ALTERRA
WAGENINGEN UR

Climate change in East Africa

Towards a methodological framework on adaptation and mitigation strategies of natural resources

Alterra-report 2018
ISSN 1566-7197

René Verburg, Eric Arets, Jan Verhagen, Catharien Terwisscha van Scheltinga, Fulco Ludwig, René Schils and Jouwert van Geene

Climate change in East Africa

Dit onderzoek is uitgevoerd in het kader van het project 'Adaptation and Mitigation to Climate Change in Developing Countries' en is onderdeel van het programma 'Beleidsondersteunend Onderzoek' van het Ministerie van Landbouw, Natuur en Voedselkwaliteit. Specifiek draagt het bij aan het cluster 'Internationaal' en 'Vitaal Platteland'.
Projectcode BO-10-008-003 en BO-01-004-03

Climate change in East Africa

Towards a methodological framework on adaptation and mitigation strategies of natural resources

René Verburg[1], Eric Arets[2], Jan Verhagen[3], Catharien Terwisscha van Scheltinga[2], Fulco Ludwig[4], René Schils[2] en Jouwert van Geene[5]

[1] LEI Wageningen UR
[2] Alterra Wageningen UR
[3] PRI -Wageningen UR
[4] Wageningen UR
[5] Wageningen International

Alterra-report 2018
LEI report: 2010-002

Alterra Wageningen UR
Wageningen, 2010

Referaat

Verburg, R., E. Arets, J. Verhagen, C. Terwisscha van Scheltinga, F. Ludwig, R. Schils, J. van Geene, 2010. *Climate change in East Africa; Towards a methodological framework on adaptation and mitigation strategies of natural resources.* Wageningen, Alterra, Alterra-report 2018. 73 blz.; 16 fig.; 3 tab.; 67 ref.

Developing countries are extremely vulnerable to climate change, due to their strong economic dependency on rain-fed agriculture. Land-use policies can offer a less vulnerable future by design and application of relevant mitigation and/or adaptation strategies. Effectiveness of such strategies depends on local conditions. Therefore, hotspot regions are defined, where specific issues related to agriculture will be assessed. Mitigation strategies in East Africa in general and Ethiopia in particular include reforestation, while adaptation covers aspects such as crop diversification and water use efficiency. An analytical framework is developed in which a science-policy interface is the main focus. On one hand policy-makers and stakeholders can be involved in such a framework for policy design, while scientists on the other hand deliver data and modeling tools. The model chain in the framework is integrated by an evaluation step where policy options are compared for efficiency on several development targets. The framework will be tested in 2010 in hotspot regions in East Africa.

Trefwoorden: Climate change, adaptation, mitigation, East Africa, Ethiopia, sustainable development, land-use, agriculture, reforestation, hotspot study, Millennium Development Goals.

ISSN 1566-7197

The pdf file is free of charge and can be downloaded via the website www.alterra.wur.nl (go to Alterra reports). Alterra does not deliver printed versions of the Alterra reports. Printed versions can be ordered via the external distributor. For ordering have a look at www.boomblad.nl/rapportenservice.

Alterra-report 2018
Wageningen, March 2010

Inhoud

Preface

Agriculture as part of the solution
In 2050 a global population of 9.1 billion people needs to be fed. To do so an increase with 70 percent of the food production will be necessary. Climate change among other stress factors hinders this ambition, especially in Africa. The overall impact of climate change on agriculture and food security in Africa is expected to be increasingly negative, particularly in regions already suffering from droughts, floods and food insecurity. Countries like Ethiopia, Kenya and Rwanda already have to cope with the impact of climate change. Scenario's and projections indicate that there is more to come. The agriculture system has to adapt to more rapid and intense changes in climate (temperature, rainfall) and related changes in distribution of pests, weeds and diseases. It is important that both adaptation and mitigation strategies to cope with future climate change are integrated in sustainable development strategies of the country. In that way they could contribute to the ambition of the millennium goals.

