

**CLIMATE CHANGE
AND FOOD SECURITY:
A FRAMEWORK DOCUMENT**

**FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
ROME, 2008**

FOREWORD

Climate change will affect all four dimensions of food security: food availability, food accessibility, food utilization and food systems stability. It will have an impact on human health, livelihood assets, food production and distribution channels, as well as changing purchasing power and market flows. Its impacts will be both short term, resulting from more frequent and more intense extreme weather events, and long term, caused by changing temperatures and precipitation patterns,

People who are already vulnerable and food insecure are likely to be the first affected. Agriculture-based livelihood systems that are already vulnerable to food insecurity face immediate risk of increased crop failure, new patterns of pests and diseases, lack of appropriate seeds and planting material, and loss of livestock. People living on the coasts and floodplains and in mountains, drylands and the Arctic are most at risk.

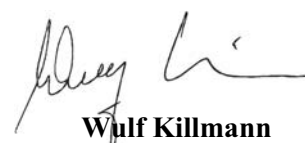
As an indirect effect, low-income people everywhere, but particularly in urban areas, will be at risk of food insecurity owing to loss of assets and lack of adequate insurance coverage. This may also lead to shifting vulnerabilities in both developing and developed countries.

Food systems will also be affected through possible internal and international migration, resource-based conflicts and civil unrest triggered by climate change and its impacts.

Agriculture, forestry and fisheries will not only be affected by climate change, but also contribute to it through emitting greenhouse gases. They also hold part of the remedy, however; they can contribute to climate change mitigation through reducing greenhouse gas emissions by changing agricultural practices.

At the same time, it is necessary to strengthen the resilience of rural people and to help them cope with this additional threat to food security. Particularly in the agriculture sector, climate change adaptation can go hand-in-hand with mitigation. Climate change adaptation and mitigation measures need to be integrated into the overall development approaches and agenda.

This document provides background information on the interrelationship between climate change and food security, and ways to deal with the new threat. It also shows the opportunities for the agriculture sector to adapt, as well as describing how it can contribute to mitigating the climate challenge.



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SUMMARY

Until recently, most assessments of the impact of climate change on the food and agriculture sector have focused on the implications for production and global supply of food, with less consideration of other components of the food chain. This paper takes a broader view and explores the multiple effects that global warming and climate change could have on food systems and food security. It also suggests strategies for mitigating and adapting to climate change in several key policy domains of importance for food security.

Defining terms and conceptualizing relationships

Food security is the outcome of food system processes all along the food chain. Climate change will affect food security through its impacts on all components of global, national and local food systems.

Climate change is real, and its first impacts are already being felt. It will first affect the people and food systems that are already vulnerable, but over time the geographic distribution of risk and vulnerability is likely to shift. Certain livelihood groups need immediate support, but everybody is at risk.

Managing risk

Risk exists when there is uncertainty about the future outcomes of ongoing processes or about the occurrence of future events. Adaptation is about reducing and responding to the risks climate change poses to people's lives and livelihoods.

Reducing uncertainty by improving the information base, and devising innovative schemes for insuring against climate change hazards will both be important for successful adaptation. Adaptive management can be a particularly valuable tool for devising strategies that respond to the unique risks to which different ecosystems and livelihood groups are exposed.

Strengthening resilience

Strengthening resilience involves adopting practices that enable vulnerable people to protect existing livelihood systems, diversify their sources of income, change their livelihood strategies or migrate, if this is the best option.

Changing consumption patterns and food preparation practices may be sufficient to protect food security in many circumstances. Both market forces and voluntary choices influence individual decisions about what food to eat and how to maintain good health under a changing climate.

Safeguarding food security in the face of climate change also implies avoiding the disruptions or declines in global and local food supplies that could result from changes in temperature and precipitation regimes and new patterns of pests and diseases.

Raised productivity from improved agricultural water management will be crucial to ensuring global food supply and global food security. Sustainable livestock management practices for adaptation and associated mitigation should also be given high priority. Conservation agriculture can make a significant difference to efficiency of water use, soil quality, capacity to withstand extreme events, and carbon sequestration. Promoting agrobiodiversity is particularly important for local adaptation and resilience.

Meeting the growing demand for energy is a prerequisite for continued growth and development. Bioenergy is likely to play an increasingly important role, but its use should not undermine food security.

Mitigating climate change

Mitigating climate change means reducing greenhouse gas emissions and sequestering or storing carbon in the short term, and – of even greater importance – making development

choices that will reduce risk by curbing emissions over the long term. Although the entire food system is a source of greenhouse gas emissions, primary production is by far the most important component. Incentives are needed to persuade crop and livestock producers, agro-industries and ecosystem managers to adopt good practices for mitigating climate change.

The way forward

In the food and agriculture sector, adaptation and mitigation often go hand in hand, so adopting an integrated strategic approach represents the best way forward.

Several funds within the United Nations system finance specific activities aimed at reducing greenhouse gas emissions and increasing resilience to the negative impacts of climate change. Because many mitigation actions that would have high payoffs also represent good options for adaptation within the food and agriculture sectors of low-income developing countries, it may be possible to obtain additional resources from bilateral and multilateral aid agencies, which are becoming increasingly interested in investing development resources in adaptive responses to climate change.

The ultimate goal of FAO's climate change work is to inform and promote local dialogue about what the impacts of climate change are likely to be and what options exist for reducing vulnerability, and to provide local communities with site-specific solutions.

ACRONYMS

CBD	United Nations Convention on Biological Diversity
CCFS	climate change and food security
CDM	Clean Development Mechanism
CER	certified emissions reduction
CIESIN	Center for International Earth Science Information Network
CIS	Commonwealth of Independent States
CO₂	carbon dioxide
COP	Conference of the Parties
DRC	Democratic Republic of the Congo
ECV	essential climate variable
EPA	Environmental Protection Agency (United States)
ESAC	Comparative Agricultural Development Service (FAO)
ESSP	Earth System Science Partnership
ETFRN	European Tropical Forestry Research Network
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FIVIMS	Food Insecurity and Vulnerability Information and Mapping System
FSIEWS	Food Security Information and Early Warning System
GCOS	Global Climate Observing System
GECAFS	Global Environmental Change and Food Systems (project)
GEF	Global Environment Facility
GHG	greenhouse gas
GIPB	Global Partnership Initiative for Plant Breeding Capacity Building
ICSU	International Council for Science
IDWG	Interdepartmental Working Group
IEA	International Energy Agency
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
IFRC-RCS	International Federation of Red Cross and Red Crescent Societies
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme on Global Environmental Change
ILO	International Labour Organization
INI	International Nitrogen Initiative
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
LDC	least-developed country
LDCF	Least Developed Countries Fund (UNFCCC)
MDG	Millennium Development Goal
NAPA	National Adaptation Programme of Action (UNFCCC)
NFP	National Forest Programme
NGO	non-governmental organization
NPFS	National Programme for Food Security
NRC	Environment, Climate Change and Bioenergy Division (FAO)
NRCB	Climate Change and Bioenergy Unit (FAO)
NRCE	Environmental Assessment and Management Unit (FAO)
NWP	Nairobi Work Programme on Impacts, Vulnerability and Adaptation to Climate Change
RICMS	Rice Integrated Crop Management Systems
RPFS	Regional Programme for Food Security
SARD	sustainable agriculture and rural development

SBSTA	Subsidiary Body for Scientific and Technical Advice (UNFCCC)
SCCF	Special Climate Change Fund (UNFCCC)
SEI	Stockholm Environment Institute
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNDPI	United Nations Department of Public Information
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forum on Forests
UK DEFRA	United Kingdom Department for Environment, Food and Rural Affairs
WCRP	World Climate Research Programme
WFS	World Food Summit
WHO	World Health Organization
WMO	World Meteorological Organization
WRI	World Resources Institute

INTRODUCTION

Mean global temperatures have been increasing since about 1850, mainly owing to the accumulation of greenhouse gases in the atmosphere. The main causes are the burning of fossil fuels (coal, oil and gas) to meet increasing energy demand, and the spread of intensive agriculture to meet increasing food demand, which is often accompanied by deforestation. The process of global warming shows no signs of abating and is expected to bring about long-term changes in weather conditions.

These changes will have serious impacts on the four dimensions of food security: food availability, food accessibility, food utilization and food system stability. Effects are already being felt in global food markets, and are likely to be particularly significant in specific rural locations where crops fail and yields decline. Impacts will be felt in both rural and urban locations where supply chains are disrupted, market prices increase, assets and livelihood opportunities are lost, purchasing power falls, human health is endangered, and affected people are unable to cope.

Until about 200 years ago, climate was a critical determinant for food security. Since the advent of the industrial revolution, however, humanity's ability to control the forces of nature and manage its own environment has grown enormously. As long as the economic returns justify the costs, people can now create artificial microclimates, breed plants and animals with desired characteristics, enhance soil quality, and control the flow of water.

Advances in storage, preservation and transport technologies have made food processing and packaging a new area of economic activity. This has allowed food distributors and retailers to develop long-distance marketing chains that move produce and packaged foods throughout the world at high speed and relatively low cost. Where supermarkets with a large variety of standard-quality produce, available year-round, compete with small shops selling high-quality but only seasonally available local produce, the supermarkets generally win out.¹

The consumer demand that has driven the commercialization and integration of the global food chain derives from the mass conversion of farmers into wage-earning workers and middle-level managers, which is another consequence of the industrial revolution. Today, food insecurity persists primarily in those parts of the world where industrial agriculture, long-distance marketing chains and diversified non-agricultural livelihood opportunities are not economically significant.

At the global level, therefore, food system performance today depends more on climate than it did 200 years ago; the possible impacts of climate change on food security have tended to be viewed with most concern in locations where rainfed agriculture is still the primary source of food and income.

However, this viewpoint is short-sighted. It does not take account of the other potentially significant impacts that climate change could have on the global food system, and particularly on market prices. These impacts include those on the water and energy used in food processing, cold storage, transport and intensive production, and those on food itself, reflecting higher market values for land and water and, possibly, payments to farmers for environmental services.

Rising sea levels and increasing incidence of extreme events pose new risks for the assets of people living in affected zones, threatening livelihoods and increasing vulnerability to future food insecurity in all parts of the globe. Such changes could result in a geographic redistribution of vulnerability and a relocalization of responsibility for food security – prospects that need to be considered in the formulation of adaptation strategies for people who are currently vulnerable or could become so within the foreseeable future.

¹ For two recent discussions of the modernization processes that have transformed food systems in the past half century, see FAO, 2004b: 18–19; and Ericksen, 2006.

The potential impacts of climate change on food security must therefore be viewed within the larger framework of changing earth system dynamics and observable changes in multiple socio-economic and environmental variables. This paper seeks to illuminate the potential impacts, both the fairly certain and the highly uncertain, at least at the local level.

Chapter 1 defines key terms and conceptual relationships and discusses possible impacts of climate change on food system performance and food security outcomes. Chapters 2 and 3 provide detail about adaptation and mitigation options for the food and agriculture sector, and Chapter 4 describes the institutional setting for acting to mitigate and adapt to climate change, and draws conclusions for follow-up action by FAO and the international community.

1. DEFINING TERMS AND CONCEPTUALIZING RELATIONSHIPS

FOOD SYSTEMS AND FOOD SECURITY

Food security

In May 2007, at the 33rd Session of the Committee on World Food Security, FAO issued a statement to reaffirm its vision of a food-secure world:

“FAO’s vision of a world without hunger is one in which most people are able, by themselves, to obtain the food they need for an active and healthy life, and where social safety nets ensure that those who lack resources still get enough to eat.” (FAO, 2007f)

This vision has its roots in the definition of food security adopted at the World Food Summit (WFS) in November 1996: “Food security exists when all people at all times have physical or economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO, 1996).

In the year and a half following WFS, the Inter-Agency Working Group that established the Food Insecurity and Vulnerability Information and Mapping System (FIVIMS) elaborated a conceptual framework that gave operational meaning to this definition (Figure 1). FAO reaffirmed this view in its first published assessment of the implications of climate change for food security, contained in its 2015 to 2030 projections for world agriculture.

FAO stressed that “food security depends more on socio-economic conditions than on agroclimatic ones, and on access to food rather than the production or physical availability of food”. It stated that, to evaluate the potential impacts of climate change on food security, “it is not enough to assess the impacts on domestic production in food-insecure countries. One also needs to (i) assess climate change impacts on foreign exchange earnings; (ii) determine the ability of food-surplus countries to increase their commercial exports or food aid; and (iii) analyse how the incomes of the poor will be affected by climate change” (FAO, 2003b: 365–366).

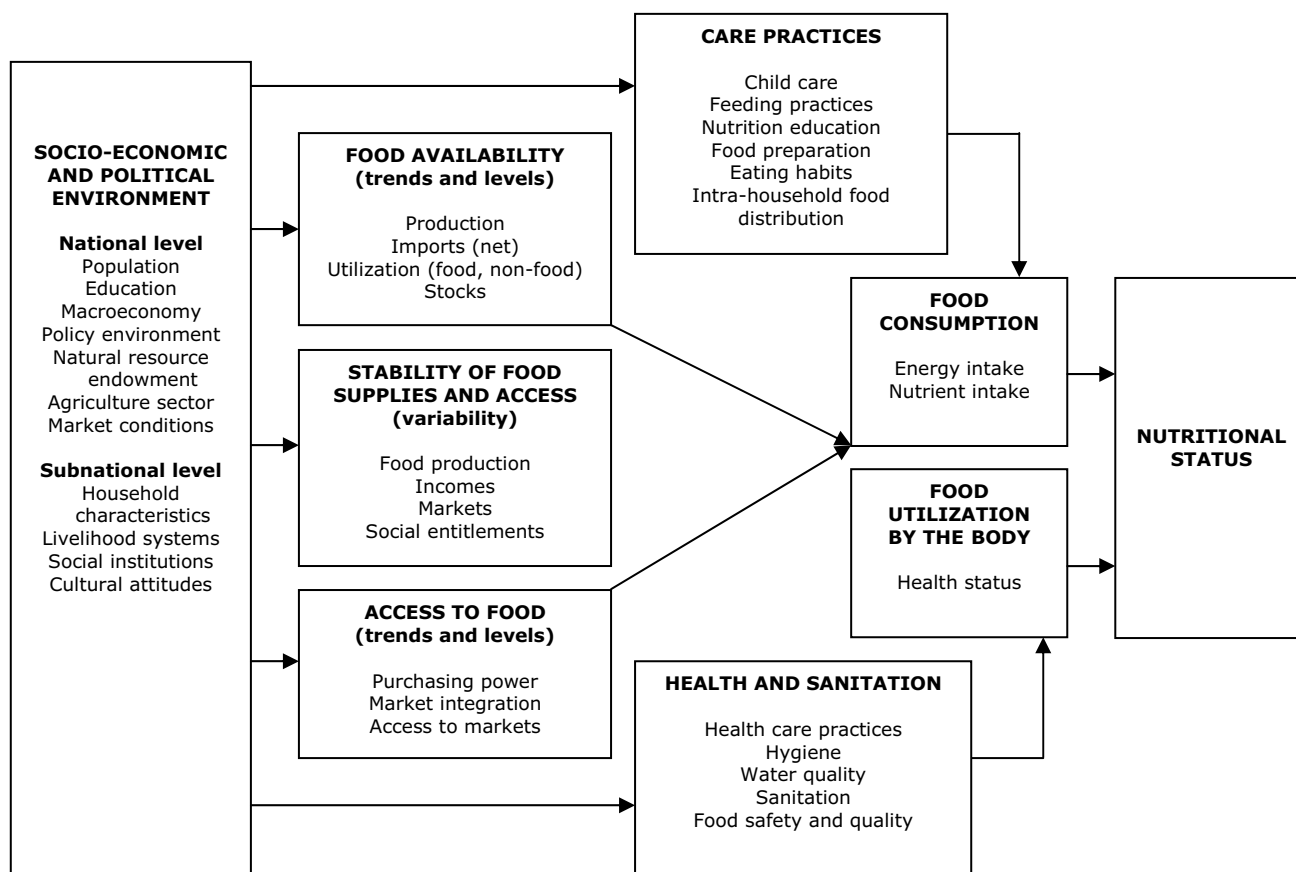
Food system

Definitions of food security identify the outcomes of food security and are useful for formulating policies and deciding on actions, but the processes that lead to desired outcomes also matter. Most current definitions of food security therefore include references to processes as well as outcomes. Recent work describing the functioning of food systems has helped to show both desired food security goals and what needs to happen to bring these about.

Between 1999 and 2003, a series of expert consultations, convened by the Global Environmental Change and Food Systems (GECAFS) project with FAO’s participation, developed a version of the FIVIMS framework that further clarifies how a variety of processes along a food chain need to occur in order to bring about food security. Taken together, these processes constitute the food system, and the performance of the food system determines whether or not food security is achieved. GECAFS gives the following definition and graphical representation (Figure 2):

“Food systems encompass (i) activities related to the production, processing, distribution, preparation and consumption of food; and (ii) the outcomes of these activities contributing to food security (food availability, with elements related to production, distribution and exchange; food access, with elements related to affordability, allocation and preference; and food use, with elements related to nutritional value, social value and food safety). The outcomes also contribute to environmental and other securities (e.g. income). Interactions between and within biogeophysical and human environments influence both the activities and the outcomes.” (GECAFS Online)

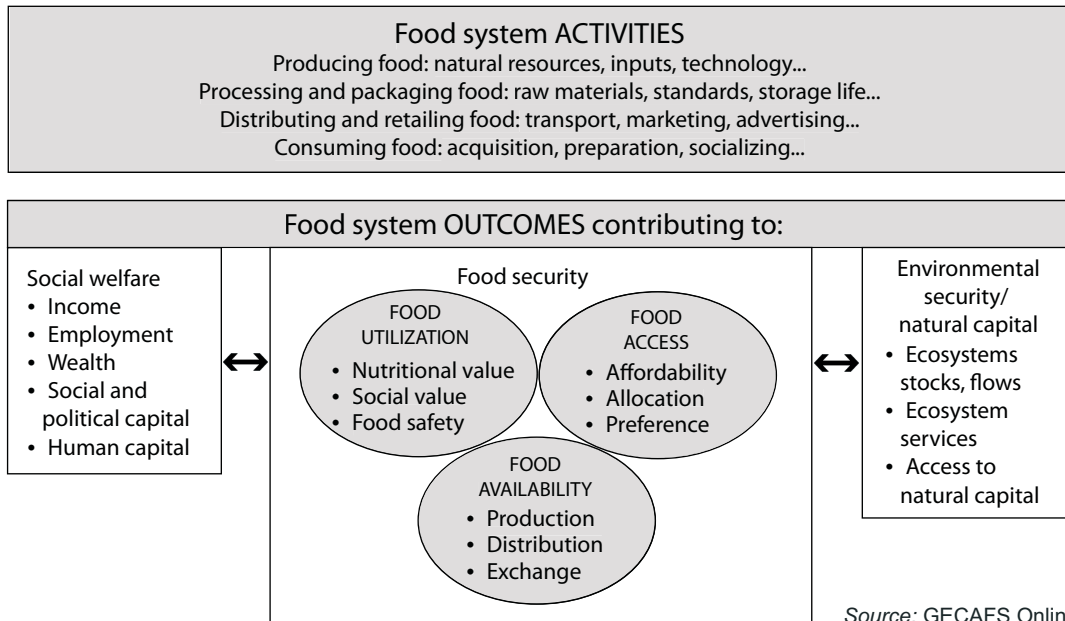
Figure 1. Conceptual framework of possible causes of low food consumption and poor nutritional status



Source: FAO, 2000c.

Another study expresses the complexity of food systems and their link to food security as follows: “Dynamic interactions between and within the biogeophysical and human environments lead to the production, processing, preparation and consumption of food, resulting in food systems that underpin food security” (Gregory, Ingram and Brklacich, 2005).

Figure 2. Food system activities and food security outcomes



Food chain

The sum of all the processes in a food system is sometimes referred to as a food chain, and often given catchy slogans such as “from plough to plate” or “from farm to fork”. The main conceptual difference between a food system and a food chain is that the system is holistic, comprising a set of simultaneously interacting processes, whereas the chain is linear, containing a sequence of activities that need to occur for people to obtain food.

