for the Fourth Assessment report. In fact, two combined effects have to be accounted for: the impacts of climate change and those of a rising atmospheric CO_2 concentration. The latter (also referred to as carbon fertilization) can increase yields and make plants more stress-resistant against warmer temperatures and drought. 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.

This current work shows that two decades of research on the global consequences of climate change for food production have begun to yield important insights. The preponderance of global agricultural studies (Adams et al., 1999; Parry et al, 1999, Fischer et al, 2001), have established, although incompletely, that climate change is not likely to diminish global agricultural capacity by more than a few percent if at all by 2050 when taking into account regions that may benefit (i.e., North America, Europe) and regions that may suffer (i.e., the Tropics). Any losses would be on top of substantial gains in world output—global agricultural capacity, climate change apart, is projected to be about 55 percent greater than current by 2030. 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 degrees C of warming before rising with additional warming—hence, 2-3 degrees of warming appears to be a crucial threshold for crop prices.

While the global situation looks manageable, there are reasons for concern at regional levels. The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), summarized by Easterling and Apps (2005), reported that a number of models simulate the capacity of temperate crops (wheat, maize, rice) to absorb 2-3 degrees C of warming before showing signs of stress. More recent assessment work found that agronomic adaptation extends the threshold to beyond 5 degrees C of warming for those crops (Figure 4.4.4.6). Tropical crops exhibit immediate yield decline with even the slightest warming (Figure 4.4.4.6) because they are currently grown under conditions close to maximum temperature tolerances—even a little warming sends them lower than current levels. Adaptation gives tropical regions a buffer of approximately 3 degrees C of warming before yields of those crops dip below current levels. In spite of this slight buffer, the news is not good for developing countries in the Tropics, especially Africa.

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 the 21st century. In India, a 2 ^{o}C increase in mean air temperature could decrease rice yield by about 0.75 tonne/ha and cause a decline in rain-fed rice in China by 5-12%. Sub-Saharan Africa could lose a substantial amount of cropland due to climate change-induced land degradation. Based results generated with the HadCM3 scenarios, as many as 40 food-insecure countries of Sub-Saharan Africa, with a projected total population in 2080 of approximately 1-3 billion, may lose on average 10-20% of their cereal-production potential caused by climate change.

In conclusion, it appears that climate change will not be a major challenge to agricultural production systems in temperate regions until well out into the 21st 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. This set of conclusions has a medium confidence. Modeling studies also suggest that real food prices will reverse their long-term decline at about 3 degrees C of warming, resulting in rising prices thereafter. This conclusion has to be given a low confidence indication.

Climate change mitigation policies and agriculture. According to several assessments, agriculture and forestry can play a significant role in mitigation policies (IPCC, 2007; MA, 2005; FAO, 2006). By laymen, agriculture is often considered to be an effective sink of CO_2. In reality however, agriculture is a source and not a sink of greenhouse gases (GHGs) (IPCC, 2007). This is caused by significant emissions of methane (CH_4) and nitrous oxide (N_2O), both being far stronger GHGs than CO_2. Methane emissions are mainly caused by livestock production and rice fields, while N_2O emissions are mainly related to the use of nitrogen fertilizers (both organic and chemical fertilizers). Despite large annual exchanges of CO_2 between the atmosphere and agricultural lands, the net flux is probably almost balanced. This balance however can be influenced by a.o. land use changes and agricultural practices.

Agriculture accounted for an estimated emission of 5.1 to 6.1 $GtCO_2$-eq in 2005, being 10-12% of the total global anthropogenic emissions of GHGs (IPCC, 2007). Current emission rates from agriculture could increase significantly with increasing population, increased demand for animal products and increased N fertilizer use.

Projections of anthropogenic land emissions and sequestration are summarized here in Subchapter 4.4.4.3. Land emissions are highly depended on land use changes, mainly caused by agriculture. Land use change is mainly driven by changes in agricultural land use, which in turn is driven by the demand for agricultural products and by changes in productivity. In general, the recent land use change carbon emissions project high annual net releases of carbon in the near future that decline over time. Future emissions are however hard to model, given the complex systems, many feed-backs and uncertainties like the effect of climate change on crop yields and soil carbon content, land use changes caused by the production of biofuel etc. There is consensus between different baseline scenarios that CH_4 and N_2O emissions from agriculture will increase in the future (Fig 4.4.4.7). At the end of the century, emission could be twice as high as present.

Policies to reduce GHG emissions might influence agriculture and AKST significantly in the future, especially if future policies not only address CO_2-emissions, but other GHGs as well. These so-called 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, 2007, Lucas et al, 2007). Including land-use mitigation option also render a higher cost-effectiveness. This paragraphs describes options for reducing emissions from agriculture, potential effects on agriculture and impacts on future AKST. The role of agriculture as a producer of bioenergy is treated in paragraph 4.4.5. Changes is land-use practices lead to significant reduction in GHGs, not only for CO_2, but also for CH_4 and N_2O.

A variety of options exists for mitigation of GHG emissions in agriculture (Table 4.4.4.2). Effective options are improved crop and grazing land management, restoration of drained organic (peat) soils and restoration of degraded lands (IPCC, 2007). Lower, but still significant mitigation is possible with improved water and rice management, set-asides, land use change and agroforestry. The actual measures which are relevant depend highly on the carbon price (the market price for reducing GHGs emissions). At low carbon prices, profitable strategies are (minor) changes in present management en production systems, like 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 very much on local conditions, including climate, agricultural practices and socio-economic circumstances. Therefore, there is no universally applicable list of effective options (IPCC, 2007, WG III, CH8). Table 4.x summarizes possible mitigation options in agriculture, including possible co-benefits and trade-offs.

4.4.4.3 Consequences for AKST

The new role of agriculture of reducing GHGs emissions lead to a whole new terrain of theoretical and practical knowledge and science to be explored. All options need to be viable and sound in the broad setting of other aspects of agriculture, like its role in sustainable (economic) development, the providing agricultural products its consequences for land management and for biodiversity, and other trade-offs. Some concrete issues are:

- new mitigation practices for livestock production;
- mitigation practices relevant for nitrogen fertilizers;
- the management of soil carbon;

An additional issue is how the contribution of an individual farmer to the mitigation be measured and rewarded? There are millions of farmers in the world, and most measures to take are much harder to monitor than e.g. the processes in a power plant. Without proper reward farmers will not be stimulated to take appropriate measures, since most measures will cost money.

4.4.5 Energy and development: implications for energy use in agriculture

4.4.5.1 Introduction

Both energy and agriculture play a major role in the history of human civilization (Fig. 4.3.4-1). In this context the industrial revolution represented a major discontinuity in previous trends. The major drive of the industrial revolution was the availability of larger and better energy surpluses delivered to society by an energy sector based on fossil energy (e.g. Cottrel, 1955; Odum, 1971; Smil, 1991). In agriculture, this eliminated the power bottlenecks typical of pre-industrial societies – in this way allowing much higher production levels per unit of land and per hour of labor. The result of this has been a dramatic increase in the global population, a related decrease in arable land per capita, a deep socio-economic transformation of developed societies associated with a massive movement of the work force away from agricultural production, and an increase in energy consumption. This situation did put agriculture in a very different context (the need for further yield increases requiring more energy inputs, transfer of labor from agriculture to industrial sectors etc.).

The global trend shown in Figure 4.4.5.1 is hiding the differences between developed and developing countries. Currently, post-industrial societies still co-exist with subsistence societies with different development needs. In relation to the issue of energy security and food security this difference between post-industrial and pre-industrial economies entails dealing with two completely different situations and therefore with different expected trends. In this chapter, we will discuss three different issues on the implications of energy use as driving force for agriculture:

- Expected changes in the energy sector as a whole;
- The role of energy in agriculture systems
- Bioenergy;

4.4.5.2 Scenarios on global energy use

Across the 20th century, global energy use increased by about 2.5% annually – with a clear transition in consumption of primary sources from coal to oil to natural gas. In relation to the mix of energy carriers needed to guarantee end uses in the various sectors of the economy, the most robust trend has been the continuous increase in the consumption of electricity. The main drivers of this increased consumption are an increasing global population (1.4%) and economic growth. The far majority of the scenarios currently developed expect a continuation of these trends. Global energy use continues to grow – and in the first decades mainly based on the consumption of fossil fuels.

Figure 4.4.5-2 shows the primary energy consumption projections in the IPCC-SRES scenarios , a range of scenarios published in literature, the projections from IEA's World Energy Outlook (IEA, 2002; IEA, 2004), US.DoE's central projection (US.DoE, 2004a) and the OECD environmental outlook. The differences between the different scenarios can be explained in terms of underlying economic growth assumptions and assumed emphasis on dematerialization. Developing countries tend have the largest contribution in increased energy consumption as 1) per capita consumption levels are lower than that of developed countries, but grow faster (consistent with the economic development stage), 2) there is a substitution from traditional to commercial energy types and 3) population growth will continue to drive energy consumption in these countries. The scenarios also share the observation that in 2030 still the majority of global energy use needs to come from fossil fuels. Nevertheless, clear differences in the energy mix may occur. The most important determinants here are the stringency of future climate policy, differences in technology expectation, growing importance of energy security and societal preferences. All in all, it is expected that global energy consumption increases by a factor of 25-100% in the next 30 years – providing a huge challenge to produce these levels of energy. Agriculture is a relatively small sector in global energy demand.