Most Least Developed Countries (LDC's) in Africa, like Ethiopia, established a National Adaptation Action Plan (NAPA). These so called NAPA's also include adaptation strategies for agriculture. Experience learns that these documents do not lead to concrete implementation due to a lack of knowledge and policy making. As a consequence no financial support can be obtained from sources like the GEF. Although in general LDC's are advocating more financial support for executing NAPA's, the main barrier for implementation seems to be the absence of a feasible strategy together with a stakeholder-based process.

In developing adaptation and mitigation strategies for the rural areas in the Netherlands knowledge, policymaking and implementation were brought together in one process. These components are seen as crucial for a successful climate strategy. It is worthwhile to investigate whether such a concept could also contribute to adaptation and mitigation challenges in East Africa. Our strength lies in what our minister of Agriculture, Nature and Food Quality refers to as the 'golden triangle': the triptych of education-research, policy and - thirdly - practice.

Hayo Haanstra

Policy coordinator
Department of Nature, Landscape and Rural affairs
Ministry of Agriculture, Nature and Food Quality

Summary for policy makers

Ethiopia expects a 2 to 4 degree increase in temperature and the horn of Africa a 10% to 30% increase in precipitation by the end of the century
Projections from global circulation models on climate change are generally consistent in predicting temperature rise across Africa, but show large uncertainty about the magnitude and directions of changes in precipitation. The current climate in Ethiopia is highly variable and climate change projections predict large regional differences in both temperature and precipitation. The highlands will suffer the most from a temperature increase of about 4 degrees, while the lowlands expect a 2-3 degree increase. Predictions on future precipitation levels are difficult to make and a variety of models predict inconsistent results. Most models, however, predict a 10-30% increase in precipitation, although projections on changes in the timing of this rainfall over the year are still unknown. Short term climate change projections for the coming decades, however, are highly uncertain.

Climate change will most severely affect developing countries
Societies in developing countries are strongly vulnerable to climate change, due to their dependence on natural resources and agriculture and their limited adaptive capacity. Climate change may therefore aggravate persistent problems such as poverty. Agriculture is the most important economic sector in sub-Saharan Africa, accounting for about 20-30% of GDP and 55% of the total value of exports. Rain fed agriculture is highly sensitive to climate change if more frequent droughts but also floods occur. Also it is expected that temperature rise will have negative effects on highly valued commodities such as coffee. Forestry and agriculture are often weakly developed, highly dependent on each other, and vulnerable to climate change. Generally, policies and measures are developed and implemented without thorough consideration of their relation to climate change.

The National Adaptation Programme of Action (NAPA) of Ethiopia primarily focuses on agricultural land-use
The adaptation strategies developed in the NAPA of Ethiopia mostly focus on agricultural land-use. Adaptation of water and other natural resource management is seen as the most urgent subject to anticipate to climate change. Diversification of farm activities and off-farm extensions may be candidates for adaptive measures. Mitigation strategies include projects like community based carbon sequestration and promotion of on-farm and homestead forestry and agro-forestry practices.

Hotspot areas are those most sensitive to climate change from the point of view of groups of people, their income, and the environment. The Central Rift Valley in Ethiopia is an example with climate change sensitive coffee production and pastoralism
The Central Rift Valley is an important area providing many commercially important natural resources, but land degradation has resulted in profound erosion problems and loss of biodiversity. Rehabilitation of Acacia forests will improve the provision of essential ecosystem goods and services. Coffee is considered to be relatively sensitive to future temperature change and adaptation strategies will need to be developed for coffee farming in Ethiopia. Many native tree species play an important role in nitrogen fixation in soils. Harvesting these trees without replanting, or replanting with non-native tree species will lead to soil degradation and loss of productivity. The project will assess strategies for the provision of various ecosystem services from a climate adaptation and mitigation perspective.