The concept of the food system is useful for scientists investigating cause and effect relationships and feedback loops, and is important for the technical analyses that underpin policy recommendations. However, when communicating the findings of such investigations it is often easier to use the concept of the food chain.

The section on Food security and climate change: a conceptual framework (p. 10) presents a simplified description of the dynamics of potential climate change impacts and feedback loops in a holistic food system. The implications are discussed linearly, however, by looking at projected changes for each of five of the most important climate variables for food systems, and at the potential impacts of each of these changes on each food system process.

A food system comprises multiple food chains operating at the global, national and local levels. Some of these chains are very short and not very complex, while others circle the globe in an intricate web of interconnecting processes and links. One simple chain, which is important for food security in many households practising rainfed agriculture, begins with a staple cereal crop produced in a farmer’s field, moves with the harvested grain through a local mill and back to the farmer’s home as bags of flour, and finishes in the cooking pot and on the household members’ plates.

This same household probably also participates in a more complex food chain to obtain salt, which is locally available in only a few places, but is used worldwide as a preservative and seasoning. Part of the meagre cash income of even the poorest farming households is often set aside to purchase salt from passing traders or local stalls.

A household’s food system comprises all the food chains it participates in to meet its consumption requirements and dietary preferences, and all the interactions and feedback loops that connect the different parts of these chains. The example of a simple two-commodity food system (grain and salt) shows that it is very unlikely that a household can achieve food security without some cash expenditure. All households need sources of livelihood that give them sufficient purchasing power to buy the food that they need but cannot or do not produce for their own consumption.

Climate is a particularly important driver of food system performance at the farm end of the food chain, affecting the quantities and types of food produced and the adequacy of

production-related income. Extreme weather events can damage or destroy transport and distribution infrastructure and affect other non-agricultural parts of the food system adversely.

However, the impacts of climate change are likely to trigger adaptive responses that influence the environmental and socio-economic drivers of food system performance in positive as well as negative ways. This paper is concerned with the projected balance of these various impacts on food system performance and food security outcomes at the local and global levels.

CLIMATE AND CLIMATE CHANGE²

Climate and its measurement

Climate refers to the characteristic conditions of the earth's lower surface atmosphere at a specific location; weather refers to the day-to-day fluctuations in these conditions at the same location. The variables that are commonly used by meteorologists to measure daily weather phenomena are air temperature, precipitation (e.g., rain, sleet, snow and hail), atmospheric pressure and humidity, wind, and sunshine and cloud cover.

When these weather phenomena are measured systematically at a specific location over several years, a record of observations is accumulated from which averages, ranges, maximums and minimums for each variable can be computed, along with the frequency and duration of more extreme events.

The World Meteorological Organization (WMO) requires the calculation of averages for consecutive periods of 30 years, with the latest being from 1961 to 1990. Such a period is long enough to eliminate year-to-year variations. The averages are used in the study of climate change, and as a base with which current conditions can be compared (UK Met Office Online).

Climate can be described at different scales. Global climate is the average temperature of the earth's surface and the atmosphere in contact with it, and is measured by analysing thousands of temperature records collected from stations all over the world, both on land and at sea. Most current projections of climate change refer to global climate, but climate can also be described at other scales, based on records for weather variables collected from stations in the zones concerned. Zonal climates include the following:

- *Latitudinal climates* are temperature regimes determined by the location north or south of the equator. They include polar climate, temperate climate, sub-tropical climate and tropical climate.
- *Regional climates* are patterns of weather that affect a significant geographical area and that can be identified by special features that distinguish them from other climate patterns. The main factors determining regional climate are: (i) differences in temperature caused by distance from the equator and seasonal changes in the angle of the sun's rays as the earth rotates; (ii) planetary distribution of land and sea masses; and (iii) the worldwide system of winds, called the general circulation, which arises as a result of temperature difference between the equator and the poles. Examples of regional climates are maritime climate, continental climate, monsoon climate, Mediterranean climate, Sahelian climate and desert climate.
- *Local climates* have influence over very small geographical areas, of only a few kilometres or tens of kilometres across. They include land and sea breezes, the orographic lifting of air masses and formation of clouds on the windward side of mountains, and the heat island effects of cities. Under certain conditions, local climatic effects may predominate over the more general pattern of regional or latitudinal climate. If the area involved is very small, such as in a flower bed or a shady grove, it may be referred to as a microclimate. Microclimates can also be

² Unless otherwise noted, definitions and explanations contained in this section are drawn from UK DEFRA, 2005. Annex I gives standard, internationally agreed terminology from the World Meteorological Organization (WMO) and the Intergovernmental Panel on Climate Change (IPCC).

created artificially, as in hothouses, museum displays or storage environments where temperature and humidity are controlled.

Climate system

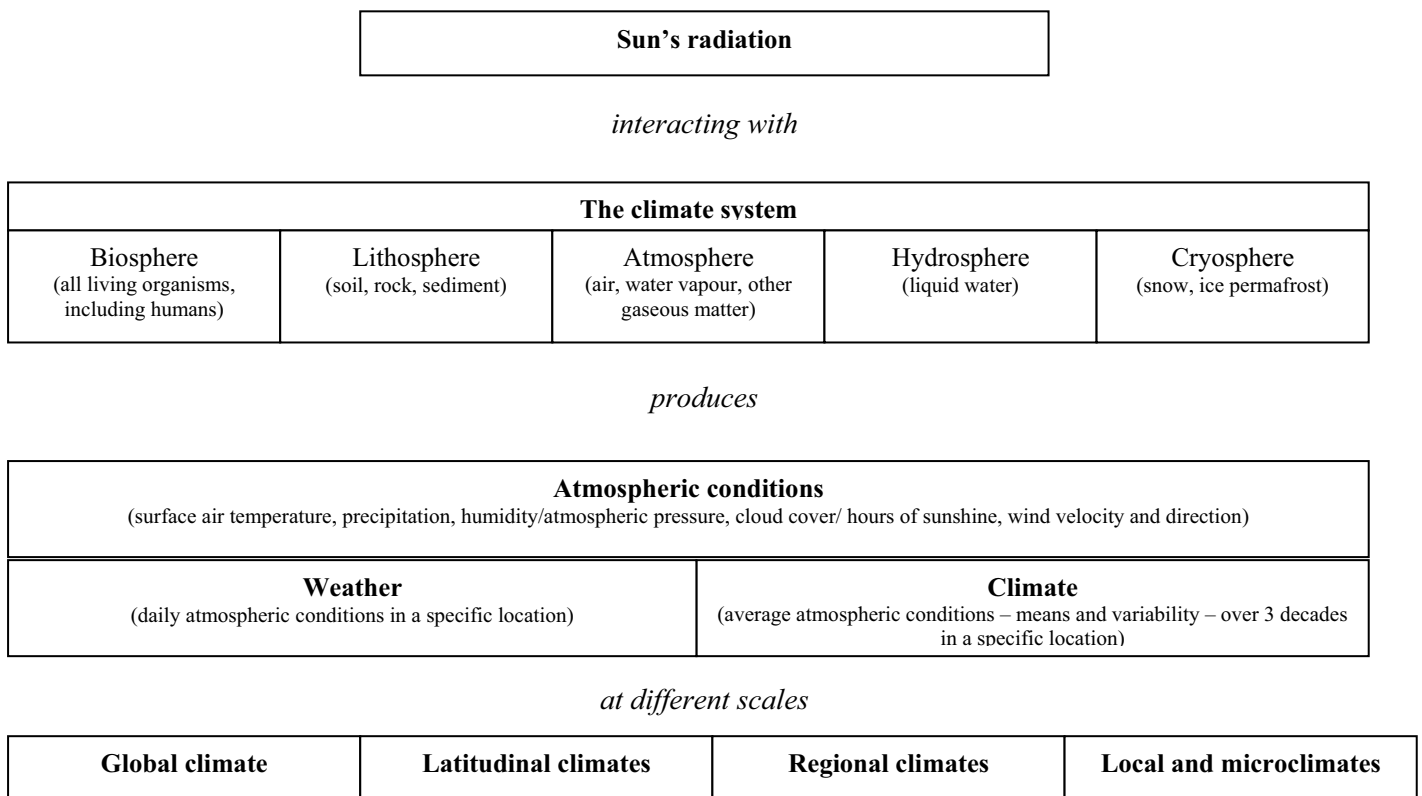
The climate system is highly complex. Under the influence of the sun’s radiation, it determines the earth’s climate (WMO, 1992) and consists of:

- the atmosphere: gaseous matter above the earth’s surface;
- the hydrosphere: liquid water on or below the earth’s surface;
- the cryosphere: snow and ice on or below the earth’s surface;
- the lithosphere: earth’s land surface (e.g., rock, soil and sediment);
- the biosphere: earth’s plants and animal life, including humans.

Although climate *per se* relates only to the varying states of the earth’s atmosphere, the other parts of the climate system also have significant roles in forming climate, through their interactions with the atmosphere (Figure 3).

The Global Climate Observing System (GCOS) has developed a list of variables essential for monitoring changes in the climate system. The list includes atmospheric, oceanic and terrestrial phenomena, and covers all the spheres of the climate system (Annex I).

Figure 3. The formation of climate



Source: FAO/NRCB.

GCOS was established by WMO, the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations Environment Programme (UNEP) and the International Council for Science (ICSU) in 1992 to ensure that the observations and information needed to address climate-related issues are obtained and made available to all potential users.

GCOS and its partners provide vital and continuous support to the United Nations Framework Convention on Climate Change (UNFCCC), the World Climate Research

Programme (WCRP) and the Intergovernmental Panel on Climate Change (IPCC). The reporting system on essential climate variables provides information to (GCOS Online a):

- characterize the state of the global climate system and its variability;
- monitor the forcing of the climate system, by both natural and anthropogenic causes;
- support attributions of climate change causes;
- support predictions of global climate change;
- enable projection of global climate change information to the regional and local scales;
- enable characterization of extreme events that are important in impact assessment and adaptation, and to the assessment of risk and vulnerability.

Climate variability and climate change

There is no internationally agreed definition of the term “climate change” (see Annex II for internationally agreed terminology on climate and climate change). Climate change can refer to: (i) long-term changes in average weather conditions (WMO usage); (ii) all changes in the climate system, including the drivers of change, the changes themselves and their effects (GCOS usage); or (iii) only human-induced changes in the climate system (UNFCCC usage).

There is also no agreement on how to define the term “climate variability”. Climate has been in a constant state of change throughout the earth’s 4.5 billion-year history, but most of these changes occur on astronomical or geological time scales, and are too slow to be observed on a human scale. Natural climate variation on these scales is sometimes referred to as “climate variability”, as distinct from human-induced climate change. UNFCCC has adopted this usage (e.g., UNFCCC, 1992). For meteorologists and climatologists, however, climate variability refers only to the year-to-year variations of atmospheric conditions around a mean state (WMO, 1992).

To assess climate change and food security, FAO prefers to use a comprehensive definition of climate change that encompasses changes in long-term averages for all the essential climate variables. For many of these variables, however, the observational record is too short to clarify whether recent changes represent true shifts in long-term means (climate change), or are simply anomalies around a stable mean (climate variability).

Effects of global warming on the climate system

Global warming is the immediate consequence of increased greenhouse gas emissions with no offsetting increases in carbon storage on earth. This paper is concerned mainly with the projected effects of the current episode of human-induced global warming on the climate system, now and for the next several decades, as these are the effects that will both cause additional stresses and create new opportunities for food systems, with consequent implications for food security.

The linear depiction shown in Figure 4 is a rough approximation of how the interactive dynamics of global warming, climate system response and changes in weather patterns may work in different parts of the globe.

Acclimatization, adaptation and mitigation

Acclimatization is essentially adaptation that occurs spontaneously through self-directed efforts. Adaptation to climate change involves deliberate adjustments in natural or human systems and behaviours to reduce the risks to people’s lives and livelihoods. Mitigation of climate change involves actions to reduce greenhouse gas emissions and sequester or store carbon in the short term, and development choices that will lead to low emissions in the long term.

Acclimatization is a powerful and effective adaptation strategy. In simple terms, it means getting used to climate change and learning to live comfortably with it. All living organisms, including humans, adapt and develop in response to changes in climate and habitat. Some

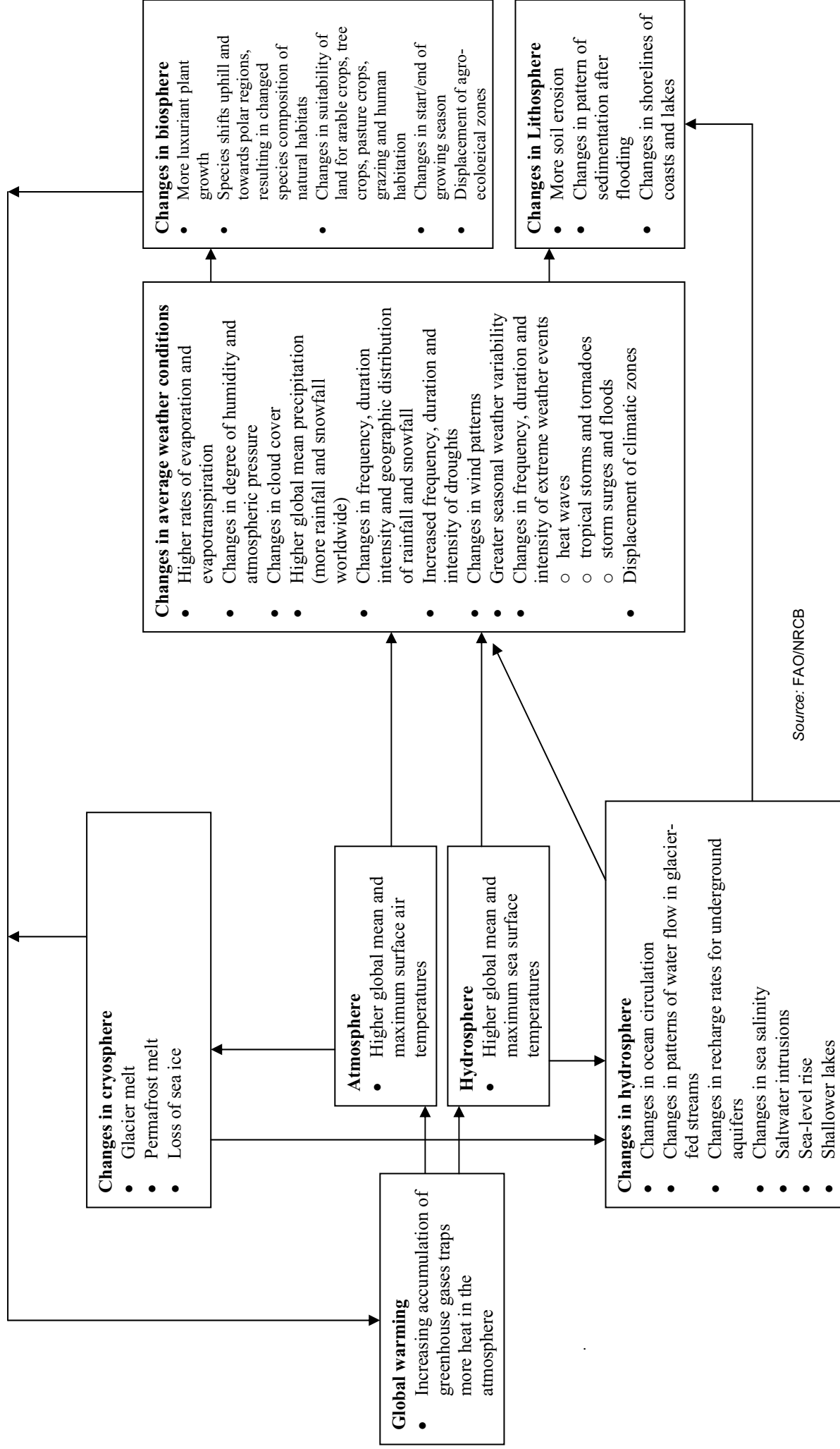
adaptations may be biological – for example, human physiology may become more heat-tolerant as global temperatures rise – but many are likely to involve changes in perceptions and mental attitudes that reinforce new, more adapted responses to extreme events.

CLIMATE CHANGE AND FOOD SECURITY

Agriculture, climate and food security

Agriculture is important for food security in two ways: it produces the food people eat; and (perhaps even more important) it provides the primary source of livelihood for 36 percent of the world's total workforce. In the heavily populated countries of Asia and the Pacific, this share ranges from 40 to 50 percent, and in sub-Saharan Africa, two-thirds of the working population still make their living from agriculture (ILO, 2007). If agricultural production in the low-income developing countries of Asia and Africa is adversely affected by climate change, the livelihoods of large numbers of the rural poor will be put at risk and their vulnerability to food insecurity increased.

Figure 4. Global warming and changes in the climate system



Agriculture, forestry and fisheries are all sensitive to climate. Their production processes are therefore likely to be affected by climate change. In general, impacts are expected to be positive in temperate regions and negative in tropical ones, but there is still uncertainty about how projected changes will play out at the local level, and potential impacts may be altered by the adoption of risk management measures and adaptation strategies that strengthen preparedness and resilience.

The food security implications of changes in agricultural production patterns and performance are of two kinds:

- Impacts on the production of food will affect food supply at the global and local levels. Globally, higher yields in temperate regions could offset lower yields in tropical regions. However, in many low-income countries with limited financial capacity to trade and high dependence on their own production to cover food requirements, it may not be possible to offset declines in local supply without increasing reliance on food aid.
- Impacts on all forms of agricultural production will affect livelihoods and access to food. Producer groups that are less able to deal with climate change, such as the rural poor in developing countries, risk having their safety and welfare compromised.

Other food system processes, such as food processing, distribution, acquisition, preparation and consumption, are as important for food security as food and agricultural production are. Technological advances and the development of long-distance marketing chains that move produce and packaged foods throughout the world at high speed and relatively low cost have made overall food system performance far less dependent on climate than it was 200 years ago.

However, as the frequency and intensity of severe weather increase, there is a growing risk of storm damage to transport and distribution infrastructure, with consequent disruption of food supply chains. The rising cost of energy and the need to reduce fossil fuel usage along the food chain have led to a new calculus – “food miles”, which should be kept as low as possible to reduce emissions. These factors could result in more local responsibility for food security, which needs to be considered in the formulation of adaptation strategies for people who are currently vulnerable or who could become so within the foreseeable future.

Food security and climate change: a conceptual framework

Food systems exist in the biosphere, along with all other manifestations of human activity. As shown in Figure 4, some of the significant changes in the biosphere that are expected to result from global warming will occur in the more distant future, as a consequence of changes in average weather conditions. In Figure 4, the most likely scenarios of climate change indicate that increases in weather variability and the incidence of extreme weather events will be particularly significant now and in the immediate future.

The projected increases in mean temperatures and precipitation will not manifest through constant gradual changes, but will instead be experienced as increased frequency, duration and intensity of hot spells and precipitation events. Whereas the annual occurrence of hot days, and maximum temperatures are expected to increase in all parts of the globe, the mean global increase in precipitation is not expected to be uniformly distributed around the world. In general, it is projected that wet regions will become wetter and dry regions dryer.

For this analysis, a conceptual framework on climate change and food security interactions was developed to highlight the variables defining the food and climate systems. The climate change and food security (CCFS) framework (Figure 5 and Table 1) shows how climate change affects food security outcomes for the four components of food security – food availability, food accessibility, food utilization and food system stability – in various direct and indirect ways.

Climate change variables influence biophysical factors, such as plant and animal growth, water cycles, biodiversity and nutrient cycling, and the ways in which these are managed

through agricultural practices and land use for food production. However, climate variables also have an impact on physical/human capital – such as roads, storage and marketing infrastructure, houses, productive assets, electricity grids, and human health – which indirectly changes the economic and socio-political factors that govern food access and utilization and can threaten the stability of food systems.

All of these impacts manifest themselves in the ways in which food system activities are carried out. The framework illustrates how adaptive adjustments to food system activities will be needed all along the food chain to cope with the impacts of climate change.

The climate change variables considered in the CCFS framework are:

- the CO₂ fertilization effect of increased greenhouse gas concentrations in the atmosphere;
- increasing mean, maximum and minimum temperatures;
- gradual changes in precipitation:
 - increase in the frequency, duration and intensity of dry spells and droughts;
 - changes in the timing, duration, intensity and geographic location of rain and snowfall;
- increase in the frequency and intensity of storms and floods;
- greater seasonal weather variability and changes in start/end of growing seasons.