In terms of the energy supply, large diversity exists among different medium- and long-term scenarios – ranging from nearly total coal use (e.g. IPCC's A2 scenario) versus nearly total renewable energy (e.g. under stringent climate policy scenarios). The search for alternative "high quality energy sources" to fuel economic growth includes important decisions on trade-offs – most importantly with global warming. Conventional use of fossil fuels implies levels of greenhouse gas emissions that are likely to create substantial global warming (see elsewhere in this chapter).

Current knowledge on climate impacts does suggest that the objective of the Climate Convention (UNFCCC), i.e. to prevent dangerous anthropogenic interference, can only be achieved by a substantial reduction of greenhouse gas emissions. In that case, fossil fuels may only be used in combination with carbon capture and storage. There are other important alternatives including energy efficiency, renewables, which includes bioenergy and nuclear power that have important trade-offs as well. The growing awareness of both the “global warming” and “peak oil” issues is finally forcing policy makers and the general public to consider energy high in their agendas.

4.4.5.3 The relationship between energy use and agriculture

Energy use and agriculture – current trends. The food and energy systems have a high degree of interaction. So far, economic development entailed a progressive growth in the allocation of direct and indirect energy inputs to agricultural production (e.g. Pimentel, 1980; Leach *et al*. 1986; Stanhill, 1984; Pimentel and Pimentel, 1979; Stout, 1991; 1992; Smil 1987; 1991a). The trends towards a dramatic reduction of the requirement of labor in agriculture has lead to a strong intensification in developed countries. Two forces, so far, have been driving technological development of agriculture (Hayami and Ruttan, 1985): 1) the trends towards continuously increasing the productivity of labor of farmers and 2) the need of continuously increasing the productivity of agricultural land.

These trends have crucial implications for the use of energy in agriculture. A comparison between the performance of developed and developing countries is provided in Tab. 4.3.4-1 and Fig. 4.3.4-3 (after Giampietro, 2002). This comparison clearly indicates key differences: 1) the productivity of MJ of food energy from crops per hour of labor in developed countries is almost 10 times than of developing countries, 2) a smaller labor force in agriculture in developed countries coincides with a higher capital intensity and 3) in spite of the low level of fossil energy inputs, as a group developing countries are already producing more food per hectare than developed ones. As a result, in these countries further yield increases as a result of further intensification will not be easy to achieve.

There is an additional complication to be considered. In order to obtain a good insight into the relationship between agriculture and energy, the system boundaries need to be enlarged to include into the picture the energy consumption related to the activities taking place in the post-harvest sector. Just to give an idea, in 1995 the agricultural sector of USA consumed 2.4 Joules of fossil energy per each Joule of food consumed at the household level (Heller and Keoleian, 2000). However, the total consumption of fossil energy of the agricultural sector was only 20% of the total energy consumed in the food system of US in that year. 80% of the fossil energy went into processing, packaging, transportation, food retail, household storage and preparation, commercial food services. More than 7 Joules of fossil energy were spent in the food system, per each Joule of food delivered to the consumer (Heller and Keoleian, 2000). In the EU, Ramirez-Ramirez (2005) estimates that the food supply chain used nearly 4000 PJ of primary energy – or about 7% of total consumption. 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. Thus, in developed countries the majority of energy consumption is not in agriculture itself – but in the secondary processing of food. In fact, here also the majority of value-added is produced. For one of the most energy-intensive products (meat) even 40-60% of the energy consumption is in processing. This increase in the energy costs in the post-harvest sector is related to the socio-economic transformations associated with economic development (see subchapter on economics).

The increase of total energy use for food consumption in Europe in the 1970-2002 period was around 1.6% per year – i.e. more-or-less equal to the increase in total energy consumption. This increase is mainly driven by the strong increase in food processing and in agriculture itself. Energy for fertilizer production in fact fell within Europe. Globally, in contrast, energy for fertilizer is strongly increasing being a net result of increasing fertilizer application, trends to more energy-intensive fertilizers and (in the opposite direction) considerable energy efficiency gains in fertilizer production.

Looking ahead - the future of energy use in agriculture. A large fraction of population growth expected in the next decades (more or less another 2 billion) will occur within developing countries. This is likely to have important implications for the relationship between energy use in agriculture. First of all, further increasing food production by itself requires a strategy of tailored intensification and consequently a further increase in the consumption of fossil energy for agricultural production. This process is likely to coincide with structural changes in the economy, leading to lower labor supply in agriculture and thus the need for further intensification in the use of inputs and technology to production. Finally, like developed country energy systems, systems in developing countries are expected to see considerable growth in energy consumption for food processing. There are important challenges in these trends: 1) intensification requires investments (which have to compete with other sectors, 2) recent trends in fossil fuel may be interpreted as suggesting a long period with tight energy markets (and thus higher prices). According to given existing trends of population growth and the strong aspiration for a dramatic improvement in economic and general living conditions in the rural areas of developing countries, one can expect a strong growth in energy consumption for food production and the other activities in the food system. At the same time, the obstacles mentioned above and rising energy prices could partly mitigate these trends.

4.4.5.4. Bioenergy

Both the issue of global warming and energy insecurity (scarcity of fossil fuels and/or dependency on imports) have increased the interest in bioenergy as an alternative to oil in transport, but also to natural gas and coal in electricity and heat generation. Most scenario studies under climate policy constraints in fact project a strong increase in the use of bioenergy. Obviously, this would have major implications for future agriculture since it could imply a dramatic change in production patterns. However, it should be noted that there is a clear ambiguity about the interpretation of the 'facts' about bioenergy and this leads to important differences in opinion on the potential role of bioenergy and its impacts which are discussed below (see also Slesser and Lewis, 1979; Smil, 2003 vis-à-vis Hoogwijk et al., 2004; Smeets and Faay, 2004).

Crucial issues for bioenergy use. There are a number crucial controversies with respect to bioenergy use. This is partly already related to what is understood under the concept of bioenergy (from cultivation of energy crops in monocultures to complete shifts in agricultural production systems). Based on this, the most controversial issues are:

- The question whether bioenergy can provide net energy gains and/or can reduce greenhouse gas emissions compared to fossil alternatives
- The costs of bioenergy
- The competition between the land requirement for energy crops and other forms land use, including food production and nature;
- The impacts of bioenergy on the prices of food crops (and thus on food security).
- The question how to use bioenergy;
- The environmental implication of large-scale energy use;

a) Net energy gains and greenhouse gas emissions

An important controversy related to the *overall net energy gains* from bioenergy production. While energy is produced (e.g. in the form of ethanol or oils) also energy is used for production (e.g. in the form of electricity and fossil fuels, during production of the crop, transport and in particular conversion from biomass to final energy carrier). Obviously, to be a viable long-term alternative for fossil fuels the net energy output needs to exceed the energy input. But even more important, in relation to its economic feasibility, the requirement of land, labor and capital for generating a net supply of biofuels should not imply a serious interference with the actual functioning of the other economic sectors. A large amount of studies has been published on this issue for different routes and crop types and using very different assumptions. In general, relatively high energy returns are found for oil crops although Ulgiati, 2001, Patsek and Pimentel (year) found a very low return for them. The production of ethanol from sugar cane also has a relatively good energy investment, but raising concerns for its high environmental impact. More controversial are figures for the ethanol from maize case. Several studies published inputs that exceed output. Farrell et al. (2006) reviewed a large number of studies and found that an important part of the controversy is related to different technology assumption and differences in accounting for so-called by-products. Using a standardized methodology uncertainty was somewhat reduced and energy outputs have a small net gain. Others, however, have commented on the study by Farrell (2006), mainly for its accounting scheme (Cleveland (2006), Kaufmann (2006), Patzek (2006), Hagens et al. (2006)). The future conversion -of cellulosic material to second generation biofuels (see subchapter 7.2.5.2.), for example switch grass, leads to much higher gains in energy terms.

The assessments of the economic and biophysical viability (in terms of land, labor demand) of energy crops-biofuel systems is not only difficult because of the high sensitivity to small differences in technology assumptions, but also because the energetic analysis of the inputs and outputs of a biofuel system refers to energy forms having different quality. As already quoted from the Farrell et al. (2006) study an important contribution to existing controversy is related to the accounting system used in different studies. Further standardization might help here – but there are some more difficult issues as well. Most of the routes to produce biofuels also create by-products and so partly costs and energy consumption needs to be attributed to these by-products. An important question, however, is whether at increased scales of bioenergy products sufficient markets for these by-products continue to exist and whether it is possible to substitute to other by-products. Also related to the issue of scale is the problem represented by the very high labor demand of biofuels per unit of net supply of energy to society (Giampietro and Ulgiati, 2005).