The framework introduced addresses land-use policies on mitigation and adaptation in relation to agriculture and integrates scientific tools with policy-making
The modelling framework includes a set of models that will assess mitigation and adaptation policy options. On one hand, the model chain simulates the effects of land-use changes imposed by policy choices. Thereby the introduced framework primarily focuses on agricultural land-use and reforestation. On the other hand, the framework evaluates the policy choices against a set of sustainable development goals. Through interaction between modelling results and policy design, the proposed mitigation and adaptation policy options are tested for efficiency and effectiveness. Therefore, the framework relies on a close interaction between scientists, stakeholders and policy-makers. As a first step, the framework will draw on policy initiatives for mitigation and adaptation strategies that are described in the NAPAs of East African countries in general and the NAPA of Ethiopia in particular.

1 Introduction

The Millennium Development Goals that were launched in 2000 form an ambitious global agenda. Among the targets set for 2015 are halving the proportion of people living in extreme poverty and hunger. Poverty and hunger are strongly linked but despite considerable improvements in food production over the last 50 years, food security still remains a problem in many parts of the developing world (FAO, 2005). High fuel prices and low productivity, both linked to climate change, are two important factors underlying the recent food crisis (Khor, 2008) which threw large numbers of the vulnerable poor into a food insecure situation.

The global human population is expected to increase to 9 billion by 2050 from 7 billion today. The increasing population combined with changing consumption patterns requires a more than doubling of global agricultural demand and will result in a greater competition for resources.

A large number of people currently live in rural areas where agriculture remains the key livelihood strategy. Besides providing food, agriculture also contributes to economic development in terms of income generation and employment. Paradoxically, however, economic growth and poverty reduction leads to a declining importance of the agricultural sector (Dorward et al., 2004). Rural development is not limited to agriculture but also has strong connections to health, education, the private sector, water, energy and the environment. Rigg (2005) and Dorward et al. (2004) both recognize a broad trend in rural areas that indicate a diversification of livelihood strategies away from agriculture to off-farm income generating activities. The picture is diverse, however, and large differences within and between countries and regions exist. Thritle et al. (2003), based on a quantitative analysis, conclude that agricultural productivity growth has had a substantial impact on poverty reduction of the rural poor in Africa and Asia. In addition Rosegrant et al. (2006) highlighted the importance of increasing productivity and economic return from agriculture in eradicating extreme poverty and reducing hunger. Farm households depending on subsistence agriculture will directly benefit from increased food production and at the same time we expect a reduction in food prices which will improve the purchasing power of the poor.

Although climate change may not be directly targeted by national policies, because it is overshadowed by urgent and immediate needs, it does have direct implications for the success of many policies. Not only does climate change have the potential to undermine food security policies, it also can irreversibly damage the natural resource base upon which agriculture depends (IAASTD, 2008) and thus hamper sustainable development. Clearly climate change is not only an environmental issue which needs to be dealt with, it is also a development issue that needs to be addressed seriously. This is not only because currently economical development is strongly linked to an increase in use of fossil fuels but also because climate change will impact all human and natural systems.

These impacts are not equally distributed; some regions and groups will be hit harder than others. It is clear that all countries will have to respond to climate change, either directly by providing security against e.g. flooding, or indirectly by increasing the adaptive capacity of human and natural systems. Without appropriate responses climate change is likely to constrain economic development, as argued above, and this will especially be true for economies in developing countries where agriculture and forestry are important economic sectors providing a livelihood to the larger part of the population.

1.1 Climate change and developing countries

Changing climate and weather patterns are predicted to have severe negative impacts on food production, food security and natural resources. Without appropriate responses climate change is likely to constrain economic development and poverty reduction efforts and exacerbate already pressing difficulties. Especially countries with economies rooted in climate-sensitive sectors such as agriculture, fisheries and forestry are expected to be hit hardest. Climate change is both a global environment and a development issue, as it could jeopardize the livelihoods of millions, particularly where its impacts are compounded by other factors or where existing poverty and hunger make it particularly difficult to cope with its impacts. Targets as defined in the Millennium Development Goals or national policies will be more difficult to reach. This is especially true for the two fundamental development objectives, eradication of poverty and hunger. But also health-related goals, ensuring environmental sustainability and building global partnerships are impacted by climate change.