This paper does not discuss in detail the wider set of factors/driving forces that govern food system activities and food security, such as demographic developments, changes in economic systems and trade flows, science and technology developments or shifts in cultural practices; a wide range of literature is available on each of these. Instead, the paper focuses on disentangling the pathways of climate change impacts on food system activities and food security outcomes.

Evidence indicates that more frequent and more intense extreme weather events (droughts, heat and cold waves, heavy storms, floods), rising sea levels and increasing irregularities in seasonal rainfall patterns (including flooding) are already having immediate impacts on not only food production, but also food distribution infrastructure, incidence of food emergencies, livelihood assets and human health in both rural and urban areas.

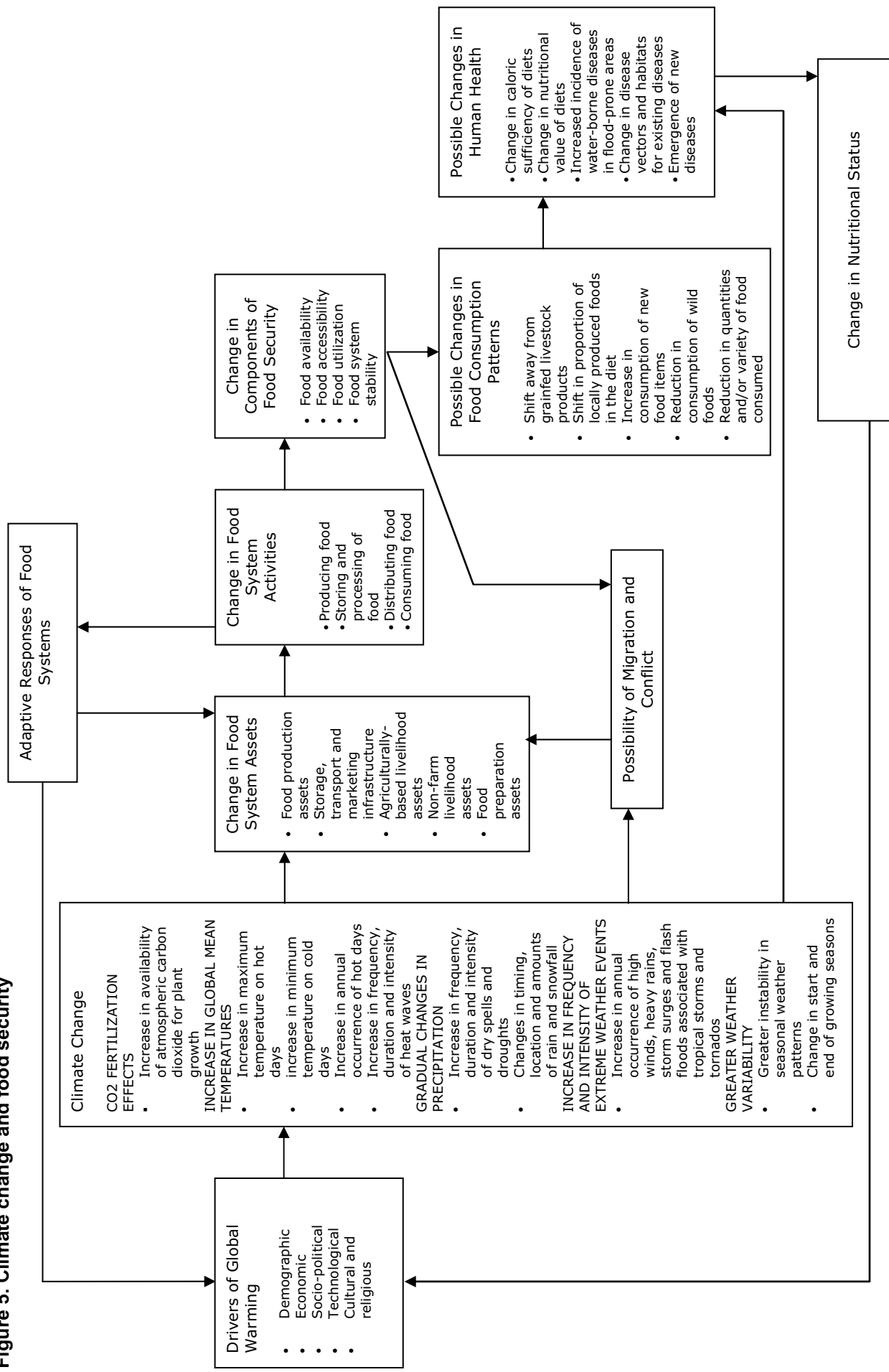
In addition, less immediate impacts are expected to result from gradual changes in mean temperatures and rainfall. These will affect the suitability of land for different types of crops and pasture; the health and productivity of forests; the distribution, productivity and community composition of marine resources; the incidence and vectors of different types of pests and diseases; the biodiversity and ecosystem functioning of natural habitats; and the availability of good-quality water for crop, livestock and inland fish production. Arable land is likely to be lost owing to increased aridity (and associated salinity), groundwater depletion and sea-level rise. Food systems will be affected by internal and international migration, resource-based conflicts and civil unrest triggered by climate change.

Vulnerability to climate change

Uncertainty and risk: Risk exists when there is uncertainty about the future outcomes of ongoing processes or about the occurrence of future events. The more certain an outcome is, the less risk there is, because certainty allows informed choices and preparation to deal with the impacts of hazardous processes or events.

Global climate change projections have a solid scientific basis, and there is growing certainty that extreme weather events are going to increase in frequency and intensity. This makes it highly likely that asset losses attributable to weather-related disasters will increase. Whether these losses involve productive assets, personal possessions or even loss of life, the livelihoods and food security status of millions of people in disaster-prone areas will be adversely affected.

Figure 5. Climate change and food security



SOURCE: FAO/NRCB.
Figure produced for this report.

Table 1
 Potential impacts of climate change on food systems and food security, and possible adaptive responses

A. CO ₂ fertilization effects				
Impact on food system assets	Impact on food system activities	Impact on food security outcomes	Impact on other human well-being outcomes	Possible adaptive responses
<p>Production assets:</p> <ul style="list-style-type: none"> ▪ Increase in availability of atmospheric carbon dioxide for plant growth 	<p>Producing food:</p> <ul style="list-style-type: none"> ▪ More luxuriant biomass ▪ Higher yields of food and cash crops, mainly in temperate regions 	<p>Food availability (production, distribution, exchange):</p> <ul style="list-style-type: none"> ▪ Increased food production in major exporting countries would contribute to global food supply but diversion of land from food to more economically attractive cash crops could negate this benefit <p>Food accessibility (allocation, affordability, preference):</p> <ul style="list-style-type: none"> ▪ Increases in food production would limit price increases on world markets, but diversion of productive assets to other cash crops could cause food prices to rise 	<p>Livelihoods:</p> <ul style="list-style-type: none"> ▪ Increased income from improved food and cash crop performance would benefit commercial farmers in developed countries but not in developing countries 	<p>Policies and regulations:</p> <ul style="list-style-type: none"> ▪ Avoidance of subsidies or other monetary or non-monetary incentives for diversion of food production assets to other uses

B. Increase in global mean temperatures				
Impact on food system assets	Impact on food system activities	Impact on food security outcomes	Impact on other human well-being outcomes	Possible adaptive responses
<p>Production assets:</p> <ul style="list-style-type: none"> Trend changes in suitability of land for crop and livestock production Gradual loss of biodiversity Trend changes in vectors and natural habitats of plant and animal pests and diseases <p>Storage, transport and marketing infrastructure:</p> <ul style="list-style-type: none"> Strain on electricity grids, air conditioning and cold storage capacity 	<p>Producing food:</p> <ul style="list-style-type: none"> Immediate crop and livestock losses due to heat and water stress Lower yields from dairy animals Reduced labour productivity due to heat stress Trend impacts uncertain, conditional on location, availability of water and adoption of new cropping patterns by farmers <p>Storing and processing of food:</p> <ul style="list-style-type: none"> Upgrade in cooling and storage facilities required to maintain food quality at higher temperatures Increasing energy requirements for cooling <p>Consuming food:</p> <ul style="list-style-type: none"> Higher intake of liquids Lower intake of cooked food Perishable products have shorter shelf life More need for refrigeration Heat stress may negatively affect people's ability to access food (no energy to shop or do productive work) 	<p>Food availability (production, distribution, exchange):</p> <ul style="list-style-type: none"> Reduced production of food crops and livestock products in affected areas Local losses could have temporary effect on local markets, Reduction in global supplies likely to cause market prices to rise <p>Food accessibility (allocation, affordability, preference):</p> <ul style="list-style-type: none"> Impacts on incomes, prices and affordability uncertain Changes in preference uncertain <p>Food utilization (nutritional value, social value, food safety):</p> <ul style="list-style-type: none"> Risk of dehydration Risk of ill health from eating food that is spoiled Ability of body to process food reduced due to heat stress or diseases <p>Food system stability:</p> <ul style="list-style-type: none"> Higher cost for storing grain and perishable products 	<p>Livelihoods:</p> <ul style="list-style-type: none"> Trend changes in vectors and natural habitats of pests and diseases that affect human health and productivity <p>Social values and behaviours:</p> <ul style="list-style-type: none"> Acceptance of a greater degree of risk and uncertainty as a natural condition of life <p>National and global economies:</p> <ul style="list-style-type: none"> Reorientation of public and private sector investments towards mitigating and adapting to climate change 	<p>Policies and regulations</p> <ul style="list-style-type: none"> Greater reliance on weather-related insurance Development of risk management frameworks <p>Farming, forestry and fishery practices</p> <ul style="list-style-type: none"> Trend changes in cropping patterns Development and dissemination of more heat-tolerant varieties and species <p>Food processing, distribution and marketing practices</p> <ul style="list-style-type: none"> Greater use of alternative fuels for generating electricity <p>Food preparation practices</p> <ul style="list-style-type: none"> Greater use of alternative fuels for home cooking

C.1. Gradual changes in precipitation

(increase in the frequency, duration and intensity of dry spells and droughts)

Impact on food system assets	Impact on food system activities	Impact on food security outcomes	Impact on other human well-being outcomes	Possible adaptive responses
<p>Production assets</p> <ul style="list-style-type: none"> Loss of perennial crops and vegetative cover for grazing and fuel wood due to water stress and increasing fire hazard Loss of livestock due to water stress and lack of feed Loss of productive assets due to hardship sales Loss of buildings, equipment and vehicles and other productive assets due to fire Changes in rates of soil moisture retention and aquifer recharge Trend changes in suitability of land for crop and livestock production Gradual loss of biodiversity Trend changes in vectors and natural habitats of plant and animal pests and diseases <p>Food preparation assets</p> <ul style="list-style-type: none"> Lack of water for cooking Lack of vegetation for fuel 	<p>Producing food:</p> <ul style="list-style-type: none"> Immediate crop and livestock losses due to water stress Trend declines in yields Change in irrigation requirements <p>Storing/processing of food:</p> <ul style="list-style-type: none"> Less need for chemicals to preserve stored grain Scarcity of water for food processing <p>Distributing food:</p> <ul style="list-style-type: none"> Easier movement of vehicles on dry land <p>Consuming food:</p> <ul style="list-style-type: none"> May not be possible to continue growing preferred foods May be necessary to purchase a larger proportion of foods consumed Diet may become less varied and / or less nutritious 	<p>Food availability (production, distribution, exchange):</p> <ul style="list-style-type: none"> Declines in production Wild foods less available Pressure on grain reserves Decrease in food exports / increase in food imports Increased need for food aid <p>Food accessibility (allocation, affordability, preference):</p> <ul style="list-style-type: none"> Local increase in food prices in drought-affected areas Loss of farm income and non-farm employment Preferred foods not available or too costly <p>Food utilization:</p> <ul style="list-style-type: none"> Risk of dehydration Ability of body to process food reduced due to diseases Dietary adjustments with different nutritional content <p>Food system stability:</p> <ul style="list-style-type: none"> Greater instability of food supply, food prices and agriculturally-based incomes 	<p>Livelihoods:</p> <ul style="list-style-type: none"> Decline in expenditure for other basic needs, e.g., clothing, shelter, health, education Trend changes in vectors and natural habitats of pests and diseases that affect human health and productivity <p>Social values and behaviours:</p> <ul style="list-style-type: none"> Food scarcity strains ability to meet reciprocal food-sharing obligations <p>National and global economies:</p> <ul style="list-style-type: none"> Strain on national budgets and aid resources due to increased need for food safety nets 	<p>Policies and regulations:</p> <ul style="list-style-type: none"> Greater reliance on weather-related insurance Development of risk management frameworks <p>Infrastructure investments</p> <ul style="list-style-type: none"> New investment in irrigation for intensive agriculture where water resources permit <p>Farming, forestry and fishery practices</p> <ul style="list-style-type: none"> Trend changes in cropping patterns Development and dissemination of more drought-tolerant varieties and species Use of moisture-retaining land management practices Use of recycled wastewater for irrigation <p>Food processing practices:</p> <ul style="list-style-type: none"> Use of recycled wastewater Use of dry processing and packaging methods <p>Food preparation practices</p> <ul style="list-style-type: none"> Use of dry cooking methods

C.2. Gradual changes in precipitation (changes in timing, location and amounts of rain and snowfall)				
Impact on food system assets	Impact on food system activities	Impact on food security outcomes	Impact on other human well-being outcomes	Possible adaptive responses
<p>Production assets</p> <ul style="list-style-type: none"> Changes in rates of soil moisture retention and aquifer recharge Increase in proportion of global population exposed to water scarcities Changes in locations where investment in irrigation is economically feasible Trend changes in suitability of land for crop and livestock production Trend changes in vectors and natural habitats of plant and animal pests and diseases 	<p>Producing food:</p> <ul style="list-style-type: none"> Trend impacts on yields uncertain, conditional on location, availability of water and adoption of new cropping patterns by farmers <p>Consuming food:</p> <ul style="list-style-type: none"> Changes in consumption patterns may occur, in response to changes in relative prices 	<p>Food availability (production, distribution, exchange):</p> <ul style="list-style-type: none"> Some local losses virtually certain, but their likely geographic distribution is not known Likely impact on global supplies, trade and world market prices is not known <p>Food accessibility (allocation, affordability, preference):</p> <ul style="list-style-type: none"> Full-cost pricing for water may cause food prices to rise <p>Food system stability:</p> <ul style="list-style-type: none"> Greater instability of food supply, food prices and agriculturally-based incomes is likely 	<p>Livelihoods:</p> <ul style="list-style-type: none"> Changes in geographic distribution of vulnerability <p>Social values and behaviours:</p> <ul style="list-style-type: none"> Acceptance of a greater degree of risk and uncertainty as a natural condition of life <p>National and global economies:</p> <ul style="list-style-type: none"> Reorientation of public and private sector investments towards mitigating and adapting to climate change 	<p>Policies and regulations:</p> <ul style="list-style-type: none"> More aggressive support for efficient water management policies and water use regulations Full-cost pricing for water <p>Infrastructure investments:</p> <ul style="list-style-type: none"> New investment in irrigation for expanding intensive agriculture where available water resources permit <p>Farming, forestry and fishery practices</p> <ul style="list-style-type: none"> Use of moisture-retaining land management practices Use of recycled wastewater for irrigation <p>Food processing practices:</p> <ul style="list-style-type: none"> Use of recycled wastewater for plant hygiene <p>Food safety and preventive healthcare practices:</p> <ul style="list-style-type: none"> Use of recycled wastewater for home hygiene

D. Impacts of increase in the frequency and intensity of extreme weather events (increase in annual occurrence of high winds, heavy rains, storm surges, flash floods and rising water levels associated with tornados, tropical storms, and prolonged heavy rains)				
Impact on food system assets	Impact on food system activities	Impact on food security outcomes	Impact on other human well-being outcomes	Possible adaptive options
<p>Production assets:</p> <ul style="list-style-type: none"> ▪ Damage to standing crops ▪ Animals stranded ▪ Increase in water-borne livestock diseases ▪ Damage to buildings and equipment ▪ Loss of stored crops <p>Storage, transport and marketing infrastructure:</p> <ul style="list-style-type: none"> ▪ Damage to roads, bridges, storage structures, processing plants and electricity grids <p>Non-farm livelihood assets:</p> <ul style="list-style-type: none"> ▪ Damage to trade goods <p>Food preparation assets:</p> <ul style="list-style-type: none"> ▪ Loss of household food supplies 	<p>Producing food:</p> <ul style="list-style-type: none"> ▪ Possibility of lower yields in flooded agricultural areas ▪ Increased soil erosion reducing future yields <p>Processing food:</p> <ul style="list-style-type: none"> ▪ Pollution of water supply used in processing food <p>Distributing food:</p> <ul style="list-style-type: none"> ▪ Disruptions in food supply chains and increase in marketing and distribution costs <p>Consuming food:</p> <ul style="list-style-type: none"> ▪ Reliance on emergency rations ▪ Possibility that preferred foods will be less available in emergency situations and food variety will decrease ▪ Increased health risks from water-borne diseases may negatively affect people's ability to access food (no energy to shop or do productive work) 	<p>Food availability (production, distribution, exchange):</p> <ul style="list-style-type: none"> ▪ Possible decrease in surplus production in flooded agricultural areas ▪ Increased need for emergency distribution of food rations <p>Food accessibility (allocation, affordability, preference):</p> <ul style="list-style-type: none"> ▪ Possible increase in food prices ▪ Possible loss of farm income and non-farm employment, depending on extent of asset loss <p>Food utilization (nutritional value, social value, food safety):</p> <ul style="list-style-type: none"> ▪ Food safety is compromised by water pollution and damage to stored food ▪ Ability of body to process food reduced due to diseases 	<p>Livelihoods:</p> <ul style="list-style-type: none"> ▪ Decline in expenditure for other basic needs, e.g., clothing, shelter, health, education ▪ Trend changes in vectors and natural habitats of pests and diseases that affect human health and productivity ▪ Changes in geographic distribution of vulnerability <p>Social values and behaviours:</p> <ul style="list-style-type: none"> ▪ Acceptance of a greater degree of risk and uncertainty as a natural condition of life <p>National and global economies:</p> <ul style="list-style-type: none"> ▪ Reorientation of public and private sector investments towards mitigating and adapting to climate change 	<p>Policies and regulations:</p> <ul style="list-style-type: none"> ▪ Development of weather-related insurance schemes for storms and floods ▪ Development of risk management frameworks ▪ Support for resettlement schemes in low-risk areas <p>Infrastructure investments:</p> <ul style="list-style-type: none"> ▪ New investment in flood embankments ▪ Use of wind resistant technologies on new and existing structures ▪ Establishment of emergency shelters on high ground <p>Farming, forestry and fishery practices</p> <ul style="list-style-type: none"> ▪ Use of practices that create more dense root mass to hold soil in place ▪ Development and dissemination of more flood-tolerant varieties and species <p>Food safety and preventive healthcare practices</p> <ul style="list-style-type: none"> ▪ Provision for emergency water supplies

E. Impacts of greater weather variability				
Impact on food system assets	Impact on food system activities	Impact on food security Outcomes	Impact on other human well-being outcomes	Possible adaptive options
<p>Production assets:</p> <ul style="list-style-type: none"> Change in frequency and extent of pests and diseases 	<p>Producing food:</p> <ul style="list-style-type: none"> Increasing uncertainty Changing yields Changing land use patterns Viability of production systems may be undermined 	<p>Food availability:</p> <ul style="list-style-type: none"> Some local losses virtually certain, but their likely geographic distribution is not known Likely impact on global supplies, trade and world market prices is not known <p>Food accessibility:</p> <ul style="list-style-type: none"> Reduced yields may lead to loss of farm income, but this depends on market conditions <p>Food system stability:</p> <ul style="list-style-type: none"> Greater instability of food supply, food prices and agriculturally-based incomes is likely 	<p>Livelihoods:</p> <ul style="list-style-type: none"> Decline in expenditure for other basic needs, e.g., clothing, shelter, health, education Trend changes in vectors and natural habitats of pests and diseases that affect human health and productivity Changes in geographic distribution of vulnerability <p>Social values and behaviours:</p> <ul style="list-style-type: none"> Acceptance of a greater degree of risk and uncertainty as a natural condition of life <p>National and global economies:</p> <ul style="list-style-type: none"> Reorientation of public and private sector investments towards mitigating and adapting to climate change 	<p>Policies and regulations</p> <ul style="list-style-type: none"> Greater reliance on weather-related insurance Development of risk management frameworks <p>Farming, forestry and fishery practices</p> <ul style="list-style-type: none"> Trend changes in cropping patterns Changes in water management regimes

Source: FAO/IDWG on Climate Change. Table produced for this report.