A directly related issue is the question whether bioenergy can contribute *to reducing greenhouse gas emissions*. Most recent lifecycle assessments of biofuels estimate positive GHG emission reductions for liquid biofuels but their extent varies greatly depending on the type of biofuel and production method. Generally, emission reduction potential is highest when high crop yields can be produced with low inputs (fertilizers, pesticides and agricultural mechanization). With considerable use of inputs, maize ethanol in the U.S. is believed to cut GHG emissions only by 10 to 20 percent compared to regular gasoline. In contrast, Brazilian ethanol from sugarcane is believed to exhibit substantially higher emission reductions of more than 90 percent (CONCAWE, 2002; European Commission, 2005; Farrell, et al., 2006; GEF, 2005; GEF, 2006; Hill, et al., 2006; IEA, 2004b). Biodiesel is estimated to reduce GHG emissions by 47 to 75 percent compared to conventional diesel (Bozbas, 2005; CONCAWE, 2002; Hill, et al., 2006; IEA, 2004b; NOVEM, 2003). However, the variance of estimates is considerable and some studies estimate a far less favorable or even negative GHG emissions picture for some types of biofuels (e.g. Delucchi, 2003; Pimentel and Patzek, 2005). While these more skeptical analyses represent a minority, they point to potential flaws in the mainstream lifecycle analyses – most notably with respect to assumptions about land-use. In fact, most studies assume that biofuels are derived from crops harvested from land already in production. However, converting intact ecosystems to production could result in reduced GHG savings or even net increases in GHG emissions – depending on the type of energy crop and the nature of the preceding ecosystem (Cowie, et al., 2006; Delucchi, 2006; Hill, et al., 2006; Kartha, 2006).

b) the costs of bioenergy

In terms of *costs*, studies on bioenergy alternatives generally find the low cost range from bioenergy to start at around 12-15$/GJ for liquid biofuels from sugar cane today to around 15-20 US$/GJ for production from crops in temperature zones. This is considerably more expensive than 6-8$/GJ for petroleum-based fuels assuming a crude oil price around 30$/bbl. At 70$/bbl, however, the costs range for oil based fuels would be around 13-14$/GJ, making low-costs liquid biofuels far more attractive (see also subchapter 3.2.2.2.4.). It is expected that costs of biofuels are further reduced due to technology progress (in particular at the higher end of the costs range that are based on more capital intensive and advanced techniques). Some recent studies of costs indicate that ethanol from sugar cane and corn are profitable enterprises compared to the current wholesale price of gasoline (Hill et al., 2006) – but this is also related to existing agricultural subsidies. Apart from oil prices, agricultural subsidies, the economic profitability also depends on the value of emission reductions. Current values (e.g the carbon credits in the European Emission Trading System) are too low to bridge the gap between biofuel productions costs and fossil fuel alternatives, but more stringent climate policies may result in higher carbon credits – and in combination with high oil prices much smaller incentives may be sufficient.

c) impact on land use

The most serious concern in the controversy on biofuels is the issue of *land scarcity and the potential competition between land for food production, energy and protection of nature*. The production of 1st generation biofuels from agricultural and energy crops is very land intensive. Based on estimates for average biofuels yields per hectare it is possible to make rough estimates of how much land will be required in the future to produce particular biofuels outputs. For example, assuming a biofuels portfolio derived from sugar cane, maize, palm oil and rapeseed (60GJ/ha/year), about 300 million ha would be needed in order to replace 10 percent of the 2005 global crude oil consumption of 30.1 billion barrels. This corresponds to about 20 percent of the globally available 1.5 billion ha of arable land (Table 4.4.5.2) (FAO, 2005).

As discussed in the subchapter on land cover, different scenarios exist for future demand for land for food production. In general, studies indicate that agricultural land for food production is likely to increase significantly in developing countries – but to decrease in developed countries. The category of ‘abandoned’ agriculture land represents one important source of land that is generally used in studies that estimate potential biofuels production. A second category considered in studies is so-called ‘degraded land’ in developing countries – which have become unsuitable for agriculture. Some studies indicate that this land can be used for extensive production of biofuels feedstocks while at the same time improving soils. There is considerable controversy on how large that contribution could be. A third category of land available for bioenergy production is natural grasslands – which provide a vast potential but at the costs of loss of natural areas. Obviously, biofuels can also simply compete with food production for current agricultural land and/or expansion of agricultural land into forest areas. Examples of this can already be seen where expansion of crop plantations for biofuels production can lead to deforestation and draining of peatlands, e.g. in Brazil, Indonesia and Malaysia (Curran, et al., 2004; FBOMS, 2006; Kojima, et al., 2007, Friends of the Earth, 2005). Studies looking into available land for bioenergy and all finding substantial potentials include those of Fischer and Schratzenholzer (2001) and Hoogwijk et al. (2004).

d) impact on food prices

Despite the fact that studies show that is theoretically possible to produce bioenergy crops on land that does not interfere with food production, as long as biofuels are produced predominantly from agricultural crops, an expansion of production will raise agricultural prices. The production of 1st generation biofuels is based on starchy and oily agricultural crops such as sugar cane, soybeans and maize, which are also traded on markets for other uses – most importantly for food and fodder. Today approximately 15 percent of the U.S. maize crop, 50 percent of Brazilian sugar cane and more than 20 percent of the European rapeseed production are used for the production of biofuels (GTZ / TERI, 2005; Ortiz, et al., 2006; Worldwatch Institute, 2006). As is becoming evident in markets today, the demand for biofuels feedstocks can lead to increases in agricultural prices. For example, the price of maize – the major feedstock in U.S. ethanol production – has risen 56 percent in 2006. Analogous price rises are expected for other biofuels feedstock crops in the future (OECD, 2006; Rosegrant et al., 2006). It is important to note that this increase in prices can be caused directly, through the increase in demand for the feedstock, or indirectly, through the increase in demand for the factors of production (e.g. land, water etc.). This means that using non-edible plants as feedstocks on a large scale may only have a limited mitigating effect on food prices. More research is needed to assess these risks and their effects but it is evident that poor net buyers of food would suffer strongly under rising prices. Some food-importing developing countries would be particularly challenged to maintain food security.

e) how to use bioenergy

A next controversy is related to *how to use bioenergy*. Most attention so-far is paid to the use of bioenergy as fuel for the transport subchapter, obviously influenced by energy security considerations and the relative scarcity of low carbon alternatives to petroleum fuels. Some studies, however, indicate that from the view point of reducing GHG emissions the use of bioelectricity and bioheat offer considerable potential. The emissions are less contentious than those from liquid biofuels, largely because electricity and heat are in most cases produced from wastes and residues and therefore do not contain considerable energy inputs. Scenario studies provide different views on this. Azar (year ???), for instance, finds that also under more stringent climate policy scenarios most bioenergy should be used in the heat and power sectors. Other studies find that given the large amount of alternative technologies to reduce emission in power (e.g. wind or capture and storage), using bioenergy for transport fuels represent a more attractive option. This also depends on the assumptions on alternative technologies, such as hydrogen.

f) environmental implications

A last issue on bioenergy production *is environmental implications*. While these are relatively low for the current small scale production levels – high levels of biofuels feedstock production will require considerably demand for water and possibly nutrients. Some attention to this is given in the subchapter on water in this chapter. As shown in the above discussion, the multitude of issues and their complex interrelationships urgently require information tools to strengthen policy and technical decision making in the bioenergy field.

Assessment of the potential for bioenergy. We provide here an overview of some of the studies that estimate the potential for bioenergy globally or its contribution in scenario studies. These studies have to be interpreted within the general framework of the existing controversies mentioned above. It can be concluded from these studies that – from a technical perspective – bioenergy could supply several hundred exajoules per year in the future, as indicated in Table 4.4.5-3 (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 (see subchapter 3.2.2.2.4.). It can also be concluded that the bioenergy demand is sensitive not only to biomass supply potentials, but also to total energy demand and competitiveness of alternative energy supply options. The major reason for the divergence among the studies is that the two most crucial parameters, land availability and yield levels in energy crop production, are very uncertain. The conclusions about future availability of forest wood and of residues from agriculture and forestry also vary substantially among the studies. Especially, the use of forest wood has been identified as a potentially major source of biomass for energy in several studies (up to about 115 EJ yr−1 in 2050). Other studies have on the other hand presented a less prominent role of forest wood in supplying biomass for energy. Here, the divergence can be explained by different approaches to estimating the bioenergy potential of forest wood: the lower end estimates restrict the bioenergy potential to certain shares of the wood flows in the forest sector (and thus to the future forest product demand), while the higher end estimates does not make such restrictions.