Simply because for most developing countries agriculture currently is the main economic activity and because agriculture traditionally has been the key livelihood strategy for most people living in rural areas, it is important in achieving development goals at national and international levels. Agriculture is at the forefront of shaping the concept of sustainable development. The basic idea of sustainable development as presented by the Brundtland commission was to link development and environment over generations. The main focus of the sustainability debate was on environmental issues; this has changed and society or people oriented issues are becoming part of the equation. Despite the fact that the term 'sustainable' is embraced and used by many people it remains subjective. Kemp and Martens (2007) argue that the subjective concept includes both the protection of amenities and the creation of new and better services for more people. The normative process of sustainable development reflects social consensus which is difficult to confine by strict rules and targets. The renewed attention for the role of agriculture in development processes will have to account for how this development is formed sustainably using current systems and structures, starting a process of improvement while including the vulnerabilities and risks posed by climate change. Enhancing the resilience of communities and increasing the robustness of landscapes and farming systems to climate change are two complementary strategies to improve the livelihoods of the rural people in developing countries.

As the impacts of climate change are local and vary strongly among different systems, sectors and regions, adaptation strategies are also local but should be embedded in regional and national activities. The nestedness of adaptation activities and the direct link to development make it difficult to clearly define an adaptation niche. In this study an approach is advocated in which sustainable development is seen as a people-driven process in which policy, research and practice work towards improving natural resource management.

Besides being affected, agricultural land use is also a major contributor to climate change via the emission of greenhouse gasses. These emissions are mainly related to land management, land conversion and livestock husbandry. Future adaptive strategies and sustainable development pathways need to take into account changes in greenhouse gas emissions.

Clearly, adaptation to climate change should not be approached from a single perspective. Developing countries are facing many challenges, of which adaptation to climate change is only one. Because adaptation to climate change and development share common goals and resources it is important that adaptation to climate change is placed in the wider framework of sustainable development. Integrating or aligning adaptation activities into development plans and programs is a sensible strategy that increases the efficiency of investments and increases the chance to achieve the desired goals.

This culminates in the so-called 'hotspot' approach, where the aspects of sustainable development (people, planet, profit) are taken into account to address climate change adaptation. Hotspots are areas where the vulnerability of human and natural systems to climate change and climate variability, now or in the future, is large. The hotspot areas are defined and selected in close cooperation with local stakeholders and preferably coincide with areas, people and sectors already targeted in policy plans.

1.2 Objectives of this study

On the request of the Ministry of Agriculture, Nature and Food Quality (LNV), Wageningen UR has taken the initiative to set up a three-tier approach with the purpose to contribute to capacity development for climate change adaptation and mitigation in developing countries. Identifying and quantifying the combinations of mitigation and adaptation options and answering related questions were the prime objective, together with capacity development, outreach and curriculum development for training.

A key constraint for developing and implementing adaptation projects is capacity. Currently basic knowledge on climate change and on how to integrate this complex topic into ongoing and planned activities of researchers, policy makers and practitioners is lacking.

There are various kinds of capacities needed to formulate and implement effective, responsive and realistic adaptation and mitigation activities. First, this concerns the ability of researchers to access and provide the right knowledge to set the policy agenda. Second, it involves the ability within the policy system to respond to the agenda based on provided evidence and societal needs and put in place policies. Third, it concerns the ability within government to translate policies into actions and to mobilise the required resources for implementation.

This phase of the study focussed on East Africa because it represents a rapidly changing region with strong urban centres, with agriculture still as a dominant economic activity. And although the diversity within and between countries is high a regional focus is taken as these economies are strongly linked. Also the diversity in natural and managed systems and the direction and magnitude of climate change varies, but within and between countries it is expected that lessons can be learned and shared between partners. Also more practical issues played a role, Wageningen UR has an extensive network in this region and LNV has a clear interest in the region.