An average of 500 weather-related disasters are now taking place each year, compared with 120 in the 1980s; the number of floods has increased sixfold over the same period (Oxfam, 2007). Population increases, especially in coastal areas, where most of the world's population now lives, mean that more and more people will be affected by catastrophic weather events.

The international aid community has developed an immediate response capacity that can limit loss of life, but there is a growing risk that its ability to assist affected people in replacing lost assets and recovering livelihoods following climate-related natural disasters will be overwhelmed. Increasing weather-related losses are causing private sector insurers to restrict the types of natural disasters or catastrophic events that can be insured, and it is not clear whether public sector safety net programmes will be able to fill the subsequent gaps.

Although the areas that are vulnerable to extreme weather events are generally known, there is still a lack of reliable information about how future changes in temperature and precipitation regimes will affect specific locations. Further scientific work can reduce the current knowledge gap, but these aspects of climate change are likely to remain uncertain for the foreseeable future, making investments in agriculture and other weather-dependent livelihoods inherently more risky.

The limited risk absorption capacity of poor people means that they are unlikely to be able to cope with the added risk imposed by climate change. These people will be exposed to greater variability in and uncertainties about food system performance, and their livelihood sources will become more vulnerable.

Food system vulnerability: Overview: A food system is vulnerable when one or more of the four components of food security – food availability, food accessibility, food utilization and food system stability – is uncertain and insecure.

Food availability is determined by the physical quantities of food that are produced, stored, processed, distributed and exchanged. FAO calculates national food balance sheets that include all these elements. Food availability is the net amount remaining after production, stocks and imports have been summed and exports deducted for each item included in the food balance sheet. Adequacy is assessed through comparison of availability with the estimated consumption requirement for each food item.

This approach takes into account the importance of international trade and domestic production in assuring that a country's food supply is sufficient. The same approach can also be used to determine the adequacy of a household's food supply, with domestic markets playing the balancing role.

High market prices for food are usually a reflection of inadequate availability; persistently high prices force poor people to reduce consumption below the minimum required for a healthy and active life, and may lead to food riots and social unrest. Growing scarcities of water, land and fuel are likely to put increasing pressure on food prices, even without climate change. Where these scarcities are compounded by the results of climate change, the introduction of mitigation practices that create land-use competition and the attribution of market value to environmental services to mitigate climate change, they have the potential to cause significant changes in relative prices for different food items, and an overall increase in the cost of an average food basket for the consumer, with accompanying increases in price volatility.

Food accessibility is a measure of the ability to secure entitlements, which are defined as the set of resources (including legal, political, economic and social) that an individual requires to obtain access to food (A. Sen, 1989, cited in FAO, 2003a). Until the 1970s, food security was linked mainly to national food production and global trade (Devereux and Maxwell, 2001), but since then the concept has expanded to include households' and individuals' access to food.

The mere presence of an adequate supply does not ensure that a person can obtain and consume food – that person must first have access to the food through his/her entitlements. The enjoyment of entitlements that determine people's access to food depends on allocation mechanisms, affordability, and cultural and personal preferences for particular food products.

Increased risk exposure resulting from climate change will reduce people's access to entitlements and undermine their food security.

Food utilization refers to the use of food and how a person is able to secure essential nutrients from the food consumed. It encompasses the nutritional value of the diet, including its composition and methods of preparation; the social values of foods, which dictate what kinds of food should be served and eaten at different times of the year and on different occasions; and the quality and safety of the food supply, which can cause loss of nutrients in the food and the spread of food-borne diseases if not of a sufficient standard. Climatic conditions are likely to bring both negative and positive changes in dietary patterns and new challenges for food safety, which may affect nutritional status in various ways.

Food system stability is determined by the temporal availability of, and access to, food. In long-distance food chains, storage, processing, distribution and marketing processes contain in-built mechanisms that have protected the global food system from instability in recent times. However, if projected increases in weather variability materialize, they are likely to lead to increases in the frequency and magnitude of food emergencies for which neither the global food system nor affected local food systems are adequately prepared.

Potential impacts of climate change on food availability: Production of food and other agricultural commodities may keep pace with aggregate demand, but there are likely to be significant changes in local cropping patterns and farming practices. There has been a lot of research on the impacts that climate change might have on agricultural production, particularly cultivated crops. Some 50 percent of total crop production comes from forest and mountain ecosystems, including all tree crops, while crops cultivated on open, arable flat land account for only 13 percent of annual global crop production. Production from both rainfed and irrigated agriculture in dryland ecosystems accounts for approximately 25 percent, and rice produced in coastal ecosystems for about 12 percent (Millennium Ecosystem Assessment, 2005).

The evaluation of climate change impacts on agricultural production, food supply and agriculture-based livelihoods must take into account the characteristics of the agro-ecosystem where particular climate-induced changes in biochemical processes are occurring, in order to determine the extent to which such changes will be positive, negative or neutral in their effects.

The so-called "greenhouse fertilization effect" will produce local beneficial effects where higher levels of atmospheric CO₂ stimulate plant growth. This is expected to occur primarily in temperate zones, with yields expected to increase by 10 to 25 percent for crops with a lower rate of photosynthetic efficiency (C3 crops), and by 0 to 10 percent for those with a higher rate of photosynthetic efficiency (C4 crops), assuming that CO₂ levels in the atmosphere reach 550 parts per million (IPCC, 2007c); these effects are not likely to influence projections of world food supply, however (Tubiello *et al.*, 2007). Mature forests are also not expected to be affected, although the growth of young tree stands will be enhanced (Norby *et al.*, 2005).

The impacts of mean temperature increase will be experienced differently, depending on location (Leff, Ramankutty and Foley, 2004). For example, moderate warming (increases of 1 to 3 °C in mean temperature) is expected to benefit crop and pasture yields in temperate regions, while in tropical and seasonally dry regions, it is likely to have negative impacts, particularly for cereal crops. Warming of more than 3 °C is expected to have negative effects on production in all regions (IPCC, 2007c). The supply of meat and other livestock products will be influenced by crop production trends, as feed crops account for roughly 25 percent of the world's cropland.

For climate variables such as rainfall, soil moisture, temperature and radiation, crops have thresholds beyond which growth and yield are compromised (Porter and Semenov, 2005). For example, cereals and fruit tree yields can be damaged by a few days of temperatures above or below a certain threshold (Wheeler *et al.*, 2000). In the European heat wave of 2003, when temperatures were 6 °C above long-term means, crop yields dropped significantly, such as by 36 percent for maize in Italy, and by 25 percent for fruit and 30 percent for forage in France (IPCC, 2007c). Increased intensity and frequency of storms, altered hydrological cycles, and precipitation variance also have long-term implications on the viability of current world agro-ecosystems and future food availability.

Wild foods are particularly important to households that struggle to produce food or secure an income. A change in the geographic distribution of wild foods resulting from changing rainfall and temperatures could therefore have an impact on the availability of food. Changes in climatic conditions have led to significant declines in the provision of wild foods by a variety of ecosystems, and further impacts can be expected as the world climate continues to change. For the 5 000 plant species examined in a sub-Saharan African study (Levin and Pershing, 2005), it is predicted that 81 to 97 percent of the suitable habitats will decrease in size or shift owing to climate change. By 2085, between 25 and 42 percent of the species' habitats are expected to be lost altogether. The implications of these changes are expected to be particularly great among communities that use the plants as food or medicine.

Constraints on water availability are a growing concern, which climate change will exacerbate. Conflicts over water resources will have implications for both food production and people's access to food in conflict zones (Gleick, 1993). Prolonged and repeated droughts can cause loss of productive assets, which undermines the sustainability of livelihood systems based on rainfed agriculture. For example, drought and deforestation can increase fire danger, with consequent loss of the vegetative cover needed for grazing and fuelwood (Laurence and Williamson, 2001). In Africa, droughts can have severe impacts on livestock. Table 2 illustrates how droughts increased livestock mortality in selected African countries between 1980 and 1999.

Storage, processing and distribution: Food production varies spatially, so food needs to be distributed between regions. The major agricultural production regions are characterized by relatively stable climatic conditions, but many food-insecure regions have highly variable climates. The main grain production regions have a largely continental climate, with dry or at least cold weather conditions during harvest time, which allows the bulk handling of harvested grain without special infrastructure for protection or immediate treatment.

TABLE 2
Impacts of droughts on livestock numbers in selected African countries, 1981 to 1999

Date	Location	Livestock losses	Source
1981–1984	Botswana	20 percent of national herd	FAO, 1984 cited in Toulmin, 1986
1982–1984	Niger	62 percent of national cattle herd	Toulmin, 1986
1983–1984	Ethiopia (Borana Plateau)	45–90 percent of calves, 45 percent of cows, 22 percent of mature males	Coppock, 1994
1991	Northern Kenya	28 percent of cattle; 18 percent of sheep and goats	Surtech, 1993 cited in Barton and Morton, 2001
1991–1993	Ethiopia (Borana)	42 percent of cattle	Dest a and Coppock, 2002
1993	Namibia	22 percent of cattle; 41 percent of goats and sheep	Devereux and Tapscott, 1995
1995–1997	Greater Horn of Africa (average of 9 pastoral areas)	20 percent of cattle; 20 percent of sheep and goats	Ndikumana et al., 2000
1995–1997	Southern Ethiopia	46 percent of cattle; 41 percent of sheep and goats	Ndikumana et al., 2000
1998–1999	Ethiopia (Borana)	62 percent of cattle	Shibru, 2001 cited in Dest a and Coppock, 2002

Source: IPCC, 2007a.

Depending on the prevailing temperature regime, however, a change in climatic conditions through increased temperatures or unstable, moist weather conditions could result in grain being harvested with more than the 12 to 14 percent moisture required for stable storage. Because of the amounts of grain and general lack of drying facilities in these regions, this could create hazards for food safety, or even cause complete crop losses, resulting from contamination with microorganisms and their metabolic products. It could lead to a rise in food prices if stockists have to invest in new storage technologies to avoid the problem.

Distribution depends on the reliability of import capacity, the presence of food stocks and – when necessary – access to food aid (Maxwell and Slater, 2003). These factors in turn often depend on the ability to store food. Storage is affected by strategies at the national level and by physical infrastructure at the local level. Transport infrastructure limits food distribution in many developing countries. Where infrastructure is affected by climate, through either heat stress on roads or increased frequency of flood events that destroy infrastructure, there are impacts on food distribution, influencing people's access to markets to sell or purchase food (Abdulai and CroleRees, 2001).

Exchange of food takes place at all levels – individual, household, community, regional, national and global. At the lowest levels, exchanges usually take the form of reciprocal hospitality, gift-giving or barter, and serve as an important mechanism for coping with supply fluctuations. If changing climatic conditions bring about trend declines in local production, the capacity of affected households to engage in these traditional forms of exchange is likely to decline.

Trade remains the main mechanism for exchange in today's global economy. Although most food trade takes place within national borders, global trade is the balancing mechanism that keeps exchange flowing smoothly (Stevens, Devereux and Kennan, 2003). The relatively low cost of ocean compared with overland transport makes it economically advantageous for most countries to rely on international food trade to smooth out fluctuations in domestic food supply. Where trade is heavily regulated, as in southern Africa, farmers' behaviour illustrates this principle. After a food crisis such as that in southern Africa in 2002, even if recovery programmes lead to a bumper harvest of maize, in some countries the maize may not find its way into national grain markets, as announced or anticipated producer prices and market regulations could encourage farmers to channel their surplus outside formal markets (Mano, Isaacson and Dardel, 2003: iv).

FAO projects that the impact of climate change on global crop production will be slight up to 2030. After that year, however, widespread declines in the extent and potential productivity of cropland could occur, with some of the severest impacts likely to be felt in the currently food-insecure areas of sub-Saharan Africa, which have with the least ability to adapt to climate change or to compensate through greater food imports (Fischer *et al.*, 2001, cited in FAO, 2003b: 358).

Although the projections suggest that normal carryover stocks, food aid and international trade should be able to cope with the localized food shortages that are likely to result from crop losses due to severe droughts or floods, this is now being questioned in view of the price boom that the world has experienced since 2006. According to FAO, the global food price index rose by 9 percent in 2006 and by 37 percent in 2007. The price boom has been accompanied by much higher price volatility than in the past, especially in the cereals and oilseeds sectors, reflecting reduced inventories, strong relationships between agricultural commodity and other markets, and the prevalence of greater market uncertainty in general.

This has triggered a widespread concern about food price inflation, which is fuelling debates about the future direction of agricultural commodity prices in importing and exporting countries, be they rich or poor, and giving rise to fears that a world food crisis similar in magnitude to those of the early 1970s and 1980s may be imminent, with little prospect for a quick rebound as the effects of climate change take their toll.

Potential impacts of climate change on food access: Allocation: Food is allocated through markets and non-market distribution mechanisms. Factors that determine whether people will have access to sufficient food through markets are considered in the following section on

affordability. These factors include income-generating capacity, amount of remuneration received for products and goods sold or labour and services rendered, and the ratio of the cost of a minimum daily food basket to the average daily income.

Non-market mechanisms include production for own consumption, food preparation and allocation practices within the household, and public or charitable food distribution schemes. For rural people who produce a substantial part of their own food, climate change impacts on food production may reduce availability to the point that allocation choices have to be made within the household. A family might reduce the daily amount of food consumed equally among all household members, or allocate food preferentially to certain members, often the able-bodied male adults, who are assumed to need it the most to stay fit and continue working to maintain the family.

Non-farming low-income rural and urban households whose incomes fall below the poverty line because of climate change impacts will face similar choices. Urbanization is increasing rapidly worldwide, and a growing proportion of the expanding urban population is poor (Ruel *et al.*, 1998). Allocation issues resulting from climate change are therefore likely to become more and more significant in urban areas over time.

Where urban gardens are available, they provide horticultural produce for home use and local sale, but urban land-use restrictions and the rising cost of water and land restrain their potential for expansion. Urban agriculture has a limited ability to contribute to the welfare of poor people in developing countries because the bulk of their staple food requirements still need to be transported from rural areas (Ellis and Sumberg, 1998).

Political and social power relationships are key factors influencing allocation decisions in times of scarcity. If agricultural production declines and households find alternative livelihood activities, social processes and reciprocal relations in which locally produced food is given to other family members in exchange for their support may change or disappear altogether.

Public and charitable food distribution schemes reallocate food to the most needy, but are subject to public perceptions about who needs help, and social values about what kind of help it is incumbent on more wealthy segments of society to provide. If climate change creates other more urgent claims on public resources, support for food distribution schemes may decline, with consequent increases in the incidence of food insecurity, hunger and famine-related deaths.

Affordability. In many countries, the ratio of the cost of a minimum daily food basket to the average daily income is used as a measure of poverty (World Bank PovertyNet, 2008). When this ratio falls below a certain threshold, it signifies that food is affordable and people are not impoverished; when it exceeds the established threshold, food is not affordable and people are having difficulty obtaining enough to eat. This criterion is an indicator of chronic poverty, and can also be used to determine when people have fallen into temporary food insecurity, owing to reduced food supply and increased prices, to a sudden fall in household income or to both.

Income-generating capacity and the remuneration received for products and goods sold or labour and services rendered are the primary determinants of average daily income. The incomes of all farming households depend on what they obtain from selling some or all of their crops and animals each year. Commercial farmers are usually protected by insurance, but small-scale farmers in developing countries are not, and their incomes can decline sharply if there is a market glut, or if their own crops fail and they have nothing to sell when prices are high.

Most food is not produced by individual households but acquired through buying, trading and borrowing (Du Toit and Ziervogel, 2004). Climate impacts on income-earning opportunities can affect the ability to buy food, and a change in climate or climate extremes may affect the availability of certain food products, which may influence their price. High prices may make certain foods unaffordable and can have an impact on individuals' nutrition and health.

Changes in the demand for seasonal agricultural labour, caused by changes in production practices in response to climate change, can affect income-generating capacity positively or

negatively. Mechanization may decrease the need for seasonal labour in many places, and labour demands are often reduced when crops fail, mostly owing to such factors as drought, flood, frost or pest outbreaks, which can be influenced by climate. On the other hand, some adaptation options increase the demand for seasonal agricultural labour.

Local food prices in most parts of the world are strongly influenced by global market conditions, but there may be short-term fluctuations linked to variation in national yields, which are influenced by climate, among other factors. An increase in food prices has a real income effect, with low-income households often suffering most, as they tend to devote larger shares of their incomes to food than higher-income households do (Thomsen and Metz, 1998).

When they cannot afford food, households adjust by eating less of their preferred foods or reducing total quantities consumed as food prices increase. Given the growing number of people who depend on the market for their food supply, food prices are critical to consumers' food security and must be watched.

Food often travels very long distances (Pretty *et al.*, 2005), and this has implications for costs. Increasing fuel costs could lead to more expensive food and increased food insecurity. The growing market for biofuels is expected to have implications for food security, because crops grown as feedstock for liquid biofuels can replace food crops, which then have to be sourced elsewhere, at higher cost.

Preference: Food preferences determine the kinds of food households will attempt to obtain. Changing climatic conditions may affect both the physical and the economic availability of certain preferred food items, which might make it impossible to meet some preferences. Changes in availability and relative prices for major food items may result in people either changing their food basket, or spending a greater percentage of their income on food when prices of preferred food items increase.

In southern Africa, for example, many households eat maize as the staple crop, but when there is less rainfall, sorghum fares better, and people could consume more of it. Many people prefer maize to sorghum, however, so continue to plant maize despite poor yields, and would rather buy maize than eat sorghum, when necessary.

The extent to which food preferences change in response to changes in the relative prices of grain-fed beef compared with other sources of animal protein will be an important determinant of food security in the medium term. Increased prices for grain-fed beef are foreseeable, because of the increasing competition for land for intensive feedgrain production, the increasing scarcity of water and rising fuel costs (FAO, 2007c). If preferences shift to other sources of animal protein, the livestock sector's demands on resources that are likely to be under stress as a consequence of climate change may be contained. If not, continued growth in demand for grain-fed beef, from wealthier segments of the world's population, could trigger across-the-board increases in food prices, which would have serious adverse impacts on food security for urban and rural poor.

Potential impacts of climate change on food utilization: *Nutritional value:* Food insecurity is usually associated with malnutrition, because the diets of people who are unable to satisfy all of their food needs usually contain a high proportion of staple foods and lack the variety needed to satisfy nutritional requirements. Declines in the availability of wild foods, and limits on small-scale horticultural production due to scarcity of water or labour resulting from climate change could affect nutritional status adversely. In general, however, the main impact of climate change on nutrition is likely to be felt indirectly, through its effects on income and capacity to purchase a diversity of foods.

The physiological utilization of foods consumed also affects nutritional status, and this – in turn – is affected by illness. Climate change will cause new patterns of pests and diseases to emerge, affecting plants, animals and humans, and posing new risks for food security, food safety and human health. Increased incidence of water-borne diseases in flood-prone areas, changes in vectors for climate-responsive pests and diseases, and emergence of new diseases could affect both the food chain and people's physiological capacity to obtain necessary nutrients from the foods consumed. Vector changes are a virtual certainty for pests and

diseases that flourish only at specific temperatures and under specific humidity and irrigation management regimes. These will expose crops, livestock, fish and humans to new risks to which they have not yet adapted. They will also place new pressures on care givers within the home, who are often women, and will challenge health care institutions to respond to new parameters.

Malaria in particular is expected to change its distribution as a result of climate change (IPCC, 2007a). In coastal areas, more people may be exposed to vector- and water-borne diseases through flooding linked to sea-level rise. Health risks can also be linked to changes in diseases from either increased or decreased precipitation, lowering people's capacity to utilize food effectively and often resulting in the need for improved nutritional intake (IPCC, 2007a).