Table 4.4.5-3. summarizes the overall findings of a literature review and evaluation. Main assumptions per (potential) biomass category are given as well. In theory, energy farming on current agricultural land could contribute over 800 EJ, without jeopardizing the world's physical food supply - albeit leading to considerable increases in food prices. Use of degraded lands may add another (maximum) 150 EJ, although this will largely be provided by low yield biomass production systems. A biomass supply equivalent to 20-50 EJ should be produced by plantations when existing forests are not able to meet the growing demand for biomaterials. Organic wastes and residues could possibly supply another 40-170 EJ, with uncertain contributions from forest residues and potentially a very significant role for organic waste, especially when biomaterials are used on a larger scale. In total the upper limit the of bioenergy potential could be over 1000 EJ (per year). This is considerably more than the current global energy use of 400 EJ. However, it should be noted that when dealing with these type of hypothetical assessment what really matters is whether or not the opportunity costs of capital, labor, circulating investments, land, and the environmental constraints will make possible to transform this biomass into a viable net energy supply to society.

The contribution indicated in Table 4.4.5-3 is by no means guaranteed: crucial factors determining biomass availability for energy 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) utilisation of biomaterials, 6) limitations in land and water availability. Major transitions are required to exploit this bioenergy potential. It is uncertain to what extent such transitions are feasible. For instance, the (net) biomass supply per region strongly depends on local factors, both physical (soil and climate) as well as socio-economic (such as costs of land and labor and level of economic development). There are strong interactions between the demand for food, bioenergy and biomaterials. The economic drivers are however so far poorly studied and better insight is highly needed. Also it should be noted that technological developments (in conversion as well as large-scale transport chains) could dramatically improve competitiveness and efficiency of bioenergy. It is however largely unknown what allocation of biomass resources results in optimal utilization; transportation fuels, power and biomaterials compete.

A wide variety of potential studies on regional and local level has been done though and partly published in open literature. They vary from very simple approaches (e.g. assumptions on the percentage of agricultural land and residues available) up to sophisticated GIS based tools. Key problem here is that the methodological approaches, depth and impacts and issues taken into account for resource potential estimates differ widely. Results are therefore generally difficult to compare and serve different purposes, such as to highlight the technical, the economic, the short or long term potential and to what extent a potential can actually be realized (e.g. taking into varying criteria with respect to ecological and socio-economic impacts).

Figure 4.4.5-4 is an example of an overview of the key elements in the assessment of the bioenergy potential from specialized bioenergy crops using a bottom-up approach and statistical data on land use on projections on population growth, agricultural and forest production, etc. (Smeets and Faaij, 2004). The modular structure of this approach makes to a large extent use of public sources such as FAOSTAT, EFI, IIASA.

Implications for agriculture. Based on the discussion above, one possible outcome it that this century could see a significant switch from a fossil fuel to a bioenergy-based economy, with agriculture and forestry as the leading sources of biomass. (FAO IBEP, 2006). The outcomes can be unclear. "*One can envision the best scenarios in which bioenergy becomes 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.*" (ESMAP 2005)

High energy prices affect the food and agriculture sector in several ways. Besides the classical ones (via macroeconomic effects affecting all aspects of production, consumption and trade, and the more direct ones on production agriculture via the effects on the costs of the energy-intensive inputs like fertilizer and fuel) they can impact agriculture by creating new markets for those products which can be used as biomass feedstocks for the production of biofuels as substitutes for the petroleum-based fuels (petrol, diesel) in transport. The case of Brazil which, after a period of shrinkage during the 1990s when oil prices were low, has now reverted to using some 50 percent of its sugar cane output to produce fuel ethanol, both for domestic use and export, is telling. Ethanol in Brazil is considered to be competitive vis-a-vis traditional fossil fuels at oil prices of US$ 35-40/barrel, although this figure can be higher depending on the world price of sugar and dollar exchange rate. Also well known is the growing use of maize in the USA (in this case with subsidies) to produce fuel ethanol. The renewable fuel provisions in the Energy Policy Act of 2005 will further promote such use: by 2015, it may become more important than exports and could account for some 23 percent of the country's maize outputs (FAO 2006).

Again with subsidies, the use of vegetable oils to produce biodiesel is expanding in certain EU countries, while the EU has a target of a 5.75 percent market share of biofuels in the petrol and diesel market in 2010. There is growing interest in the countries with abundant, or potentially so, production potential of suitable feedstock (like palm oil for biodiesel in Malaysia and Indonesia, community cassava and sugar cane for ethanol in Thailand) for going the way of producing biofuels, b6th for domestic use and export.

Although at present the promotion of biofuels is often used in several industrialized countries as a means to create alternative demand for agriculture, in the future it can have far-reaching effects on world agriculture as it can offer novel development opportunities for countries with significant agricultural resources, if barriers to trade of biofuels were eased or removed. 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. The competitiveness of biofuels may be further enhanced if the savings of greenhouse gas emissions resulting from substituting ethanol for gasoline were to be monetized in the form of tradable carbon credits (Certified Emission Reductions of greenhouse gases).

Agriculture may be affected if the use of energy crops were to be increased and consolidated. Possible impacts of an expanded biomass use touches on emissions (water, air soil), water use, impacts on soil quality, consequences for land use (possible competition with other land use and leakage effects on very different scale levels), socio-economic impacts (involvement of different sectors and stakeholders as agriculture, forestry, energy sector and respective benefits or negative impacts). 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. In more generic terms, one wants to be able to assess how sustainable biomass for energy is. Linked to this, one can aim to set criteria and standards for what can actually be considered sustainable use of biomass and, again, how to optimize its use considering the very different ecological, economic and social dimensions.

4.4.5.5 Most important implications for AKST

Historically, there have been strong links in the development of the energy and agriculture sector – with the food systems becoming in time an important net consumer of energy. Given the trends described in the subchapter on energy scenarios (potentially higher energy prices and increased fuel scarcity) it is important for developed and especially developing countries to focus on relatively energy efficient food production systems.

Large scale bioenergy use could transform the agricultural system into a net producer of energy. Knowledge and science and technology on bioenergy is of high strategic importance. 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 stretch through areas as varied as agricultural and energy policies, natural resources and biodiversity protection and rural development.

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 biodiversity impacts. These four points have to be framed within the more general goals and constraints associated with rural development.

Implication for AKST in the bioenergy field necessarily involve a series of stakeholdres covering the above issues. Interaction between the agricultural sector and the energy, environment and indutrial sectors is vital for bioenery to fulfill its global role. Nevertheless, it is agriculture that should provide overall guidance on the bioenergy path since it is this part of society, with its own variety of stakeholders (farmers, cooperatives, government, agroindustry, commodity markets, etc.), which is in the best position to strike the balance between orderly, well informed and planned, economic and socially motivated action and the pressures from the environmamntal and energy sectors avid to fulfill their own expectations in terms of energy markets and climate change mitigation objectives. Sustainability criteria and practical approaches must guide action in the bioenergy field.

4.4.6 Labor

4.4.6.1 Introduction

Economically, labor is regarded as one of the factors of production. The composition of labor in agriculture has changed over time, particularly with the sector being affected by different stages of economic development (Hayami and Rutan, xx). The supply, conditions and quality of labor is critical in driving agricultural change and AKST. This subchapter seeks to asses how labor as a driver has been witnessing change at present and what is the likelihood of the direction of such a change to take place in future. Unlike other assessments, the IAASTD aims to introduce labor as a direct driver of agricultural change with implication to future AKTS demand, development, dissemination and utilization. The analysis draws heavily on the International Labor Organisation reports, with supplementary perspectives from limited additional sources (REF). Subchapter 4.4.6.2 looks into overall trends in agricultural labor and employment. Next Subchapter 4.4.6.3 looks into the gender perspective in labor. Finally Subchapter 4.4.6.4 looks into labor productivity issues to identify related drivers of productivity. The Subchapter concludes by assessing the implications of labor issues for AKST. It should be noted that most of the earlier assessments introduced in Subchapter 4.2 do not pay explicit attention to labor.

4.4.6.2 Trends in employment of labor in agriculture

Table 4.4.6.1 and 4.4.6.2 provide an estimate of employment in agriculture at the regional and world level and female employment for last 10 years respectively. The following trends can be observed.

- Over the last 10 years, there has been a decline in the relative share of employment in agriculture all over the world: from 45.6 per cent in 1994, it declined to 44.2 per cent in 2000 and 42.8 per cent in 2004.
- However, agriculture continued to be the largest source of employment in Sub-Saharan Africa, South Asia and East Asia with respectively 64.5, 62.2 and 57.7 per cent people being engaged in it. This implies that the role of agriculture in Africa and Asia is expected to remain high in the future.
- The share of agriculture in total employment in developed countries is small: only 3.9 per cent in 2004 and it is likely to decline further.
- The agricultural share in employment in Middle East and North Africa and Latin America and Caribbean countries is relatively small. In the Middle East and North Africa, this is mainly the result of the low share of agricultural employment in the oil-producing economies. In Latin America and the Caribbean, the figure masks a wide range of differently structured economies. Agriculture still plays an important role in terms of employment in this region (World Employment Report, 2004-05, ILO).