In 2009 the following targets were addressed:
- Contribute to a regional network to exchange information and tools on sustainable land-use and strategies integrating climate adaptation and mitigation issues.
- Provide information on climate change issues related to agriculture and natural resource management.
- Improve capacity development for climate change mitigation and adaptation programs and projects in developing countries and implementing agencies.
- Contribute to increased accessibility of Wageningen UR knowledge in the climate change arena in developing countries.

An interdisciplinary scientific team started working on the three-tier approach of the project, knowledge - capacity development - support to policy development. Various disciplines such as economics, land use change, agriculture, sustainable development, social learning and change processes, were all represented in the team. In order to be able to assist in concrete cases of climate change in developing countries, a joint theoretical framework was required and the objective of this study therefore was to develop such a framework, through which scientists from different disciplines can jointly analyse adaptation to climate change.

1.3 Outline of the report

This report is the result of the 'knowledge' part of the project on adaptation in developing countries (BO-10-008-003, BO-01-004-416). The documentation of the process, and as such the results of the parts on 'capacity development' and 'assistance to policy support' are reported elsewhere (see e.g. Terwisscha van Scheltinga and Van Geene, forthcoming).

This report is a work in progress, documenting the state of the art for this framework. It first presents the climate change projections in East Africa with special reference to Ethiopia. Then the concept of vulnerability will be presented. Adaptation and mitigation strategies are described in general, with an evaluation of the NAPA of Ethiopia and of how to conceptualize dealing with uncertainties and risk. Possible application of the study in hotspot areas are described and in the following chapter 4 a framework is presented to simulate land-use effects of mitigation and adaptation strategies and evaluate the policy options against a framework of sustainable development. In chapter 5 preliminary conclusions are discussed.

2 Climate change and vulnerability in East Africa

2.1 Introduction

Africa has a wide variety of climate systems and bioclimatic zones. Many of these zones are characterised by a large temporal variability in climate conditions, especially rainfall. Although the level of understanding of the climate systems in Africa differs between regions, in general it is low compared to the understanding of climate systems in Europe.

In this chapter both climate change and socio-economic projections for East Africa and Ethiopia are presented. In addition, the concept of ecosystem services is discussed, which was for the first time extensively elaborated within the framework of the Millennium Ecosystem Assessment.

2.2 Climate change projections for East Africa and Ethiopia

The climate of East Africa is extremely variable in both time and space. Parts of the region are very arid with rainfall lower than 200 mm per annum. High rainfall areas are concentrated in the highlands of Ethiopia and the western parts of the region. In most parts of East Africa a bimodal rainfall season is recognized with a short rainy season between September and December and a long rainy season between February and May. The rainfall in the northern regions determines the timing of the wet season in the eastern regions.
Inter-annual rainfall variability is very high in Ethiopia and country wide average rainfall varied from 1025 mm in 1996 to 553 mm in 2000 (figure 2.1). As a result of increased greenhouse gas

concentration in the atmosphere, global temperature will increase. Average global temperature is likely to increase between 2 and 6 °C in the coming century. Downscaled scenarios for East Africa show that temperature will increase more than average in the Ethiopian Highlands, and less than average in the coastal regions of Kenya and Tanzania (figure 2.2). In the highlands of Ethiopia, temperatures are projected to increase by more than 4 °C. In Kenya and Tanzania temperatures are projected to increase between 2 and 3 °C by the end of the century.