Where vector changes for pests and diseases can be predicted, varieties and breeds that are resistant to the likely new arrivals can be introduced as an adaptive measure. A recent upsurge in the appearance of new viruses may also be climate-related, although this link is not certain. Viruses such as avian flu, ebola, HIV/AIDS and SARS have various implications for food security, including risk to the livelihoods of small-scale poultry operations in the case of avian flu, and the extra nutritional requirements of affected people in the case of HIV-AIDS.

The social and cultural values of foods consumed will also be affected by the availability and affordability of food. The social values of foods are important determinants of food preferences, with foods that are accorded high value being preferred, and those accorded low value being avoided. In many traditional cultures, feasts involving the preparation of specific foods mark important seasonal occasions, rites of passage and celebratory events.

The increased cost or absolute unavailability of these foods could force cultures to abandon their traditional practices, with unforeseeable secondary impacts on the cohesiveness and sustainability of the cultures themselves. In many cultures, the reciprocal giving of gifts or sharing of food is common. It is often regarded as a social obligation to feed guests, even when they have dropped in unexpectedly. In conditions of chronic food scarcity, households' ability to honour these obligations is breaking down, and this trend is likely to be reinforced in locations where the impacts of climate change contribute to increasing incidence of food shortages.

Food safety may be compromised in various ways. Increasing temperature may cause food quality to deteriorate, unless there is increased investment in cooling and refrigeration equipment or more reliance on rapid processing of perishable foods to extend their shelf-life. Decreased water availability has implications for food processing and preparation practices, particularly in the subtropics, where a switch to dry processing and cooking methods may be required. Changes in land use, driven by changes in precipitation or increased temperatures, will alter how people spend their time. In some areas, children might have to prepare food, while parents work in the field, increasing the risk that good hygiene practices may not be followed.

Potential impacts of climate change on food system stability: *Stability of supply:* Many crops have annual cycles, and yields fluctuate with climate variability, particularly rainfall and temperature. Maintaining the continuity of food supply when production is seasonal is therefore challenging. Droughts and floods are a particular threat to food stability and could bring about both chronic and transitory food insecurity. Both are expected to become more frequent, more intense and less predictable as a consequence of climate change. In rural areas that depend on rainfed agriculture for an important part of their local food supply, changes in the amount and timing of rainfall within the season and an increase in weather variability are likely to aggravate the precariousness of local food systems.

Stability of access: As already noted, the affordability of food is determined by the relationship between household income and the cost of a typical food basket. Global food markets may exhibit greater price volatility, jeopardizing the stability of returns to farmers and the access to purchased food of both farming and non-farming poor people.

Food emergencies: Increasing instability of supply, attributable to the consequences of climate change, will most likely lead to increases in the frequency and magnitude of food

emergencies with which the global food system is ill-equipped to cope. An increase in human conflict, caused in part by migration and resource competition attributable to changing climatic conditions, would also be destabilizing for food systems at all levels. Climate change might exacerbate conflict in numerous ways, although links between climate change and conflict should be presented with care. Increasing incidence of drought may force people to migrate from one area to another, giving rise to conflict over access to resources in the receiving area. Resource scarcity can also trigger conflict and could be driven by global environmental change.

Grain reserves are used in emergency-prone areas to compensate for crop losses and support food relief programmes for displaced people and refugees. Higher temperatures and humidity associated with climate change may require increased expenditure to preserve stored grain, which will limit countries' ability to maintain reserves of sufficient size to respond adequately to large-scale natural or human-incurred disasters.

Livelihood vulnerability

The livelihoods perspective is often used as a means of investigating a range of sectors and how they affect individual livelihoods. Viewing food security from a livelihoods perspective makes it possible to assess the different components of food security holistically at the household level.

Livelihoods can be defined as the bundle of different types of assets, abilities and activities that enable a person or household to survive (FAO, 2003a). These assets include physical assets such as infrastructure and household items; financial assets such as stocks of money, savings and pensions; natural assets such as natural resources; social assets, which are based on the cohesiveness of people and societies; and human assets, which depend on the status of individuals and can involve education and skill. These assets change over time and are different for different households and communities. The amounts of these assets that a household or community possesses or can easily gain access to are key determinants of sustainability and resilience.

Marginal groups include those with few resources and little access to power, which can constrain people's capacity to adapt to climate changes that could have a negative impact on them. It is usually people's few productive assets that are at greatest risk from the impacts of climate change. Physical assets can be damaged or destroyed, financial losses can be incurred, natural assets can be degraded and social assets can be undermined.

The change in seasonality attributed to climate change can lead to certain food products becoming more scarce at certain times of year. Such seasonal variations in food supply, along with vulnerabilities to flooding and fire, can make livelihoods more vulnerable at certain times of the year. Although these impacts might appear indirect, they are important because many marginal livelihood groups are close to the poverty margin, and food is a key component of their existence.

Agriculture is often at the heart of the livelihood strategies of these marginal groups; agricultural employment, whether farming their own land or working on that of others, is key to their survival. In many areas, the challenges of rural livelihoods drive urban migration. As the number of poor and vulnerable people living in urban slums grows, the availability of non-farm employment opportunities and the access of urban dwellers to adequate food from the market will become increasingly important drivers of food security.

A recent International Labour Organization study (ILO, 2005) suggests that there will be significant differences between middle- and low-income countries in the ways in which climate change affects agriculture-based livelihoods. Table 3 shows regional differences in the share of agriculture in total employment and changes in these shares over the past decade. In middle-income countries, a commercialization process appears to be bringing about declines in unpaid on-farm family labour and increases in wage employment.

TABLE 3
Employment in agriculture as share of total employment, by region

Region	1996	2006
Developed economies and EU	6.2	4.2
Central and southeastern Europe (non-EU) and CIS	27.2	20.3
East Asia	48.5	40.9
Southeast Asia and the Pacific	51.0	45.4
South Asia	59.7	49.4
Latin America and the Caribbean	23.1	19.6
North Africa	36.5	34.0
Sub-Saharan Africa	74.4	65.9
Middle East	21.2	18.1
World	41.9	36.1

EU = European Union.

CIS = Commonwealth of Independent States.

Source: ILO, 2007.

In low-income countries, however, wage work is declining, while self-cultivation and mixed contractual forms increase. This means that while the adverse impacts of climate change on agricultural production in middle-income countries are more likely to be felt as loss of employment opportunities, reduction in wage earnings and loss of purchasing power for agricultural wage workers, in low-income countries they are likely to be felt as declines in own production for household consumption by smallholder farming households.

Livelihood groups that warrant special attention in the context of climate change include:³

- low-income groups in drought- and flood-prone areas with poor food distribution infrastructure and limited access to emergency response;
- low- to middle-income groups in flood-prone areas that may lose homes, stored food, personal possessions and means of obtaining their livelihood, particularly when water rises very quickly and with great force, as in sea surges or flash floods;
- farmers whose land becomes submerged or damaged by sea-level rise or saltwater intrusions;
- producers of crops that may not be sustainable under changing temperature and rainfall regimes;
- producers of crops at risk from high winds;
- poor livestock keepers in drylands where changes in rainfall patterns will affect forage availability and quality;
- managers of forest ecosystems that provide forest products and environmental services;
- fishers whose infrastructure for fishing activities, such as port and landing facilities, storage facilities, fish ponds and processing areas, becomes submerged or damaged by sea-level rise, flooding or extreme weather events;
- fishing communities that depend heavily on coral reefs for food and protection from natural disasters;
- fishers/aquafarmers who suffer diminishing catches from shifts in fish distribution and the productivity of aquatic ecosystems, caused by changes in ocean currents or increased discharge of freshwater into oceans.

Within these livelihood groups, producers at different points of the food chain, such as fishers versus fish cleaners, would have different vulnerabilities and access to coping

³ This expanded list has been developed from a shorter list contained in FAO, 2003b: 368.

mechanisms. Producers of different types of crops, such as crops for sale versus those for home consumption, may face different risks and management options (e.g., access to irrigation water or seeds). Gender and age differences will also affect the degree of risk faced by individuals within a vulnerable group.

Agriculture-based livelihood systems that are already vulnerable to climate change face immediate risk of increased crop failure, loss of livestock and fish stocks, increasing water scarcities and destruction of productive assets. These systems include small-scale rainfed farming, pastoralism, inland and coastal fishing/aquaculture communities, and forest-based systems. Rural people inhabiting coasts, floodplains, mountains, drylands and the Arctic are most at risk. The urban poor, particularly in coastal cities and floodplain settlements, also face increasing risks. Among those at risk, pre-existing socio-economic discriminations are likely to be aggravated, causing nutritional status to deteriorate among women, young children and elderly, ill and disabled people.

Over time, the geographic distribution of risk and vulnerability is likely to shift. Future vulnerability is likely to affect not only farmers, fishers, herders and forest-dependent people, but also low-income city dwellers, in both developed and developing countries, whose sources of livelihood and access to food may be at risk from the impact of extreme weather events and variable food prices, and who lack adequate insurance coverage. Some agriculture-based livelihoods may benefit from the effects of climate change, while others will be undermined.

The livelihood status of agricultural workers will also change if centres of agricultural production shift or methods of production become less labour-intensive in response to climate change. All wage earners face new health risks that could cause declines in their productivity and earning power. Climate change will also affect people differently depending on such factors as landownership, asset holdings, marketable skills, gender, age and health status.

Fishing is frequently integral to mixed livelihood strategies, in which people take advantage of seasonal stock availability or resort to fishing when other forms of food production and income generation fall short. Fishing is often related to extreme poverty and may serve as a vital safety net for people with limited livelihood alternatives and extreme vulnerability to changes in their environment. However, the viability of fishing as a sustainable livelihood is threatened by climate change.

Fishing communities that depend on inland fishery resources are likely to be particularly vulnerable to climate change; access to water resources and arrangements with other sectors for sharing and reuse will become a key to future sustainability. Climate change is also likely to have substantial and far-reaching impacts on coastal fisheries and fishing communities. Major physical impacts of climate change on the marine system will be changes in ocean currents, a rise in average temperature, sharpening of gradient structures, and large and rapid increases of freshwater discharge; these often trigger an increase in chemical nutrients, typically compounds containing nitrogen or phosphorus, resulting in lack of oxygen and severe reductions in water quality and in fish and other animal populations (eutrophication).

Biological responses to these changes are expected to be ratchet-like, i.e., once a threshold is reached, the situation shifts from one phase to another. Fishing is essentially a hunting activity, so its success or failure depends heavily on the vagaries of nature. Climate change is creating more anomalies, both failures and bonanzas, among multiple species, as well as drastic shifts in the areas where small, migrating fish are found. Coastal peoples and communities that depend on fishing in locations where a rise in sea level makes relocation inevitable will require extra support, as they must not only migrate, but in many instances also find new, unfamiliar ways of earning a living (FAO, 2007b).

All IPCC emission scenarios assume that economies for the world as a whole will continue to grow, albeit at different rates and sometimes with significant regional differences, depending on the scenario (IPCC, 2000). However, it is also possible that the impact of climate change will actually curtail economic growth.

If global financial markets are not able to keep pace with continued high losses from extreme weather events, and large numbers of individual households in developed and emerging developing countries experience uncompensated declines in the value of their personal assets and income-generating capacity, global economic recession and a deterioration in the food security situation at all levels is also a possibility, putting everybody at risk.

2. PROTECTING FOOD SECURITY THROUGH ADAPTATION TO CLIMATE CHANGE

FAO'S STRATEGIC APPROACH

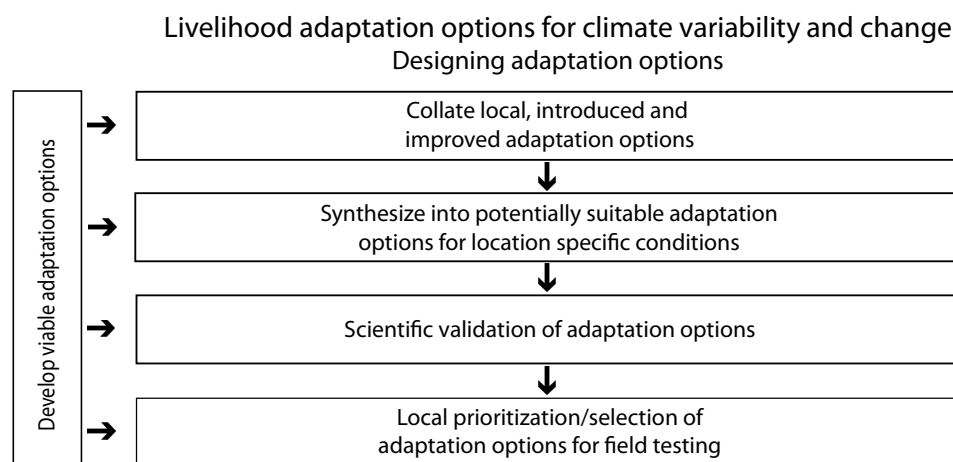
IPCC defines adaptation as “Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC Online, 2001). It involves learning to manage new risks and strengthening resilience in the face of change. Risk management focuses on preparing to deal with shocks. Change management focuses on modifying behaviours over the medium-to-long term to avoid disruptions or declines in global and local food supplies due to changes in temperature and precipitation regimes, and to protect ecosystems through providing environmental services. The following practices for adapting to climate change in the food and agriculture sector are described in this chapter:

- Protecting local food supplies, assets and livelihoods against the effects of increasing weather variability and increased frequency and intensity of extreme events, through:
 - general risk management;
 - management of risks specific to different ecosystems – marine, coastal, inland water and floodplain, forest, dryland, island, mountain, polar, cultivated;
 - research and dissemination of crop varieties and breeds adapted to changing climatic conditions;
 - introducing tree crops to provide food, fodder and energy and enhance cash incomes.
- Avoiding disruptions or declines in global and local food supplies due to changes in temperature and precipitation regimes, through:
 - more efficient agricultural water management in general;
 - more efficient management of irrigation water on rice paddies;
 - improved management of cultivated land;
 - improved livestock management;
 - use of new, more energy-efficient technologies by agro-industries.
- Protecting ecosystems, through provision of such environmental services as:
 - use of degraded or marginal lands for productive planted forests or other cellulose biomass for alternative fuels;
 - Clean Development Mechanism (CDM) carbon sink tree plantings;
 - watershed protection;
 - prevention of land degradation;
 - protection of coastal areas from cyclones and other coastal hazards;
 - preservation of mangroves and their contribution to coastal fisheries;
 - biodiversity conservation.

Figures 6 and 7 set out the steps recommended by FAO for selecting adaptation options and designing strategies to operationalize them. FAO has defined the following elements in a framework for climate change adaptation (FAO, 2007a):

- legal and institutional elements;
- policy and planning elements;
- livelihood elements;
- cropping, livestock, forestry, fisheries and integrated farming system elements;
- ecosystem elements;
- linking climate change adaptation processes with technologies that promote carbon sequestration and substitutes for fossil fuels.

Figure 6. Steps for selecting adaptation options



Source: FAO, 2006a.

FAO stresses the importance of addressing impacts and responses across sectors and scales and of establishing institutional mechanisms for upscaling adaptation measures. Figure 8 illustrates the range of tools available for obtaining information about current and future climate impacts at different scales – from climate forecasts for farm-level decision-making to impact assessments based on climate change scenarios. Figure 9 shows how these tools can be used to inform multistakeholder coordination processes that seek to mainstream climate change adaptation into sustainable development approaches.

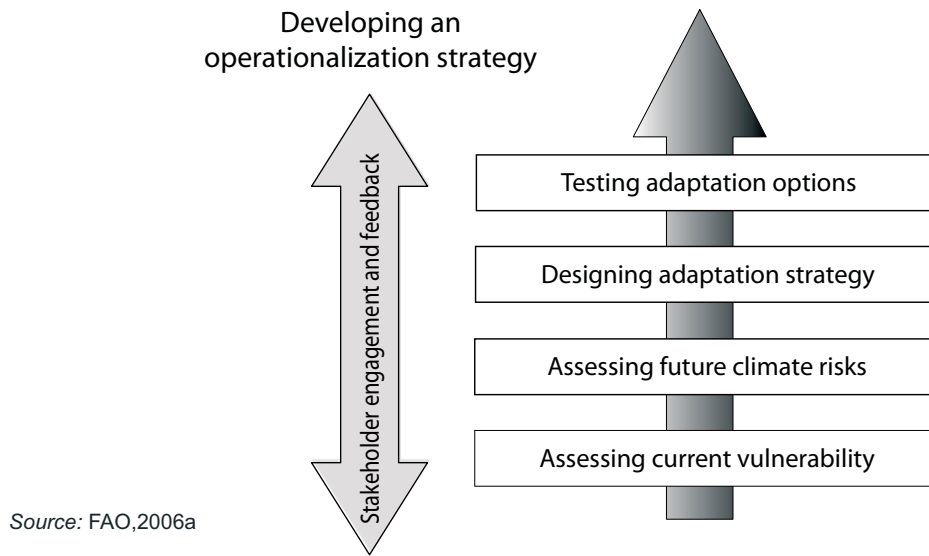
LIVING WITH UNCERTAINTY AND MANAGING NEW RISKS

Adapting to climate change involves managing risk by improving the quality of information and its use, providing insurance against climate change risk, adopting known good practices to strengthen the resilience of vulnerable livelihood systems, and finding new institutional and technological solutions.

People in the insurance business make a clear distinction between certain and uncertain risks: a risk is certain if the probabilities of specific states occurring in the future are precisely known, and uncertain if these probabilities are not precisely known (Kunreuther and Michel-Kerjan, 2006).

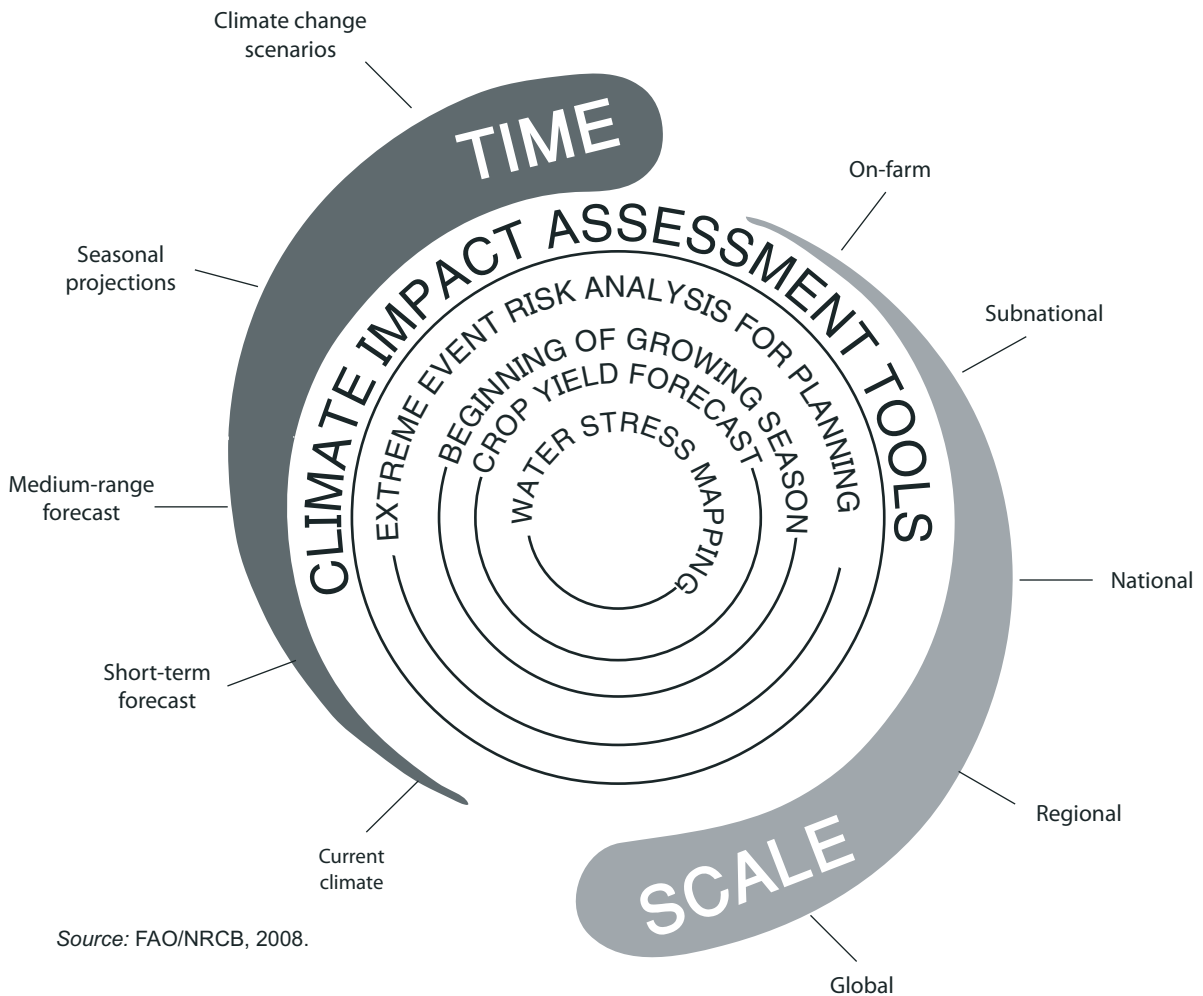
Figure 7. Steps for designing a strategy to implement the adaptation options selected

Livelihood adaptation options for climate variability and change



Source: FAO, 2006a

Figure 8. Methods and tools for assessing climate change impacts for different time periods and at various scales



Source: FAO/NRCB, 2008.