It should be noted that in the regions with a high percentage of people working in agriculture (Sub Saharan Africa, South Asia and South East Asia) there is a marked concentration of the poor who depend on agriculture compared to other sectors. One may conclude that agricultural functional services are therefore less effective in addressing poverty with higher incidence of distress employment of labor (see also Fan et al, 1999).
As the trends observed above seem to occur all around the world – one may expect them to continue in the future. This is also a notion that underlies many of the economic projections of

scenarios on the future. More explicitly, one may expect the share of agriculture in total employment to decrease dramatically in developing countries – and to decline slowly in developed countries.

4.4.6.3 Gender perspectives in agricultural labor

As agriculture and food systems evolve over the next decades, gender issues and concerns will highly likely continue to be central to AKST development, at least in the developing countries where women have played a significant role in traditional agricultural production technology. The understanding of women's and men's contribution in both the agricultural division of labor and its reproduction, traditional structures of resource allocation will continue to be key as will the gender differentiated access to the basic factors of production in agriculture as well as to access and utilization of AKST. This would affect participation of the gender components of agricultural labor in resource control, decision making, and production. Over the years improvement in agricultural technologies, have been gender insensitive with women seldom being recipients of the benefits, although they no doubt are capable of using them. This issue that is central to agricultural development has not been adequately addressed in past assessments, especially from a futuristic perspective. This has been the result of insensitivity in agricultural program and technology design and implementation.

Another significant aspect is that women work more in agriculture than men. For example, women in rural Africa produce, process and store up to 80 per cent of foodstuffs, while in South and South East Asia they undertake 60 per cent of cultivation work and other food production (UNIFEM, 2000). This might be the reason why poverty among women is higher than among men.

Based on the historic trends in Table 4.4.6.2 the following trends in female labor in agriculture can be hypothesized:

- Employment of the female vis-à-vis male workers is likely to decline in the future as women get more employment in other sectors. The evidence in table 4.4.6.2 show a declining trend in the world over during the last 10 years. It was 46.7 per cent in 1994. However, it declined to 43.2 per cent in 2004.
- The intensity of female employment in agriculture vis-à-vis male exhibits little different trend of employment in agriculture. It was 68.7 per cent of those engaged in agriculture were female in South Asia in 2004. This was followed by Sub- Saharan Africa with 66.5 per cent female employment of the total employment and 61.4 per cent in the case of East Asia.

Other literature on gender division of agricultural labor and gender issues and concerns in agricultural labor is characterized by three major sets of interrelated concerns: distribution of resource control, marginalization of women in production systems and decision making, higher labor intensity that usually accompany agricultural technological change for small farmers that increases labor demands on already overburdened rural women. This situation is poised to be central to agricultural development over the next decades as it would shape the trade-offs between intensification and extensification of production systems (Mehra and Gammage, 1999).

The increasing participation of women in subsistence production in agriculture is highly likely to continue facilitating male out-migration to urban areas and away from the sector to other sectors such as mining and commercial farming areas at lower cost than would otherwise be possible. At the same time, the already large role of women in subsistence agriculture and food production will probably expanded in the next few decades. There seem to be important gender deviations in the general trend of labor moving out of agriculture. This 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 lagging behind men and abandoning agriculture at a slower rate (Mehra and Gammage, 1999).

FAO (2000) underscores the need to understand the poverty gender links in addressing future food security needs of the rural population together with the increasingly feminised agricultural labor. The distribution of total global and regional agricultural and non-agricultural labor force. The potential of human resources as driver of the future evolution of agricultural and food systems is critical and should be appraised so as to gauge its future influence on development and sustainability goals. Gender-specific information and sex-disaggregated data are therefore crucial, as is the use of participatory approaches.

4.4.6.4 Labor productivity in agriculture

One of the pertinent drivers of future agricultural development is labor productivity. Labor productivity is calculated as output per person employed (ILO, 2004). Accordingly, the expression labor productivity, productivity, output per worker, output per person employed and GDP per person employed, or value added per worker are used synonymously (ILO, 2004: 23; Gardner, 2005; Strategis, website)). Basically, labor productivity measures the extent in which labor is efficiently used. An increase in labor productivity is associated with increases to real incomes and the standard of living for an economy (Strategis). Theoretically, the benefits of productivity growth include declining product prices, increased wages, increased investment, increased employment overall, and new products (ILO, 2005: 81, 97).

Future trends in labor productivity are expected to increase, based on the evidence over the past decade. ILO (2005:28) shows that labor productivity in the world increased by almost 11 per cent over the past ten years. This was mainly 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 percent 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 tendency of positive future productivity trends in agriculture 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, and the transition economies and the Mediterranean countries (Gardner). Gardner also showed a positive correlation between agricultural GDP per laborer and national GDP based on data for 85 countries for 1960-2001. Within each of the regional groupings (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 like Brazil. These trends are corroborated by ILO (2005:151). Fig 3.14 in ILO (taken from World Bank, 2004[a]) gives growth trends and levels in labor productivity in agriculture. Latin America levels of productivity 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 all have considerably lower average labor productivity figure. ILO further asserts that these are the regions in which the largest number of the world's poor live. This implies an association between productivity and poverty.

The future increases in agricultural productivity hold lot of potential for development. Empirical evidence illustrated in ILO (2005:153-4) indicates that increase in agricultural labor productivity appears to have amore significant direct effect on poverty reduction than increases in TFP. The indirect impacts on poverty are due to the impact both on food production and food prices (ILO; Mahendra, 1988).

The other effect pertains to the often concern among workers that increase in productivity are synonymous with substitution of capital intensive production techniques for labor, leading to mass destruction of jobs (ILO). It is generally accepted that productivity gains can lead to job losses, but at the same time productivity gains lead to employment creation as well – since technology also creates new products and new process – in creative destruction of employment. As such, the increasing trends in productivity could lead to expanded employment in other sectors such as ICT (ILO, 2005:78). ILO further suggests the need to ensure growth in the long-term, while at the same time providing adjustment strategies (in financial assistance and retraining) for displaced workers.

While in the short run, increased productivity might affect growth of employment in agriculture adversely, this may not hold good in the long run. Economic history shows that, in the long run, the growth of output, employment and productivity proceed in the same positive direction (ILO, 2004-2005). However, social cost to be incurred by the economy in the short run might be too high to bear with.

4.5 Food Systems, Agricultural Products and Services in the Future, Based on Existing Assessments

4.5.1. Characterization and future of production systems

4.5.1.1. Why is it relevant to discuss 'production systems'?

One way to characterize production systems is on the basis of the degree of human intervention: i.e., (i) fully colonized agroecosystems (e.g. producing crops, often in monocultures, intensive livestock and specialized dairy farms); (ii) 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 distinctions 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 for humans in terms of their 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.

To study production systems, one needs to integrate (i) socio-economic analysis, looking at the economic and social viability of the process and (ii) biophysical analysis, looking at the flows of biomass produced. When discussing sustainability, these include not only the costs and benefits for humans, but also the "costs" and "benefits" to the environment. For this reason it is important to adopt a general system of classification of production systems that can be used to discuss drivers and scenarios. Two important elements to consider are the roles played by the Production System within the socio-economic process and within the agroecological processes. With respect to the first process, a distinction can be made between production/consumption systems focused on sustaining livelihoods (which is often the case in developing countries) and production systems focused on producing commodities. A key element for systems focused on sustaining livelihoods is multifunctionality, not only in terms of producing a range of different goods, but also in terms of response to potential perturbations.

With respect to agroecological processes, production systems often function like specialized organs of a more complex body. They have a clearly defined goal: producing the food input required by society at the maximum achievable efficiency. To support this goal, the scientific disciplines dealing with agriculture are strongly focused on yields. In the last decades the validity of this focus has been increasingly challenged by the sweeping changes occurring in the agricultural sector. From an agroecological perspective, production systems can be further distinguished based on whether they rely primarily on low external inputs, exploiting existing nutrient cycles, or rely on high external inputs.

While low input systems tend to have fewer environmental impacts, this is only if the extracted flows are equivalent to the natural flow of inputs. These systems become extremely fragile when facing an increase in demographic pressure. High input systems benefit from a high degree of energy put into the system. The massive use of external inputs is good for increasing the material standard of living of farmers, but it constrains economic viability. That is, these production systems become fragile when the price of the purchased inputs goes up faster than the price at which their outputs are sold.

In Figure 4.5.1 we present an integrated view of food production systems based on the considerations discussed above. It should be noted that these are illustrations, and actual values can differ among studies). The cash flow per hour of work and the economic investment required per worker show very large differences among different production systems (Giampietro, 1997). The figure also indicates the spatial density of the cash flow and the available area of production system per household. Again, very large differences can be found among different production systems. This also translates into different ecological impacts; for instance for aquaculture in China and Italy, the amount of nitrogen pollution is negligible in the Chinese system and 30,000 kg per hectare in the Italian system. At the same time, the output of the Italian system is also 40 times higher (Gomiero et al., 1997).