In the field of climate change, there is still much uncertainty about the probabilities of various possible changes occurring in specific locations. This can be dealt with by investing in improved information to reduce the degree of local uncertainty, or by spreading the uncertain risk through some form of global insurance scheme.

Knowledge about the future will always be uncertain, but the current high degree of uncertainty about potential local impacts of climate change could be reduced through improving the science. Other priorities include recognizing the need for decision-making in the face of uncertainty, bridging the gap between scientific and traditional perceptions of climate change, and promoting the adoption of practices that are consistent with the precautionary approach and adaptive management principles and that will strengthen the resilience and sustainability of vulnerable livelihood systems.

Climate-related risks affect everybody in one way or another, so innovative insurance schemes such as a global reinsurance fund for climate change damage, or expanded local coverage of weather-based insurance are likely to be needed. No risk management policy or programme will work unless those at risk feel that it addresses their needs, so adequate provisions must be made to allow the most vulnerable to participate in deciding which actions to take to strengthen their resilience.

The state of the art for these approaches and the implications of each for protecting food security in the face of climate change are explored in the following sections.

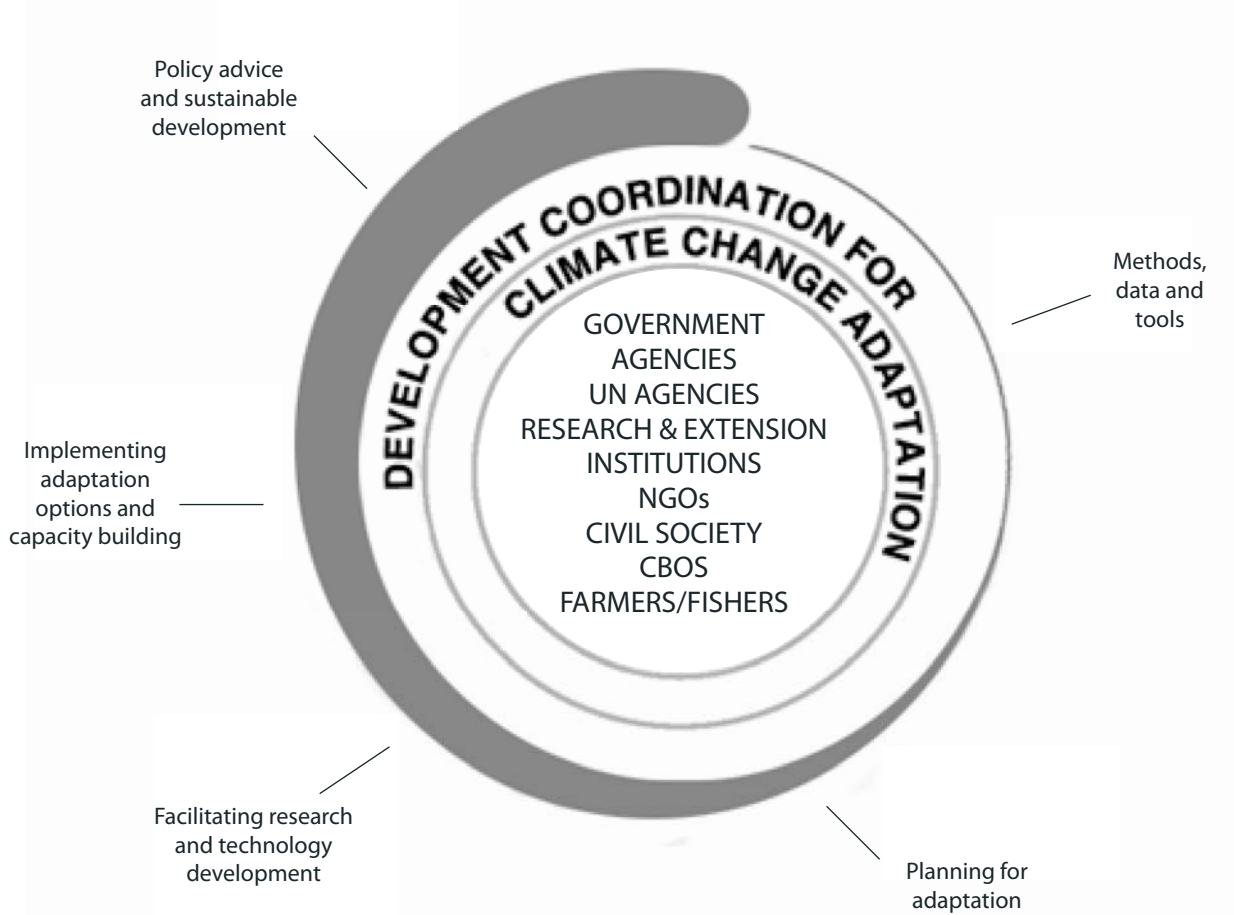
Improving the quality of information and its use

Information is a crucial tool in decision-making, particularly in the context of climate change where there is high uncertainty. The type of information, its source(s), to whom it is targeted, and how it is to be used are important elements in determining the impact and response that information may generate. Good information about uncertainties and risks can make the difference between resilience and collapse for an affected livelihood system or ecosystem, as in the case of climate change.

The rest of this section explores vulnerable people's needs for information about climate change, how best to satisfy these, the current state of the art regarding weather and climate monitoring, and priorities for improving scientific understanding of climate change.

Reaching vulnerable rural people with useful information: Information generation and dissemination are political in that they involve the power of one person's perception to influence that of another. This is illustrated by Turton's (2001) example of how hidden value judgements underlie the dominant perception of climate change. He points out that the concept of climate changes is commonly understood to mean not only that a change is occurring but also that there is need for some sort of response.

Figure 9. Multistakeholder processes for mainstreaming climate change adaptation into sustainable development approaches



Source: FAO/NRCB, 2008.

This perception is not universally shared, however. Although it has been scientifically demonstrated that climate is changing worldwide, not everyone has the same understanding of, or places the same value on, the significance of scientific results. For example, the climate data made available to rural farmers often do not refer to local knowledge on climate and agriculture, which leads to resentment towards scientific data, or the abandonment of information that may have been useful. Despite the increasing variability in climatic conditions, many rural farmers still predict climate using traditional methods, which may not be capable of detecting longer-term trends.

One implication of increasing variability and uncertainty about future weather patterns is that traditional knowledge will not necessarily be adapted to the new climatic conditions. There will therefore need to be more reliance on scientific knowledge and assessment of viable options, and bridging the gap between scientific and traditional perceptions of climate change will be fundamental for successful adaptation.

Ethnographic research suggests that the current mismatch between the understanding and interpretations of climate by farmers who rely on traditional knowledge and the understanding and interpretations of the scientific research community constitutes an important challenge for climate adaptation work that aims to provide climate information for a range of decision-makers, with differing education and resource levels (Roncoli, 2006). Participatory approaches to climate predictions have become a popular way of eliciting farmers' understanding of climate and climate information and determining how to improve the relation between these perspectives and scientific forecasts. Roncoli argues that participatory technology development and collaborative learning would be promoted by a better understanding of how scientists' cultural models may (or may not) be affected by interaction with farmers and other stakeholders, including other scientists, funding agencies, policy-makers and the media (Roncoli, 2006).

The benefits of applying gender-sensitive participatory approaches for using information to avert loss of property and life during cyclones are illustrated in Box 1 with the case of Bangladesh.

Another important issue is the availability of climate data for rural farmers who are often inaccessible to field site educators. When information is available and farmers show interest in it, institutional structures need to be in place to disseminate the information to farmers in remote rural areas, otherwise the only farmers to benefit will be those who already have the advantages of being in cooperatives and having the necessary disposable resources to act according to the information. Successful adaptation to climate change depends on reaching the most vulnerable, who may not have easy access to and appropriate understanding of existing climate information.

Box 1. Benefits of women's participation in cyclone preparedness in Bangladesh

An International Federation of Red Cross and Red Crescent Societies (IFRC-RCS) case study illustrates the importance of gender-sensitive participation in decision-making about cyclone preparedness. This study of a community-based cyclone preparedness programme in Bangladesh found that the highest proportions of cyclone victims came from sites where women were not involved in the village-level disaster preparedness committees responsible for maintaining cyclone shelters and transmitting warnings. In Cox's Bazaar in east Bangladesh, women are fully involved in disaster preparedness and support activities (education, reproductive health, self-help groups, and small and medium-sized enterprises), and there have been enormous reductions in the numbers of women killed or affected by cyclones.

Source: IFRC-RCS, 2002, cited in Lambrou and Laub, 2004.

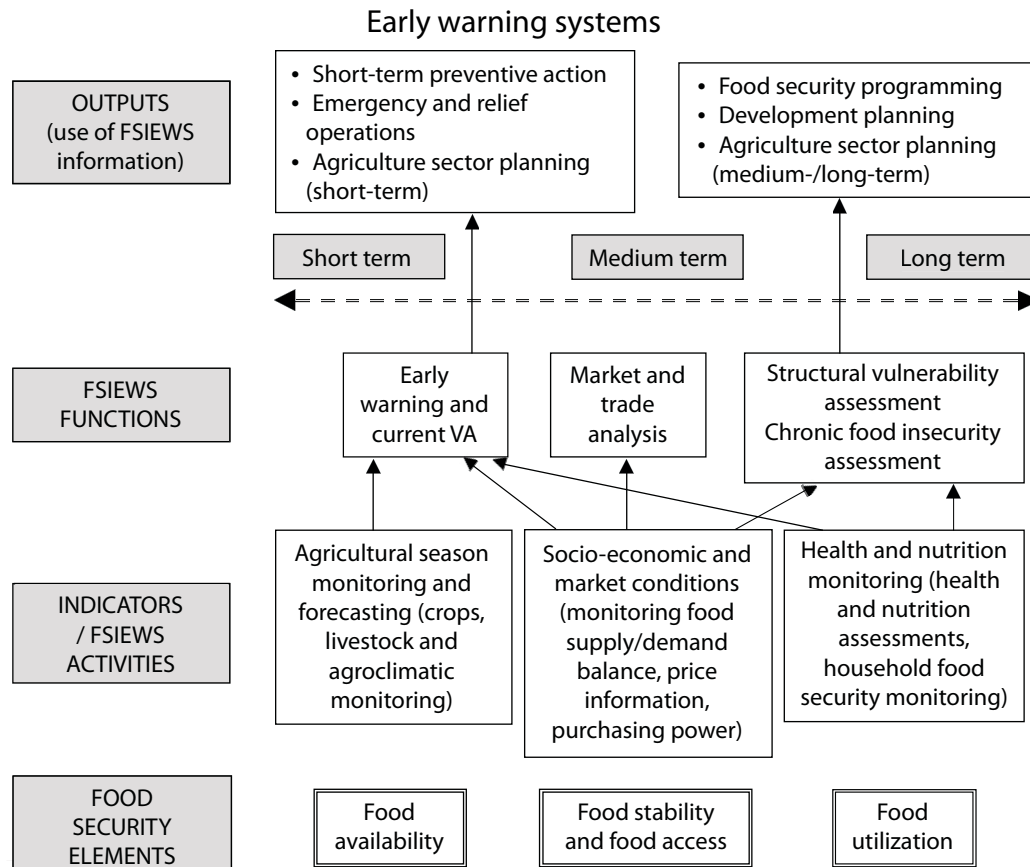
Monitoring weather and improving scientific understanding of climate change: Scientific work in response to the challenge of climate change includes development of tools and technologies for improved monitoring of weather and climate, incorporation of climate change variables and assessments into food security information and early warning systems, and observation and modelling of climate impacts on rural livelihoods. As already noted, it is critical that information generated by early warning systems and climate change models be packaged in ways that are accessible to vulnerable people, so it can assist them in making sound choices about how to adapt to climate change and other stressors. All actors in the food system need access to reliable information about climate change and its potential impacts, to avoid breakdowns in the system and adverse food security outcomes.

Figure 10 depicts FAO’s view of the short-, medium- and long-term functions of a Food Security Information and Early Warning System (FSIEWS) that covers the information needs of all components of the food system and addresses all aspects of food security. Typically, these systems have focused on monitoring current weather and using this information, together with other socio-economic data, to forecast the adequacy of food supplies and assess food aid needs in developing countries with high risk of drought.

Time series data generated by FSIEWS are increasingly used to support longer-term policy and planning work. Once improved methods and tools for monitoring climate change variables and assessing their significance at the local level become more widely available, it is expected that these will be adopted by FSIEWS.

At present, the main users of FSIEWS are the national authorities and non-governmental organizations (NGOs) that implement safety net programmes covering the basic needs of people who are experiencing either temporary or chronic food insecurity. One of the challenges for these information systems is to develop channels for disseminating relevant and usable information directly to communities that are experiencing climate change and need to understand what is happening in order to adapt in constructive ways.

Figure 10. Providing timely weather information for all actors in the food system



Source: FAO, 2000b.

An important gap is the lack of weather stations in many rural parts of the developing world, particularly in Africa, where climate change is expected to have important local impacts. These impacts cannot be assessed without reliable weather data, and without such assessments, there is no solid basis for recommending adaptation options. Increased investment in regular and timely collection of weather data in Africa should therefore be accorded very high priority for protecting food security in the face of climate change in that region.

Adequate preparedness for foreseeable natural disasters is an important adaptation strategy that is relevant in many parts of the globe, and not only in Africa, where FSIEWS are most commonly found. Other types of monitoring systems give advance warning of sudden-onset events such as high winds and storm surges associated with hurricanes, cyclones, typhoons and tornadoes; risk of flooding and landslides after heavy rains; and heat waves and increased wildfire risk. These warnings enable people to protect property and stock appropriate supplies or move to safe shelters before the forecasted event.

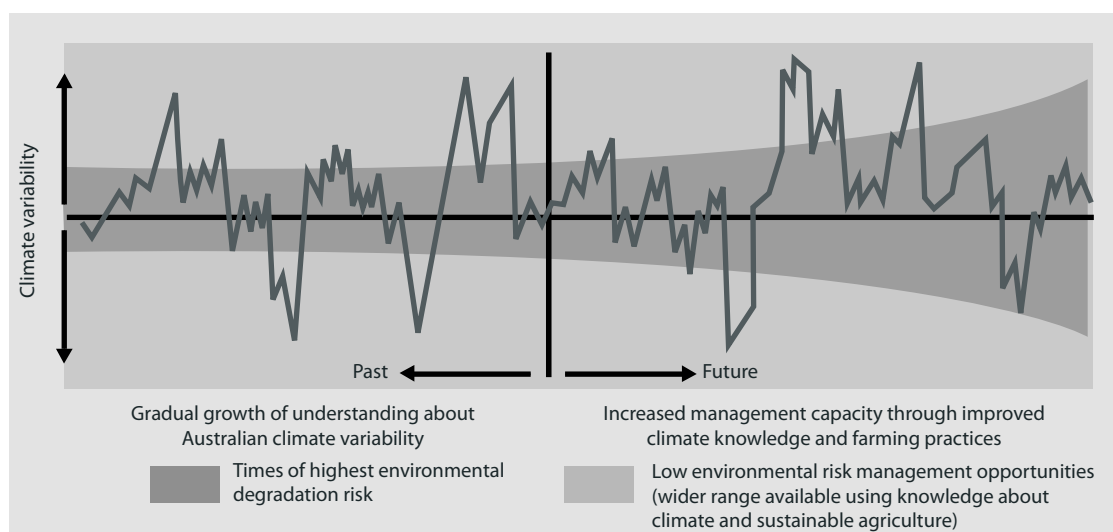
Among FAO's efforts to improve the quality of weather and climate information and its use are:

- maintaining up-to-date agrometeorological data;
- developing methods and tools for assessing extreme weather impacts and guiding adaptation;
- agro-ecological zoning for impact modelling and vulnerability assessment;
- land-cover mapping;
- global assessments, such as of crops and forest resources;
- tailoring information to the perceptions and needs of rural households and providing gender-sensitive guidance for adaptive livelihood development.

For rural people who depend on the natural resource base for their livelihoods, protecting food security in the face of climate change will require improved management of the environment, especially during climate extremes, which bring the greatest risk of degradation of the environment and threat to the sustainability of the livelihood systems that depend on it.

Figure 11 uses data from Australia to illustrate how improved climate understanding and forecast skill may increase the range of low-risk conditions, and enhance the capacity to manage high-risk periods.

Figure 11. Benefits of improved climate information for reducing risk in Australia



Source: Australian Bureau of Meteorology, 2006.

Promoting insurance schemes for climate change risk

In 2007, the World Economic Forum outlined the five core areas of global risk as economic, environmental, geopolitical, societal and technological. Within these, climate change is seen as one of the defining challenges for the twenty-first century, as it is a global risk with impacts far beyond the environment (World Economic Forum, 2007). The insurance industry is among the economic sectors that are already experiencing adverse impacts of climate change.

Wealthy countries depend heavily on the private insurance industry to protect their citizens against natural disasters. According to a recent report, these countries account for 93 percent of the global insurance market (Hamilton, 2004). This market is increasingly strained as it tries to respond to astronomical increases in claims related to the impacts of extreme weather events in North America and Europe.

In the United States, a 2005 study on the availability and affordability of climate risk insurance found that weather-related losses were growing ten times faster than both premiums and the overall economy, and more than ten times faster than the population; it also noted that this trend would be compounded by continued settlement in high-risk areas (Mills, Roth and Lecomte, 2005).

Higher losses are already leading the insurance industry to charge higher premiums, raise deductibles, lower maximum coverage limits, and restrict the types of natural disasters or catastrophic events that can be insured. The authors conclude that, "Given the critical role that insurance plays in the US and global economy, reduced access to affordable insurance would have profound impacts on both consumers and businesses" (Mills, Roth and Lacomte, 2005). Although this statement refers to the United States economy, it is equally applicable everywhere in the world, and the implications for future food security are potentially very serious.

Typical forms of insurance coverage for weather- and climate-related events (e.g., floods, windstorms, thunderstorms, hailstorms, ice storms, wildfires, droughts, heat waves, lightning strikes, subsidence damage and coastal erosion) include coverage for property damage, business interruptions, and loss of life or limb. If climate stresses cause the insurance industry in the developed world to stop providing such coverage when natural disasters are involved, many previously food-secure people will be exposed to significant uncompensated losses of property and means of livelihood, which could plunge them into a state of vulnerability that has previously been associated mainly with developing countries.

Increasing climate stresses and the retreat of the private sector insurance industry from covering losses caused by catastrophic natural events will lead to increasing calls for national and local governments to step in. Most governments already operate public sector insurance programmes for major risks if there is no private sector coverage, such as for crop loss, flood and earthquake damage; they also typically pay for disaster preparedness and recovery operations. These programmes are also experiencing increasing losses, however, so the financial burden of maintaining the current social safety net protection in the face of additional demands generated by the impacts of climate change may be beyond what many governments in developed countries can afford.

Because there is little private sector insurance in developing countries, other approaches to insurance have evolved to accommodate low-income groups. Informal, locally based micro-insurance initiatives offer a popular alternative because the premiums are low and the rules are often less stringent than for commercial insurance (Hashemi and Foose, 2007). Public-private partnerships are also increasingly popular, and often involve the government coordinating and/or adding to premium payments made by those to be insured. An example from Ethiopia is given in Box 2.

As climate-related risks affect everybody, insurance against the consequences of catastrophic weather events needs to be globalized, and costs minimized through action to mitigate climate change. The World Economic Forum suggests the following two global approaches for addressing climate risk (World Economic Forum, 2007):

Box 2. Drought insurance in Ethiopia

In Ethiopia, contingency funding was secured through a private sector reinsurance company, AXA Re, to experiment with a new approach to weather insurance whereby vulnerable households sign financial contracts obligating them to pay an insurance premium prior to each growing season. The contracts entitle them to receive insurance payouts whenever abnormally low rainfall cause the value of crops in the ground to fall below a specified trigger. The scheme's success depends on the ability of local weather stations to track the development of the growing season accurately, so capacity building for the meteorological service was part of the initial experiment. Payout funds from this insurance scheme help vulnerable households when crops fail because of drought, and reduce their dependence on emergency relief.

Source: Hess, 2006.

- Designating country risk officers – analogous to chief risk officers in the corporate world – to serve as focal points for managing a portfolio of risks across disparate interests, setting national prioritization of risk and allowing governments to engage in the necessary actions to begin managing global risks rather than coping with them.
- Creating cooperation among relevant governments and companies around different global risks – “coalitions of the willing” – to make risk mitigation a process of gradually expanding alliances rather than a proposition requiring permanent consensus.

Innovative insurance schemes, such as a global reinsurance fund for climate change damage or expanded local coverage of weather-based insurance, are likely to be needed (Osgood, 2008).

Developing national risk management policies

It is possible to reduce risks by mainstreaming national risk management policy frameworks within policies and programmes for sustainable development. From a food security perspective, the objective of such frameworks is to protect local food supplies, assets and livelihoods against the effects of increasing weather variability and the increased frequency and intensity of extreme events. Frameworks should include pre-event preparedness, risk mitigating strategies, reliable and timely early warning and response systems, and innovative risk financing instruments to spread residual risks. Elements of such frameworks that are applicable for both rural and urban populations in all ecosystems include effective early warning systems; emergency shelters, provisions and evacuation procedures; and weather-related insurance schemes.

The objectives of managing climate change risk are to: (i) reduce risk exposure; and (ii) reduce negative outcomes. The process entails first risk mapping, which includes identifying areas, populations and livelihoods at risk, followed by analysis of the kinds of risks involved, and estimation of the levels of risk exposure of different areas, groups and livelihoods in terms of their risk absorption capacity and the size and degree of risk, with explicit attention to the gender dimension.

Participatory approaches to assess vulnerability and needs should involve representatives of all community members in a dynamic process of reflection, planning and action that is livelihoods-based and gender-sensitive, and that draws on local knowledge and priorities. Typical components of national risk management policies and programmes include:

- infrastructure investments to protect against asset loss;
- climate information and advisory services for agricultural communities;
- reliable and timely early warning systems;
- rapid emergency response capacity;
- innovative risk financing instruments and insurance schemes to spread residual risks.

To protect local food supplies, assets and livelihoods from the effects of increasing weather variability and increased frequency and intensity of extreme events, adaptation measures will need to respond to a variety of risks, many of which are specific to particular ecosystems.

The Millennium Ecosystem Assessment report (2005) evaluated potential climate change impacts for ten ecosystems: urban, marine, coastal, inland water and floodplain, forest, dryland, island, mountain, polar, and cultivated. The nature of the risks and the affected livelihood groups vary considerably from one ecosystem to another, so adaptation responses have to be tailored to local conditions and needs.

STRENGTHENING RESILIENCE AND MANAGING CHANGE

In addition to risk management, climate change also requires adaptive management that focuses on modifying behaviours over the medium-to-long term to cope with gradual changes in precipitation and temperature regimes. These modifications are likely to concern consumption patterns, health care, food and agricultural production practices, sources and use of energy, and livelihood strategies.

Strengthening resilience for all vulnerable people involves adopting practices that enable them to:

- protect existing livelihood systems;
- diversify their sources of food and income;
- change their livelihood strategies;
- migrate if there is no other option.

Additional action areas that can strengthen resilience of agriculture-based livelihood systems include:

- research and dissemination of crop varieties and breeds adapted to changing climatic conditions;
- effective use of genetic resources;
- promotion of agroforestry, integrated farming systems and adapted forest management practices;
- improved infrastructure for small-scale water capture, storage and use;
- improved soil management practices.

Adjusting consumption and responding to new health risks

Current projections for continued economic growth to 2030 and beyond imply a continued increase in demand for animal protein as average incomes in developing countries rise. This will lead to increased demand for water and, to a lesser extent, land for livestock production. Increased demand, coupled with growing scarcities of water, land and fuel, could bring about increases in food prices, even without climate change.

Additional pressures on water availability, due to climate change, the introduction of mitigation practices that create competition for land, and the attribution of market value to environmental services to mitigate climate change, could also cause significant changes in relative prices for different food items, and an overall increase in the cost of an average food basket for the consumer. Although not foreseen in the projections, current market developments suggest that some of these factors may already be at work in global food markets, driving up prices and increasing the number of people who lack access to an adequate supply of food daily.

Faced with rising prices and increased awareness of the environmental consequences of their food choices, consumers may modify their spending and eating habits. Environmentally

conscious consumers may choose to change their food consumption patterns – relying more on local produce with a lower carbon footprint, and reducing their consumption of grain-fed livestock with large requirements for increasingly scarce land and water resources. Examples of possible changes in food consumption patterns include:

- shift in staple food preferences;
- shift away from grain-fed livestock products;
- increased consumption of new food items;
- reduced consumption of wild foods;
- reduced quantities and/or variety of food consumed.

As well as adjusting consumption patterns to obtain a sufficient quantity of food, it will also be necessary to make adjustments to maintain dietary quality. This could involve:

- protecting biodiversity and exploiting wild foods;
- promoting urban and school gardens;
- increasing use of dry cooking methods to conserve water;
- promoting energy-efficient and hygienic food preparation practices;
- teaching good eating habits to reduce malnutrition and diet-related diseases.

Increased incidence of water-borne diseases in flood-prone areas, change in disease vectors and habitats for existing diseases, and emergence of new diseases will pose new risks for food security, food safety and human health. Vector changes are a virtual certainty for pests and diseases that flourish only at specific temperatures and under specific humidity and water irrigation management regimes. This will expose crops, livestock, fish and humans to new risks to which they have not yet adapted. It will also place new pressures on care givers within the home, who are often women, and challenge health care institutions to respond to new parameters. Where such vector changes can be predicted, varieties and breeds that are resistant to the likely new arrivals can be introduced as an adaptive measure (WHO, 2007).

Intensifying food and agricultural production

To meet the food demand of a global population that is projected to increase by 2.5 billion by 2050, it will be essential to intensify production, obtaining higher yields per unit of input – whether this be land, water, nutrient, plant or animal. Improved land management practices can contribute to soil moisture retention, maintain appropriate amounts of nutrients in the soil, strengthen resilience and enhance productivity. Maintaining and enhancing plant and animal genetic resources, and managing livestock operations and fisheries more efficiently will also be crucial. Above all, however, a more variable climate and less reliable weather patterns will make increased capacity for storing water for agricultural use and greater efficiencies in its application essential.

Managing agricultural water more efficiently: Even without climate change, the global water economy is already in trouble. A major study, *Water for food, water for life*, released in 2007 by Earthscan and the International Water Management Institute (IWMI), reveals that one in three people today face water shortages (CA, 2007). Although there is theoretically sufficient freshwater to meet all the world's projected needs for the foreseeable future, water is not necessarily accessible in the locations where it is needed. Unsustainable use (with use rates exceeding recharge rates) is putting additional pressure on available supplies in many parts of the world. One important reason for this is the increased per capita demand for water that accompanies modern life styles.

The water needs of a single human being grow exponentially as that person's wealth and position in life increase. Each person requires a mere 2 to 5 litres of water a day for survival, and from 20 to 50 litres for cooking, bathing and cleaning. In urban areas worldwide,

however, average household water consumption is about 200 litres per person per day. This includes all uses of running water in and around the home, plus other withdrawals from city water supplies for use by public or commercial properties (CA, 2007). Without water, people cannot produce the food they eat. FAO estimates that it takes an average of about 1 000 to 2 000 litres of water to produce 1 kg of irrigated wheat and 13 000 to 15 000 litres to produce the same quantity of grain-fed beef. Thus, each human being “eats” an average of 2 000 litres of water a day (CA, 2007).

Water use has been growing at more than twice the rate of population increase in the last century, and although there is no global water scarcity as such, an increasing number of regions are chronically short of water. As the world population continues to increase, and rising incomes and urbanization cause food habits to change towards richer and more varied diets, even greater quantities of water will be required to guarantee food security (UN Water and FAO, 2007).

Water scarcity is being exacerbated by climate change, especially in the driest areas of the world, which are home to more than 2 billion people, including half of the world’s poor. Climate change is expected to account for about 20 percent of the global increase in water scarcity, and countries that already suffer from water shortages will be hit hardest. Even the increasing interest in bioenergy created by the need to reduce the carbon emissions that cause global warming could increase the burden on scarce water resources.

Although precipitation is projected to increase at the global level, this will not necessarily lead to increased availability of water where it is needed. In fact, FAO’s 2015/2030 projections, citing a 1999 Hadley Centre report, state that “substantial decreases are projected for Australia, India, southern Africa, the Near East/North Africa, much of Latin America and parts of Europe” (FAO, 2003b: 364).

Increasing water scarcity and changes in the geographic distribution of available water resulting from climate change pose serious risks for both rainfed and irrigated agricultural production globally. With a more variable climate and less reliable weather patterns it will be essential to increase the water storage capacity for agriculture, to maintain global food supplies while satisfying other competing uses for agricultural water (Parry *et al.*, 2007).

Looking ahead to 2030, irrigated areas will come under increasing pressure to raise the productivity of water, both to buffer the more volatile rainfed production (and maintain national production) and to respond to declining levels of this vital renewable resource. This risk will need to be managed by progressively adjusting the operation of large-scale irrigation and drainage systems to ensure higher cropping intensities and reduce the gaps between actual and potential yields.

The inter-annual storage of excess rainfall and the use of resource-efficient irrigation remain the only guaranteed means of maintaining cropping intensities. Water resource management responses for river basins and aquifers, which are often transboundary, will be forced to become more agile and adaptive (including near-real-time management), as variability in river flows and aquifer recharge becomes apparent.

Competing sectoral demands for water will increase pressure on the agriculture sector to justify the allocations it receives. Water allocation strategies should protect the ecological reserve – the water required by the environment for the effective maintenance of hydrological ecosystems and services – as a crucial component of adaptive capacity and a buffer against the ecological risks that ensue when water becomes scarce.

Key adjustments for maintaining cropped areas include:

- optimizing operational storage, i.e., manageable water resources such as water stored behind a dam;
- controlling releases to improve hydraulic performance and salinity control;
- optimizing crop water productivity.

Water allocations and releases to agriculture across river basins are essential for improving operational performance. Well-targeted investments in small-scale water control facilities and

the upgrading of larger-scale facilities, together with associated institutional reforms, will pay off in the medium term. Other strategies that can increase water productivity directly or have indirect water saving benefits include (Pretty et al., 2006):

- reducing soil evaporation through conservation agriculture practices;
- planting more water-efficient crop varieties;
- enhancing soil fertility to increase yields per unit of water utilized;
- decreasing runoff from cultivated land;
- reducing crop water requirements through microclimatic changes;
- reusing wastewater for agricultural purposes.

Currently, about 2 million hectares are irrigated by reused wastewater, but this area could grow (CA, 2007).

In the longer term, a transition towards more precision-irrigated agriculture should be anticipated. Conservation agriculture, precision-irrigated agriculture and the resulting improved water productivity require specialized tools and equipment; incentives are needed to ensure that these inputs are adopted in areas where the expansion of commercial agriculture is desirable.

Managing land sustainably: Production risks can be spread and buffered by a broad range of land management practices and technologies. Enhancing residual soil moisture through land conservation techniques assists significantly at the margin of dry periods, while buffer strips, mulching and zero-tillage mitigate soil erosion risk in areas with increasing rainfall intensity.

Conservation agriculture is an option for adaptation as well as for mitigation because the increase in soil organic matter reduces vulnerability to both excessive rainfall and drought. The impact is not immediate; soil under zero-tillage tends to increase the soil organic matter content by approximately 0.1 to 0.2 percent per year, corresponding to the formation of 1 cm of new soil over a ten-year period (Crovetto, 1999). However, not only does organic matter facilitate soil structuring, and hence the infiltration and storage of water in the soil, but it also directly absorbs up to 150 m³ water per hectare for each percent of soil organic matter. In addition, under conservation agriculture, no soil moisture is lost through tillage and seedbed preparation.

This means that seeding often does not need rainfall, because the seed can use the existing soil moisture. The total water requirements for a given crop are also lower in conservation than in conventional agriculture, which is of particular interest where water is scarce; reported water savings amount to at least 30 percent. This is because less water is lost through surface runoff and unproductive evaporation, and more is stored in the soil. Crops under conservation agriculture suffer much less from drought conditions, and are often the only crops to yield in such situations. Yield fluctuations under conservation agriculture are generally much less severe than under comparable conventional agriculture (Tebrügge and Bohmsen, 1998; Derpsch, 2005).

Among the disadvantages of conservation agriculture are its tendency to produce weed problems that require chemical herbicides to control; it is a technology requiring relatively high management skills, as many of the field operations must be implemented with a considerable degree of precision; and although permanent soil cover is ideal in the long term, there are short-term costs that must be covered before the system is well-established. Start-up incentives and training may therefore be needed to encourage farmers to adopt the conservation agriculture approach.

Maintaining biodiversity: Promoting agrobiodiversity is crucial for local adaptation and resilience. Biodiversity in all its manifestations – genes, species, ecosystems, etc. – increases resilience to changing environmental conditions and stresses. Genetically diverse populations and species-rich ecosystems have greater potential to adapt to climate change. FAO promotes the use of indigenous and locally adapted plant and animal diversity, and the selection and multiplication of crop varieties and autochthonous races that are adapted or resistant to adverse conditions.

Effective use of genetic resources can reduce negative effects of climate change on agricultural production and farmers' livelihoods. As women are traditionally the carriers of local knowledge about the properties and uses of wild plants, and the keepers of seeds for cultivated varieties, they have an important role in protecting biodiversity. Providing appropriate compensation for this service could guarantee a sustainable livelihood to these women, many of whom belong to vulnerable and food-insecure groups.

Breeding plants and animals for tolerance to drought, heat stress, salinity and flooding will also become increasingly important. FAO promotes the rebuilding of developing country national capacities to breed such crops, especially those in which the private sector is not involved. The Global Partnership Initiative for Plant Breeding Capacity Building (GIPB), facilitated by FAO, was launched on the margins of the first Governing Body Meeting of the International Treaty on Plant Genetic Resources in June 2007. It will contribute to Article 6 of the treaty, regarding sustainable use of plant genetic resources.

Adapting crops cannot be separated from other management options within agro-ecosystems; for example, rice is both affected by and has an effect on climate. Climate change is expected to have a significant impact on the productivity of rice systems, and thus on the nutrition and livelihood of millions of people. Rice systems, especially in south and east Asia, are under increasing pressure because of their high water needs and their role as a source of methane emissions. New crop management systems are therefore required that increase rice yields and reduce production costs by enhancing the efficiency of input application, increasing water use efficiency, and reducing greenhouse gas emissions.

Rice is currently the staple food of more than half the world's population. In Asia alone, more than 2 billion people obtain 60 to 70 percent of their calories from rice and its products. It is the most rapidly growing source of food in Africa, and is of significant importance to food security in an increasing number of low-income, food-deficit countries. Rice-based production systems and their associated post-harvest operations employ nearly 1 billion people in rural areas of developing countries.

About 80 percent of the world's rice is grown by small-scale farmers in low-income and developing countries. Efficient and productive rice-based production systems are therefore essential for economic development and improved quality of life for much of the world's population (FAO, 2004c).

Rice is a highly adaptable staple with many properties that have not yet been exploited in large-scale production systems. It is tolerant to desert, hot, humid, flooded, dry and cool conditions, and grows in saline, alkaline and acidic soils. At present, however, only two of the 23 rice species are cultivated. Science can help improve the productivity and efficiency of rice-based systems. Improved technologies enable farmers to grow more rice on limited land with less water, labour and pesticides, thus reducing damage to the environment. In addition, improved plant breeding, weed and pest control, water management and nutrient-use efficiency can increase productivity, reduce costs and improve the quality of the products of rice-based production systems.

New rice varieties being developed exhibit enhanced nutritional value, require less water, produce high yields in dryland conditions, minimize post-harvest losses, and have increased resistance to drought and pests and increased tolerance to floods and salinity. For example, rice varieties with salinity tolerance have been used to expedite the recovery of production in areas damaged by the 2005 Asian tsunami.

The Consultative Group on International Agricultural Research and FAO are promoting Rice Integrated Crop Management Systems (RICMS). By introducing integrated soil, water and nutrient management practices for sustainable rice-wheat cropping systems in Asia, RICMS would complement the introduction of new varieties and address the environmental problems that have emerged in these systems since earlier yield-enhancing technologies were introduced (International Rice Commission, 2002).

Improving livestock management: In its recent publication, *Livestock's long shadow: Environment issues and options*, FAO points out that approximately 70 percent of the world's agricultural land is used by the livestock sector, including grazing land and cropland for feed production (FAO, 2006c). Current prices of land, water and feed do not reflect true scarcities,

leading to the overuse of resources and major inefficiencies in the livestock sector. Full-cost pricing of inputs and widespread adoption of improved land management practices by both intensive and extensive livestock producers would help to resolve more sustainably the competing demands for animal food products and environmental services.

Increased intensification and industrialization are improving efficiency and reducing the land area required for livestock production, but they are also marginalizing smallholders and pastoralists, increasing inputs and wastes and concentrating the resultant pollution. Extensive grazing still occupies and degrades vast areas of grassland.

Overgrazing is the greatest cause of grassland degradation, an important contributor to deforestation and the overriding human-influenced factor in determining soil carbon levels of grasslands. In many systems, improved grazing management, such as optimized stock numbers and rotational grazing, will therefore result in substantial increases in carbon pools. Improved pasture management and integrated agroforestry systems that combine crops, grazing lands and trees in ecologically sustainable ways are also effective in conserving the environment and mitigating climate change, while providing more diversified and secure livelihoods for inhabitants.

Improving fisheries management: Worldwide, some 200 million people and their dependants, most of them in developing countries, live from fishing and aquaculture. Fish provide an important source of cash income for many poor households and are a widely traded food commodity. As well as stimulating local market economies, fish can also be an important source of foreign exchange.

Variability across different time scales has always been a feature of fisheries, especially capture fisheries. Recruitment and productivity in most fisheries vary from year to year, and are also subject to longer-term variability that typically occurs on a decadal scale. For example, populations of small pelagic fish in upwelling systems vary both from year to year and on a decadal scale, often showing shifts in productivity patterns and dominant species.

Where management is effective, fishery systems have developed adaptive strategies and, through monitoring and feedback, fishing effort and catches are regularly modified according to the state of the stock. Fishers must have adequate robustness and/or flexibility to absorb the changes in resource abundance, while avoiding negative ecological, social or economic impacts (FAO, 2007b).

Creating an eco-friendly energy economy

A fundamental principle for adaptation in the energy sector is that meeting the demand for bioenergy should not undermine food security. This demand has been growing because of the rising cost of petroleum, concern about dependence on fossil fuel imports, the climate change mitigation benefits of reducing reliance on fossil fuels, and the increase in demand for fuelwood and charcoal for expanding populations in many parts of the developing world. This section explores the intersections among climate change, energy security and food security, and the prospects for second-generation biofuels and increased energy efficiency as alternatives to biofuel crops. Another important issue, which is sometimes overlooked in discussions of the global energy economy, is the role of sustainably managed forests and trees as a source of energy at the national and household levels.