4.5.1.2. Major agricultural production systems.

In light of the above discussions, we make use of a widely accepted and truly global cultivation system framework, built on easily accessible, more highly aggregated system characteristics, based on two key dimensions of cultivated systems – the agroecological dimension, and the enterprise/management dimension (Table 4.5.1). The agroecological dimension is divided into (sub-) tropical and temperate regions, reflecting broad daylength, radiation, and thermal differences, and into (sub-) humid and (semi-)arid environments, reflecting differences in rainfall and evapo-transpiration regimes. The importance and distinctiveness of highland and mountain cultivated systems in the (sub-) tropics is further recognized. Cultivation enterprises are divided into seven broad categories: (1) irrigated, (2) high external-input rainfed, (3) low external-input rainfed, (4) shifting cultivation, (5) mixed crop and livestock (6) confined ("landless") livestock production, and (7) freshwater aquaculture. Intersecting the agroecological and enterprise/management dimensions generates a matrix into which most of the world's important cultivated systems can readily be categorized. Extensive grazing systems are not included as cultivated systems here.

Crop cultivation accounts for four of the cultivated system classes: (1) all forms of irrigated systems, (2) rainfed, high input permanent cropping (3) rainfed, low-input permanent cropping, and (4) shifting cultivation.

Irrigated Systems. The roughly 18 percent (250Mha) of total cultivated area that is irrigated accounts for about 40 percent of crop production (Gleick 2002). Irrigated systems are served by water from impoundment or diversion structures, boreholes, and wells or other means of delivering water. From an investment perspective, irrigation systems range from large civil engineering works delivering water to hundreds of thousands of hectares in Pakistan and India (FAO 2004), farm-based wells that utilize small pumps to tap ground water aquifers, to small-scale community-based systems powered by draught animals and manual labor such as those found in the West Asia, North Africa, and the Sahel (FAO 2004). In addition to increasing and stabilizing the yields of individual crops, irrigation can extend the growing period and allow two or even three crops to be grown each year on the same piece of land where water availability and temperature permit such intensification.

Rainfed Systems. Rainfed agricultural systems comprise the largest share (about 82 percent) of the total agricultural land area, and exist in all regions of the world. In Asia and the Pacific for example, rainfed agriculture represents about 223 million ha, or 67 percent of the total arable land (Asian Development Bank 1989), and rainfed production accounts for 16-61 percent of agricultural GDP in this region (excluding Pakistan as part of West Asia).

Rainfed systems are prevalent in both high and low yield-potential areas as largely determined by the amount and distribution of precipitation in relation to crop water requirements. The discussion here focuses on more favorable rainfed areas where both high and low levels of external inputs are used to produce crops. Pressure on these systems is increasing as (1) arable land is becoming scarce, (2) the productivity of existing irrigated lands is reduced due to a reduction in water availability or due to land degradation, especially salinization, and (3) food demand increases.

Rainfed systems may involve both annual and perennial cropping systems, as well as livestock. In Asia, the rainfed humid/sub-tropical systems and arid /semi-arid areas include a range of various mixed crop-livestock systems, which can be categorized into lowland and upland systems. The former is associated more with crop cultivation due to higher levels of soil moisture. Rainfed lowland rice, for example, is defined as non-irrigated, but the topography is generally flat and the soil surface is inundated for at least part of the crop cycle with sustained flooding. Rainfed upland rice, on the other hand, is grown on well-drained fields that are never flooded. Major rice cropping systems in the rainfed lowlands are rice-wheat, rice-pulses (including chickpea, lentil, peanut, and pigeon pea), and rice-mustard. Maize, sugarcane, and cotton are also important crops in humid lowland areas of tropical/subtropical Asia. Cropping systems that utilize more drought-tolerant cereal crops such as sorghum and millet are practiced in semi-arid rainfed lowland areas.

The uplands, by comparison, have sloping to hilly topography, and typically have less fertile soil that is easily degraded by erosion and nutrient depletion without the use of appropriate husbandry practices. Although both annual (e.g. cereals, legumes, roots and vegetables) and perennial crops (e.g. coconuts, oil palm, rubber and fruit trees) are grown, agroforestry systems involving the latter are especially important. Rainfed areas have relatively large populations of livestock and their contribution via animal manure to crop cultivation, food security and the livelihoods of poor people is significant (Devendra 2000). Over-stocking and uncontrolled grazing of ruminants are major problems in semi-arid rainfed regions where land tenure rights are not well defined, such as in the Sahel region of SSA.

Shifting cultivation. Shifting cultivation, alternatively called “swidden” agriculture or “slash-and-burn” agriculture, is one of the oldest forms of agriculture and consists of cropping on cleared plots of land, alternated with lengthy fallow periods. These systems are the dominant form of agriculture in tropical humid and sub-humid upland regions and are typically associated with tropical rainforests. Shifting cultivation is practiced on about 22 percent of all agricultural land in the tropics, and is the primary source of food and income for some 40 million people (Giller and Palm, 2004). While the contribution to global food security is negligible given the low yields and general lack of infrastructure in areas where shifting cultivation predominates, this method of cultivation has a potentially large impact on regional and global ecosystem services through its effects on biodiversity, greenhouse gas emissions, and soil nutrients (Tomich, 2003). Although these systems are generally practiced on soils of low fertility, they are highly sustainable and resource-conserving in areas with low population density. High population density increases the pressure on available land and resources, reducing the time available for a regenerative fallow between cropping cycles. One method used to raise productivity and reduce land degradation in areas of shifting cultivation is "alley cropping," growing tree crops in conjunction with annual crops. In the Philippines, for example, alley cropping in sloping upland rice areas with *Flemingia macrophylla* showed that over two years, average soil loss was cut down to 42 m^3 / ha compared to 140 m^3 / ha under traditional practices, together with concurrent increases in rice yields (Labios et al., 1995).

Mixed crop and livestock systems. Mixed crop-livestock farming systems, where crops and animals are integrated on the same farm, represent the backbone of smallholder agriculture throughout the developing world, supporting an estimated 678 million rural poor. In Asia, more than 95 percent of the total population of large and small ruminants, and a sizeable number of pigs and poultry, are reared on small farms with mixed crop-livestock systems, which are dominant in both irrigated and rainfed areas in humid and sub-humid environments.

Mixed farming systems enable farmers to diversify agriculture, to use labor more efficiently, to have a source of cash for purchasing farm inputs, and to add value to crops or their by-products. Mixed farming systems provide the best opportunities to exploit the multipurpose role of livestock in many rural societies (Devendra 1995). There are a number of crop-animal interactions which are important and which dictate the development of mixed systems. These include animal traction for field operations, animal manure, and animal feeds from crops as evident in sub-Saharan Africa (McIntire et al. 1992) and Asia (Devendra and Thomas 2002). These interactions have demonstrated the important contribution that animals make to increased production, income generation, and the improved sustainability of annual and perennial cropping systems.

Crop-livestock systems can be separated into those that mix animals with annual crops, and those that mix animals with perennial crops. Of the two, the potential of the latter is often underestimated. Examples of integrated annual crop-animal systems include rice, maize, cattle, and sheep in West Africa; rice, wheat, cattle, sheep, and goats in India; rice, goats, duck, fish in Indonesia; rice, buffalo, pigs, chicken, duck, fish in the Philippines; rice, vegetables, pigs, ducks, fish in Thailand; and in Vietnam, vegetables, goats, pigs, ducks, and fish. Examples of integrated perennial tree crop-animal systems include rubber and sheep in Indonesia; oil palm and cattle in Malaysia and Columbia; coconut, sheep, and goats in the Philippines; and coconut, fruit, cattle, and goats in Sri Lanka. In West Asia and North Africa (the WANA region), integration of sheep with wheat, barley, peas and lentils is common, together with olives and tree crops.

With annual cropping systems, ruminants graze native grasses and weeds on roadside verges, on common property resources, or in stubble after the grain crop harvest. Crop residues and by-products are also fed to livestock throughout the year or seasonally, depending on availability. In the perennial tree crop systems, ruminants graze the under storey of native vegetation or leguminous cover crops. Non-ruminants in these systems mainly scavenge in the villages, on crop by-products, and kitchen waste. However, village livestock systems can evolve into more intensive production systems depending on the availability of feeds, markets, and the development of co-operative movements. This is evident in many parts of Central America, West Africa (e.g. Nigeria), South East Asia (e.g. Indonesia) and in South Asia (e.g. Bangladesh).

Because of the synergies between crop and livestock components, mixed crop-livestock systems have shown themselves to be both economically and environmentally robust from a smallholder perspective. It is likely that smallholder mixed farms will remain the predominant form of agricultural land use in rainfed cropping regions in developing countries where labor is abundant.

Confined livestock systems. 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. Such large-scale livestock systems are also being established in Asia to meet increasing demand for meat and dairy products. In addition, beef and mutton are produced from intensive confined feeding operations, the former mostly in North America and the transition states of Eastern Europe. The majority of sheep and goat fattening under "landless" (non-grazing) conditions occurs in the Near East and in much of Africa. Cut-and-carry, zero-grazing dairy production systems are similar to confined systems in industrialized countries in that hand feeding and disposal of manure are involved. These systems involve cutting feed, crop residues, and/or litter and transporting them to livestock which, are confined in pens on the farm.