Understanding linkages among climate change, energy security and food security: It is hypothesized that ethanol produced from biomass⁴ can help mitigate climate change and reduce greenhouse gas emissions by substituting fossil fuel. IPCC estimates that by 2030,

⁴ As yet, there is no consistent international usage of bioenergy terminology. This paper uses the following terms and meanings: *biomass* = material of biological origin (excluding material embedded in geological formations and transformed to fossil); *biofuel feedstock* = organic materials used in the production of liquid and gaseous biofuels; *biofuel* = fuel produced directly or indirectly from solid, liquid or gaseous biomass; *bioenergy* = energy production from biofuels, including wood energy (derived from fuelwood, charcoal, forestry residues, black liquor and any other tree product) and agro-energy (derived from purpose-grown crops and from agricultural and livestock by-products, residues and wastes); *first-generation biofuels* = fuels produced from purpose-grown crops; *second-generation biofuels* = fuels produced from cellulosic materials (woody material and tall grasses), crop residues, and agricultural and municipal wastes.

liquid biofuels could supply 3 percent of the transport sector's energy needs, rising to 5 to 10 percent if second-generation biofuels take off (IPCC, 2007b). As a spin-off benefit, the rural sectors in developing countries can attract investment by generating tradable emission reduction credits – certified emission reductions (CERs) – through the Kyoto Protocol and the international market for greenhouse gas emission reductions.

There are uncertainties surrounding the potential climate change-related benefits, however. For example, with respect to the implications for climate change, the energy balance needs to be calculated over the whole production chain from bioenergy crop to biofuel end-product. Biofuels can be considered to contribute to climate change mitigation only if their use has produced fewer net emissions of greenhouse gases at the end of the production process than the average emissions from fossil fuel use. Even if there is a net contribution, producing biofuel from purpose-grown crops is not necessarily the most efficient use of available land.

A UN-Energy publication sponsored by FAO (UN Energy, 2007) identifies nine factors that must be considered in determining the sustainability of bioenergy development:

- ability of modern bioenergy to provide energy services for the poor;
- implications for agro-industrial development and job creation;
- health and gender implications;
- implications for the structure of agriculture;
- implications for food security;
- implications for government budget;
- implications for trade, foreign exchange balances and energy security;
- impacts on biodiversity and natural resources management;
- implications for climate change, including avoidance of deforestation and creation of a positive energy balance.

Biofuel crops have potential for large-scale production wherever food crops are currently grown or could be grown. Table 4 indicates the areas of land that would have to be devoted to the production of first-generation biofuel feedstocks if they were to substitute 25 percent of the current demand for transportation fuels (or 10 percent of total energy demand). It uses data on the potential yields of a number of crops and their fuel conversion efficiencies.

TABLE 4
Land required to replace 25 percent of current fuel demand for transport (45 EJ/year)

	Yield (gross) (GJ/ha/year)	Agricultural land required (% of currently available 2.5 billion ha)
Sugar cane	104	17
Sugar beet	90	20
Palm-oil	81	22
Maize	54	33
Wheat	45	40
Barley	20	91
Rape	20	91
Sunflowers	16	111
Soybean	9	200

Source: Dutch EnergyTransition.

TABLE 5
Distribution of global land area, 2004

Land use, 2004	Area (billion ha)
Arable land	1.4
Permanent crops	0.1
Pastures	3.4
Forest	3.9
Other	4.5
Total	13.4

Source: FAO Online, FAOStat.

As Table 4 clearly shows, grain crops in particular have too low a production potential for this ambitious target to be realized, underlining the need to increase efficiency of the whole production and conversion process. Moreover, as Table 5 shows, the assumption that 2.5 billion ha of agricultural land is available is optimistic, given the far smaller area that current statistics give as land for arable crops.

If production of feedstocks for liquid biofuels takes good arable land out of food production, it could reduce the availability of food on global markets and raise market prices, with consequent negative effects on food security at all levels (household, national and global). Furthermore, most sources of liquid biofuels are currently not commercially viable without subsidies, mandates and/or tariffs. If subsidized production of liquid biofuel from field crops becomes an important factor in global agricultural markets, competition for land and water will increase, putting upwards pressure on food prices and increasing the prevalence of food insecurity.

There are other possible negative effects of biomass production for bioenergy, including the risk that dedicating large tracts of land to monocropping of energy crops will contribute to deforestation, land degradation, carbon emissions, contaminated surface and groundwater, and loss of biodiversity, and it is not clear that the net energy gain from biofuel production will be positive. In response to these and other concerns about whether large-scale production of bioenergy crops is really sustainable (Dutch EnergyTransition), the United Nations Special Rapporteur on the Right to Food, Mr Jean Ziegler, called for a five-year moratorium on the conversion of arable land to biofuel production. Speaking at a press conference for the opening of the Fifth Special Session of the Human Rights Council in New York, he stated that:

“The creation of ‘pure fuels’, or biofuels, to protect the environment and reduce oil dependence is not a bad idea, but its negative impact on hunger would be catastrophic. When tonnes of maize, wheat, beans and other food staples are converted to fuel, food prices rise and arable land is lost to food production. Last year, the price of wheat doubled and of maize quadrupled.

“As prices rise, the poorest countries cannot pay, and the poorest people, generally living without access to subsistence farming, cannot purchase more expensive foodstuffs. The amount of corn needed to make enough ethanol to fill a single car’s fuel tank could fill a child for an entire year.

“Non-food agricultural products that could grow in soil unfit for food production could be used as an alternative source of biofuels. For example, in a project in Rajasthan, India, the Mercedes company is growing jatropha for biodiesel in arid land. Following a moratorium, such projects could be evaluated and new fuels produced.” (UNDPI, 2007)

An expert meeting convened by FAO in February 2008 confirmed that there were significant concerns about the potential impacts of biofuels on food security. Early evidence suggests that the introduction of biofuels initially reduces food availability and increases food prices, with immediate adverse impacts on the food security situation for poor consumers in both urban and rural areas. These impacts affect people’s access not only to starchy staples, but also – and often more important – to foods needed for a balanced diet, such as vegetable oil and animal products. Because food and energy supply are both subject to random shocks,

profitability will lead to cycles of expansion and contraction, which will increase food security concerns (FAO, 2008).

It is already anticipated that traditional safety nets may not be adequate in the face of new and increasing vulnerabilities caused by climate change. Market-induced vulnerability attributable to higher and more variable prices for food as a consequence of biofuel demand will only compound this problem. Expansion of liquid biofuel production would intensify the impact on food prices and land availability if the expansion were based on the continued use of present technologies in current policy environments (FAO, 2008).

However, experts at the meeting also expressed the view that liquid biofuel development does not have to be adverse for food security, particularly if production is allowed to find its natural competitive equilibrium, which today would favour production of sugar cane and discourage production of starchy crops as liquid biofuel feedstocks. Emergent poor farmers with sufficient skills and assets to become successful commercial farmers can take advantage of the emerging liquid biofuel market, provided they live in locations where growing conditions are suitable and appropriate infrastructure is present. If domestic markets are functioning efficiently, higher prices can benefit the farmers producing such cash crops as sunflower, soybean, rapeseed or sugar cane, irrespective of the final use of the harvested crop. However, higher prices for staple cereals such as maize will increase food insecurity for poor farming households that are net buyers of the staple concerned, as is often the case (FAO, 2008).

On the other hand, if second-generation biofuels come on stream during the next decade or two, as many experts predict they will, they could create new livelihood opportunities and improve food security for many currently vulnerable people living on degraded lands where cellulosic feedstocks could be produced. Such a development would also constitute a good option for mitigating and adapting to climate change on these lands, because the introduction of woody vegetation would sequester carbon, improve the water retention capacity of the soil and reduce erosion (FAO, 2008).

Even without second-generation biofuels, the mix of feedstocks and biofuels in use is likely to change over the medium term. For example, the International Energy Agency (IEA) foresees changes in the relative importance of different biofuel feedstocks over time (IEA, 2006), and FAO projects that traditional sources of biofuel will decline in importance as opportunity costs for labour increase and rural people can no longer afford the time to collect fuelwood or burn charcoal. At some point, rising prices for oil will make methane (biogas) competitive, and eventually butanol is likely to replace ethanol for mixture with gasoline as a transport fuel.

Planted forests represent only 7 percent of global forest cover, but they account for more than half of global industrial roundwood production (FAO, 2006b). There is significant potential for expanding planted forests on marginal lands or lands released from crop or livestock production. Increasing proportions of sustainably produced industrial roundwood and wood for energy generation will come from planted rather than native forests.

Increasing energy efficiency: Although the debate about biofuel/food security tradeoffs has so far focused on how to manage competing demands for scarce productive resources, it is equally important to consider energy saving and efficient use for reducing the demand for energy, including bioenergy.

Inefficient use of water for irrigation also results in energy inefficiency, so gains in irrigation efficiency can be expected to lead to energy savings and reduced pumping costs. Over the entire cropping cycle, conservation agriculture generates diesel fuel saving of about 60 percent compared with conventional tillage. Reduced fuel requirements for primary and secondary tillage operations and planting are particularly significant. Use of other inputs that require energy for their manufacture, such as machinery, fertilizer and pesticides, is also lower. One study (FAO/SDR Energy Programme, 2000) estimates that overall, conservation agriculture consumes 40 to 50 percent less energy than conventional tillage, including the energy requirements for producing inputs. This lower fossil fuel requirement for field operations is the main driving force for adopting zero-tillage cropping systems in mechanized farming, under scenarios of increasing fuel costs.

The fisheries sector can play only a small part in reducing CO₂ emissions through greater energy efficiency, but there may be synergies among emissions reductions, energy savings and responsible fisheries. For example, reducing the fuel subsidies granted to fishing fleets would encourage energy efficiency and assist the reduction of overcapitalization in fisheries; static gear – pots, traps, longlines and gillnets – uses less fuel than active gear such as trawls and seines.

Micro- and small-scale agroprocessing industries have an important role in increasing and diversifying livelihood opportunities for the rural poor. However, these people are often handicapped by poverty and lack of assets, low education levels, poor understanding of the sector, and low levels of inputs, reducing their competitiveness. In addition, the practices that they employ often degrade and contaminate the environment. Regarding energy use, most small-scale agroprocessing operations are intensive consumers of fuelwood, so contribute to the problems referred to in the previous section. More energy-efficient technologies could be employed by small-scale agroprocessing industries, but operators need to obtain the necessary skills and start-up capital to adopt them. Many operators are women, who could be reached through programmes that target women as a vulnerable group (FAO, 2002).

Exploiting forests sustainably: Sustainable forest management is a dynamic and evolving concept. The aim is to maintain and enhance the economic, social and environmental values of all types of forests for the benefit of present and future generations (UNFF, 2007). In its broadest sense, forest management encompasses the administrative, legal, technical, economic, social and environmental aspects of the conservation and use of forests. It implies various degrees of deliberate human intervention, ranging from actions to safeguard and maintain the forest ecosystem and its functions, to favouring specific socially or economically valuable species or groups of species for the improved production of goods and services.

Especially in the tropics and subtropics, however, many of the world's forests and woodlands are still not managed in accordance with the Forest Principles adopted at the United Nations Conference on Environment and Development (UNCED) in 1992. Many developing countries have inadequate funding and human resources for the preparation, implementation and monitoring of forest management plans, and lack mechanisms to ensure the participation and involvement of all stakeholders in forest planning and development. Where forest management plans exist, they are frequently limited to ensuring sustained production of wood, without due concern for non-wood forest products and services or social and environmental values. In addition, many countries lack appropriate forest legislation, regulation and incentives to promote sustainable forest management practices.

Climate change will influence forests in all regions. In Africa, for example, lower rainfall is expected to decrease forest productivity and increase the area of dryland forests. In Latin America, the forest of the eastern Amazon is expected to be replaced by savannah. In North America and northern Europe, higher temperatures may make forests more productive and alter the ranges of some species.

Trees under stress are also more susceptible to harmful insect pests and diseases. Recent outbreaks of insect pests, especially in temperate regions, have been linked to alterations in their fertility and mortality related to climate change. An example of this is the recent outbreak of the mountain pine beetle, which has already destroyed 12 million ha of forests in Canada.

Sustainable forest management includes adapting and planning ahead for these changes, as well as managing forests and woodlands to cope with new climatic conditions so that they contribute to flood prevention and provide habitats and wildlife corridors for a diversity of flora and fauna. When planting new forests, careful consideration needs to be given to species choice, particularly where timber production is important.

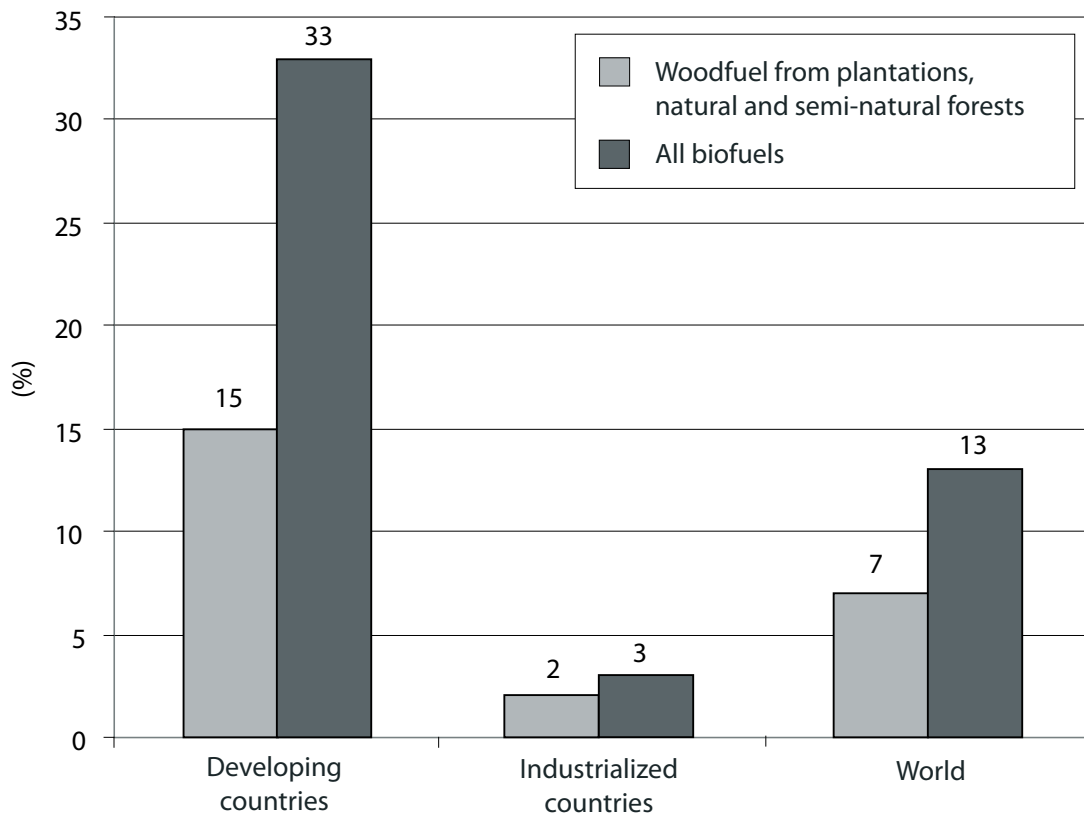
The United Nations Forum on Forests (UNFF) has provisionally identified seven thematic areas that need to be addressed to achieve more sustainable forest management (FAO Online Forestry):

- extent of forest resources;
- biodiversity;
- forest health and vitality;
- productive functions of forest resources;
- protective functions of forest resources;
- socio-economic functions of forest resources;
- the legal, policy and institutional framework for sustainable forest management.

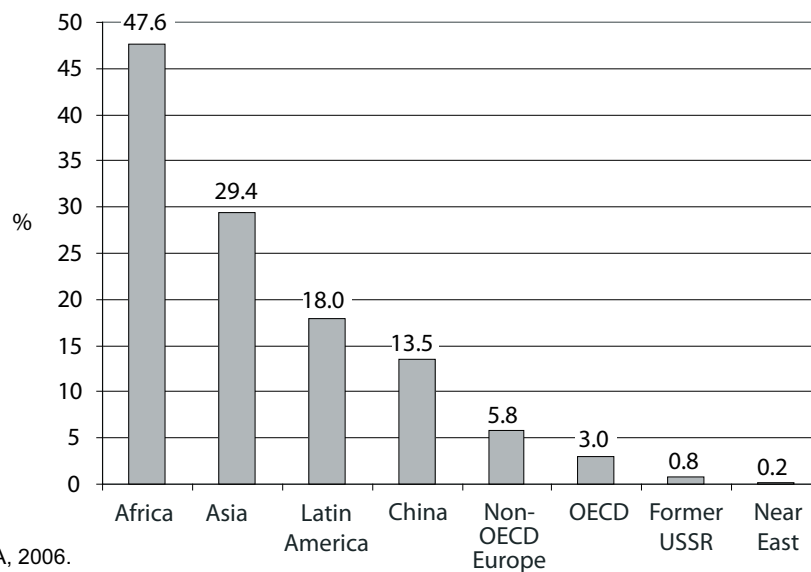
Achieving the transition from deforestation to forest conservation and management is a huge challenge. It involves protecting and managing what already exists, reducing deforestation and forest degradation, restoring more of the world’s forest cover, using more wood for energy, making greater industrial use of wood to replace other materials, ensuring the livelihoods of forest-dependent people and safeguarding the ecosystem services of forests.

Improving household energy security and food security simultaneously: Less publicized, but equally important, is the energy demand of both rural and urban poor people. Bioenergy is already the dominant source of energy for about half of the world’s population, most of whom live on less than US\$2 per day (FAO Online, Bioenergy). Figures 12 and 13 show how important this form of energy already is in developing countries – a point that is sometimes overlooked in the current enthusiasm about bioenergy as a substitute for fossil fuel in the transport sector.

Figure 12. Shares of bioenergy in total energy supply



Sources: FAO, 2000a.

Figure 13. Shares of bioenergy in total primary energy supply in different regions in 2004

Source: IEA, 2006.

For food system performance and food security, improving the management of biomass sources for household use can make important contributions in parts of the developing world where large numbers of poor or very poor people live. The incidence of poverty and food insecurity correlates almost exactly with what is called the “energy ladder.” At the household level, the poorest people use manure, twigs and low-grade biomass for cooking and heating, and only human force in their productive activities. As they become less poor and move up the economic ladder, they switch to fuelwood, progressing through charcoal, kerosene and gas to electricity, and integrating animals and simple tools into production processes. At a certain level of development, they will integrate some level of mechanization, irrigation and fertilization, moving on – if successful – to mechanized equipment such as tractors and harvesters, which imply a switch to fossil fuels (FAO, 2005).

In both household and economic activities, the energy ladder follows and influences the economic ladder. If attempts to alleviate hunger and promote rural development and food security are to have lasting success, they must recognize and address the key role of energy. Current practices are adding to carbon emissions through deforestation and desertification caused by increasing population pressure on natural fuelwood sources. They also have adverse health impacts caused by smoke inhalation from unvented cooking stoves and outdoor fires. Scarcity of fuel restricts the amount of cooked food that can be prepared, often with adverse consequences for food security and the nutritional quality of the diet. Box 3 illustrates the multiple cascading effects of inaction for the case of Rwanda and eastern Democratic Republic of the Congo (DRC).

Incorporating trees and woodlands in traditional farming systems enhances energy and food security and protects the environment. Various fast-growing tree species are well-adapted to grassland ecosystems, where many currently vulnerable people live. Introducing such species in managed woodlots could provide a vital source of fuel and fodder, as well as holding soil, retaining water, eliminating the need for continued cutting of natural stands of trees and shrubs, and contributing tree crops to the diet. In the past, however, such introductions have often failed when local people have not perceived the need to manage the trees.

Thus the cycle of energy impoverishment, environmental degradation, rising rates of carbon emissions and increasing food insecurity is perpetuated (ETFRN, 2003). Essential investments to break this cycle include: (i) sustainable development of agroforestry parklands; (ii) introduction of integrated food and bioenergy systems at the household level; and (iii) promotion of smallholder production of such crops as palm-oil, rapeseed and jatropha, which can produce oils for making biodiesel for decentralized power generation and water pumps (FAO, 2007e).