The use of purchased cereals and oilseeds for feed in confined livestock systems allows separation of crop production and utilization of feed in livestock rations. These concentrated feeds are less perishable and easier to transport than the livestock products. Even if several kilograms of concentrates are needed to produce one kilogram of meat, it is still cheaper to establish the production system near the consumer market and to transport the feeds to the animals. A significant share of the increase in cereal imports to developing countries over recent decades has been to provide feed for the expanding poultry or pig industries (Delgado et al. 1999).

Animal confinement facilitates the management of nutrition, breeding and health, but increases the labor and infrastructure requirements for feeding, watering, and husbandry of the livestock.

Apart from the capital embodied in the animals, additional investment is needed in providing fencing, housing, and specialized equipment for feeding and other activities. Special equipment is also needed for animal slaughter and meat processing, or for milk cooling and processing. 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). This has often led to either co-operative group activity or vertical integration of smallholder producers with large scale processing and marketing organizations.

While there are good economic arguments for the concentration of large numbers of animals associated with many confined systems, there can be significant impacts on surrounding ecosystems. Problems often arise in the disposal of large amounts of manure and slaughtering by-products. While some types of manure can be recycled onto local farmland, soils can quickly become saturated with both nitrogen and phosphorus because it is too costly to transport manure, which has relatively low nutrient concentration, for long distances. Manure treatment or digestion to produce methane can help minimize pollution, but even in countries with strong regulation and enforcement systems, nutrient and bacterial leakage to water-courses can occur, with consequential impacts on freshwater and aquatic systems (de Haan et al. 1997)

Confined systems tend to be located near markets in peri-urban areas. Distance from these centers, or from their main transport routes, has an important influence on the net prices received for farm products. Similarly location in relation to urban centers affects access to markets for purchased inputs and the costs of such inputs (Upton 1997). Transport costs vary from one commodity to another, depending on their perishability and bulk-to-value ratio. Milk and eggs are relatively perishable and therefore are most-often produced intensively in peri-urban zones. Furthermore, agricultural enterprises dependent on purchased inputs, such as concentrate feeds, are likely to be established in peri-urban zones with easy access to input markets. In contrast, ruminant meat can be produced in more distant rural areas and transported as live animals to urban markets for slaughter.

Freshwater aquaculture systems. Aquaculture is a form of agriculture that involves the propagation, cultivation, and marketing of aquatic plants and animals from a controlled environment (Swann 1992) and involves tenure and ownership compared to the open-access or common property systems that occur in fishing (FAO 2000). Aquaculture can be applied in coastal (mariculture), brackish or freshwater (inland), and there are four types of production systems: ponds, cages, raceways and recirculating systems. In addition, production system can be distinguished by the level of production intensity or amount of inputs (labor, feed, materials, or equipment) used in aquaculture operations. Such production intensity can be *extensive*, where low levels of external inputs result in lower production levels, or *intensive*, where higher levels of inputs of technology and greater degree of management generally increase yield (FAO 2000, Swann 1992).

Aquaculture can also be land-based or water-based. Land-based aquaculture comprises mostly ponds, rice fields and other facilities built on dry lands. Carp and tilapia are the mostly commonly grown species in freshwater ponds while shrimp and finfish are cultivated in brackish-water ponds. Water-based systems include enclosures, pens, cages and rafts and are usually situated in sheltered coastal or inland waters. Pens and cages are made up of poles, mesh and netting. Cages are suspended from poles or rafts which float on water surface while pens rest on the bottom of the water body (FAO 2000).
Unlike livestock, where only a limited number of species are farmed, aquaculture production involves many species of aquatic organisms. In freshwater aquaculture alone, some 115 freshwater species of finfish, crustaceans, and mollusks were cultured in 2000, with finfish contributing the bulk of production. Over the period 1991-2000, carp (and other cyprinids) and tilapia (with other cichlids) ranked first and second respectively in global freshwater fish production, accounting for 76-82 percent and 5-6 percent respectively of the total (FAO 2002b).

4.5.1.3 Production systems in the future

What are the conclusions that can be made from this general discussion of production systems? In the future, we can expect economic drivers to further push cultivation systems into high-tech commercial farming. Interestingly, those production systems (in developing countries) that will experience the most dramatic increase in “economic pressure” will also be those systems that simultaneously experience the major increase in “demographic pressure”. These pressures may be met by a large increase in the performance of current technical coefficients .However, such changes might be limited by social and ecological constraints. AKST could be required, over a very limited time span (i) to look for new paradigms of production on the technical side; (ii) to help negotiate a re-definition of the social contract of agriculture on the socio-political side; and (iii) to learn how to ensure the ecological compatibility of any proposed changes.

4.5.2 Forecasting change in food demand and supply

Over the past 50 years, there have been at least 30 quantitative projections of global food prospects (supply and demand balances), as well as numerous qualitative predictions, with the latter often tied to short-term spikes in global food prices. Global simulation models that tried to simulate the interrelationships among population growth, food demand, natural resource degradation and food supply, are yet another class of forecasting exercises (Meadows et al. 1972, Meadows et al. 1992; Mesarovic and Pestel 1974; Herrera 1976), which are, however, not commonly used nowadays. The number of players engaging in projections of future food demand, supply, and related variables at the global level has been declining over time. Important organizations include the Food and Agriculture Organization of the United Nations (FAO), the Food and Agriculture Policy Research Institute (FAPRI), 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, like the European Union. Finally, many individual analyses and projections are carried out at the national level by agriculture departments and national-level agricultural research institutions. Results from some of these models are published periodically with updated projections. In addition to coverage and regional focus, existing approaches vary in the length of the projections period, the approach to modeling, and in the primary assumptions made in each model.

4.5.2.1. The Millennium Ecosystem Assessment (MA)

The MA set out to provide an integrated assessment of the consequences of ecosystem change for human well-being. A specific focus was on ecosystem services, including products such as food, fuel, and fiber (see MA, 2003). In other words, cultivated systems were explicitly considered in the assessment. Moreover, several drivers of change considered in the MA have direct links with the IAASTD. Chapter 26 of MA's Volume 1 (Cassman and Wood, 2005) provides a thorough overview of the current state and trends of cultivated systems. In addition, the MA discussion of scientific and technological development includes questions around development of new agricultural technologies, including biotechnologies, and their rate of adoption (MA, 2003).

With respect to projections into the future, two models were used in the MA that include agriculture and 'food provisioning' as an ecosystem service; IMPACT (Rosegrant et al., 2002) and IMAGE 2.2 (see Alcamo et al., 1998). Both are also being used in the IAASTD assessment (Chapter 5?). Thus, the output from these models reported in the MA is highly relevant for this assessment. Figure x.1 and x.2 are two examples of the reported output of the modelling groups within the MA relevant to IAASTD. The MA considered four future scenarios: Order from Strength (OS), Adapting Mosaic(AM), TechnoGarden(TG) and Global Orchestration (GO). The major difference among the MA scenarios regarding land use is the projection that there will be an increase in cropland and pasture under OS relative to current land use and future land use under the three other scenarios (Figure x.1). However, yield per unit land area was projected to differ significantly over time to 2050 among the 4 scenarios (Figure x.2), implying that agricultural production would be greatest in GO and least in AM and OS.

Because of the involvement of both groups of modellers in the IAASTD, links with the MA are ensured (see Alcamo et al., 2005). Within the MA storylines, however, the discussion of the future outlook of cultivated systems is not very comprehensive (see Cork et al., 2005). The most detailed information can be found in Techno Garden, which addresses technological progress and Global Orchestration, which discusses global trade and policies. In general, Order from Strength and Adaptive Mosaic focus on issues that only indirectly connect to the agricultural sector. However, all scenarios do provide important projections for indirect and direct drivers of agriculture. This information is provided in both qualitative and quantitative form, and provides an excellent and sound foundation for the IAASTD.

4.5.2.2. The Global Environment Outlook (GEO)

This analysis refers only to Global Environment Outlook 3 (GEO-3; UNEP, 2002). Earlier outlooks had little specific information on future development, while GEO-4 is currently under review. Its final publication is therefore outside the scope of this assessment. As the name suggests, GEO-3 describes the current and future state of the environment. Funded by UNEP, it focuses on the various conventions such as the UNFCCC (Climate Change); CBD (Biodiversity); or the UNCCD (Desertification). The themes ‘land’, ‘biodiversity’, and ‘forest’ all relate to agriculture. For two reasons, however, information on the future outlook of agriculture within GEO-3 is limited. Firstly, a large part of the report is devoted to the past and present situation, leaving little space for elaborating on the future. Secondly, the four future scenarios contain only general information on the development of main drivers. More attention is paid to the general impacts of changes in policies, without documenting in much detail what specific changes will occur in different sectors, including agriculture. Like in many of the global scenario studies, the IMAGE model (Alcamo et al., 1998) has been used to quantify a range of variables, including land cover and land use, and global trade. Within GEO-3, however, documentation of assumptions is much more synoptic than for example in the MA. The information in the storylines is very ad hoc, with one-liners such as “progress in biotechnology is beneficial to agriculture” (in Global Orchestration).

In conclusion, the GEO-3 report was a milestone in scenario development studies and furthered the understanding of and competency in scenario development methods. As such it built on previous studies (namely the work of the Global Scenario Group) and has been important for following assessments (such as the Millennium Assessment). As a study in its own right, however, the information on agriculture is limited.

4.5.2.3. The FAO food outlook

FAO develops projections through many iterations and adjustments in key variables based on extensive consultations with experts in different fields, particularly during analysis of the scope for production growth and trade. The end product may be described as a set of projections that meet conditions of accounting consistency and to a large extent respect constraints and views expressed by the specialists in the different disciplines and countries (Bruinsma 2003, p. 379). The FAO study only uses one scenario: a baseline that projects the future that the authors anticipate to be most likely.

The FAO has recently released its interim food outlook to 2030/2050 report (FAO 2006). This is the first time that the FAO projects food supply and demand out to 2050 and is an extension to the FAO Study “World agriculture: towards 2015/2030” published in 2003 (Bruinsma, 2003). In terms of food production growth, the FAO study concludes that future growth might continue to slow drastically, to 1.5 percent per year out to 2030 and to 0.9 percent per year from 2030-2050, as a result of slowing demand. Biofuel demand could change this outlook, however. Total cereal production is estimated to grow from approximately 2 billion metric tons in 2005 to 3 billion metric tons by 2050.

4.5.2.4. The IFPRI IMPACT model

The International Model for Policy Analysis of Agricultural Commodities and Trade was developed at IFPRI in the early 1990s (Rosegrant et al. 1995). IMPACT is a representation of a competitive world agricultural market for 32 crop and livestock commodities and is specified as a set of 43 country or regional sub-models; supply, demand, and prices for agricultural commodities are determined within each of these. World agricultural commodity prices are determined annually at levels that clear international markets.

Food projections using IMPACT have consistently shown a tightening of the world food situation out to 2050, as a result of increasing environmental constraints and a lack of investment in agricultural research and supporting services. While food demand continues to grow rapidly, food supply continues to slow. Emerging constraints that might adversely affect food outcomes include increased climate variability and climate change, competition of cropland for food production with cropland for biofuel production, emerging diseases (particularly in the livestock and fisheries sector), and persistent low investment levels in research, infrastructure, and capacity building.

4.5.2.5. IPCC assessments

The IPCC Special Report on Emission Scenarios (Nakicenovic, 2000) described a set widely diverging scenarios in order to support assessment of climate change, impacts and mitigation options. In most of the work of IPCC, however, no explicit set of scenarios is used – and assessment focussed on all available literature. The main contribution of the IPCC work in the context of this report is related to climate change – and has been discussed explicitly in Subchapter 4.4.4.

Concentrating on the potential contribution of the IPCC on agricultural outlook, one needs to conclude that the IPCC SRES scenarios (given their focus) are very detailed in terms of emissions and energy system detail – but much less elaborated for land-use related issues, let alone details on the agricultural system. An important exception here forms the elaboration of the IPCC-SRES scenarios by the IMAGE Integrated Assessment model (IMAGE-team, 2001), which provide very detailed agricultural scenarios. These scenarios indicate a strong increase in food demand. However, in terms of land use a strongly diverging picture is provided on the basis of different assumptions with respect to agricultural yields. The results vary from a strong increase in land use (A2) to only a temporary increase, followed by a decline to current levels (B1). In terms of food production systems the scenarios depict an increase in land use for meat production, either by use of natural grasslands or by increased feed production.

4.5.2.6. OECD Environmental Outlook

<To be added>

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, socio-cultural and other parameters. However, its future is determined by an even larger set of direct and indirect drivers. The first subchapters of this chapter have focused on review and discussion of relevant projections of the key direct and indirect drivers of agriculture identified in the IAASTD conceptual framework as they would play out towards 2050.

Global assessments, provided by the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment, and the UN Food and Agriculture Organization, 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. Note that neither of these approaches aims to predict the future – rather they provide a framework to explore key interlinkages between different drivers and resulting changes. Key findings from these previous assessments regarding possible changes in agriculture are presented and discussed.

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. This subchapter will draw on the material presented earlier in this chapter to focus on the key question “What are the development and sustainability challenges that can be addressed through AKST?" The question 'What are the conditions needed to help effect the potential of AKST to realize development and sustainability goals?' will be partially addressed by reiterating the importance of considering future changes in the drivers of agricultural systems. We will use the information on drivers of agricultural change and AKST (and the lack thereof) also to identify those areas that need further attention in subsequent (forward looking) chapters of this assessment.

4.6.1 What are the development and sustainability challenges that can be addressed through AKST?

The projected increase in global population in the next 50 years (by about 2-3 billion people), on-going urbanization, and changing lifestyles will lead to a strongly increasing demand for agricultural products and services while at the same time exert pressure on the natural resource base of the agricultural system. Historic evidence shows shifts towards more meat intensive consumption patterns going along with increasing incomes – and projections expect a similar trend in the future. The demand for agricultural products has to be met while simultaneously addressing the critical role agriculture and land use change play in global environmental problems. In this context, it should be noted that food demand and food security, land use, loss of biodiversity and natural areas and AKST are intrinsically linked. A major uncertainty in the land use change scenarios presented in the literature stems from the assumed degree of extensification and intensification of agriculture. However, changes in food demand and international trade will also clearly play an important role in the level of use of land related goods and services. Drivers, including transformations in AKST, can work together to create rapid land use and land cover change. AKST must address the need for productivity gains while simultaneously considering the role of agriculture and land use on local, regional and global environmental problems.

Agriculture will be significantly impacted by climate change, as it is highly sensitive to climate. The relevant changes in climate of importance to agriculture include not only changes in mean temperature but even more importantly, seasonal variability and extreme events. Without stringent climate policies, global mean temperature is likely to increase by somewhere between 1.3-6.4 degree Celsius during the 21st century. Stringent climate scenario may limit climate change to about 0.5-3^{o}C (uncertainty coming from uncertainty in climate sensitivity). 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 determine the capacity of food systems to respond to the likely changes. Agriculture is also a source of greenhouse gas emissions for CO_2 and non-CO_2 gases and therefore agriculture can play a significant role in mitigation policies. In order to play this role, new AKST options for reducing emissions of methane from agriculture need to be developed.

The rapid expansion of irrigation and associated agricultural water withdrawal 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. AKST must continue to address the need to develop sustainable agricultural systems in these regions.

The projected urbanization will highly likely lead to increasing industrial growth while at the same time a decline in the percentage of population depending directly on agriculture for their livelihood. Projected increasing income levels implies changing diets (from carbohydrates to protein based, thus, the livestock revolution), and changing manner of food preparation. This will certainly create changes in food consumption patterns and more demand for non-home based preparation of food and the use of supermarkets. The increasing rate of population ageing is expected to result in a decline in the population support ratio, which will also lead to a smaller potential working population for agricultural operations. 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 since changes in energy prices will influence agriculture's use and production of energy. 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. Increasing energy prices and changing subsidies are likely to be important for trends in agricultural production systems. At the same, agriculture may become an important producer of energy in the form of bioenergy, based on both energy-security and climate change considerations. The potential of bioenergy, however, is very controversial and depends on assumptions about overall efficiency, trade-offs with food production and biodiversity. AKST can play an important role in the assessment and development of bioenergy systems, as well as address the need to make agricultural systems more energy efficient.

A final important factor is the role of agriculture in the nitrogen cycle, with both impacts on local and regional scale. Decreasing these impacts may require important changes in application of fertilisers.

In summary, agriculture will need to adapt to several key changes in driving forces in the next decades. These include the challenges of ensuring food security for a larger global population, increasing productivity while sustaining the natural resource base, adapting production systems to climate change, diversifying agricultural output in response to changing food preferences, developing sustainable systems for fragile or degraded regions, enhancing labor productivity in response to a decreasing labor force, and improving the energy efficiency of agricultural systems. AKST will play a vital role in meeting these challenges.

4.6.2. What are the conditions needed to help effect the potential of AKST to 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 impact 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.

In addition, 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 still now and likely to be a significant lag between the recognition of development or sustainability goal and the time required for AKST to contribute to addressing that goal. Frameworks that consider important drivers of change and their interlinkages can be used to initially explore and at least partially assess 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, previous agricultural assessments (FAO, IFPRI) are of type 2, whereas most environmental assessments are of type 1. 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. The next chapter describes both the quantitative and qualitative modeling tools used in this assessment to develop a forward looking perspective on agriculture and the potential role AKST should play in helping to meet the development and sustainability goals.