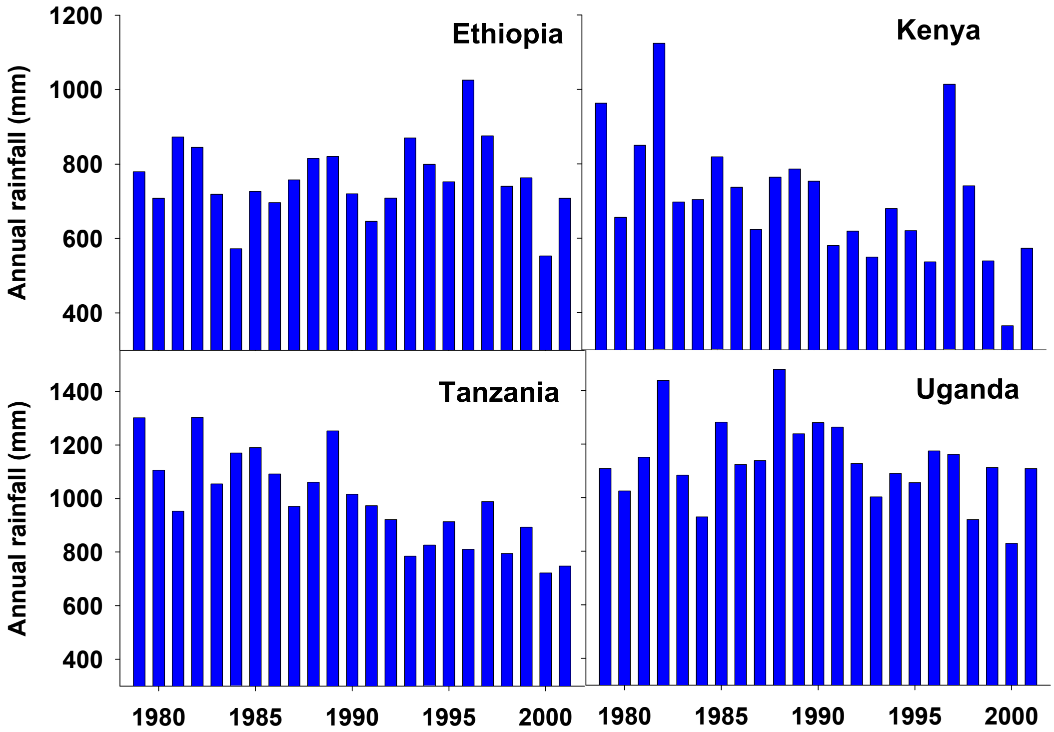


Figure 2.1.
Annual rainfall in four East African countries for the period 1979 and 200.

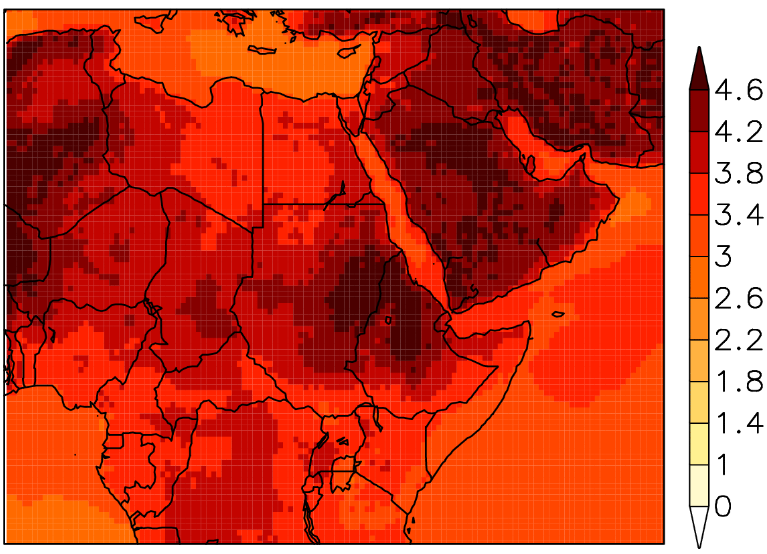


Figure 2.2.
Results from the regional climate model REMO showing the increase in temperature for the 2071-2100 period compared to 1961-1990 using the A1B emission scenarios. (A1B is a moderate emission scenario, {Nakicenovic, 2000 #3392} (graph provided by D. Jacob of the Max-Planck-Institute for Meteorology).

While projections from global circulation models for climate change are generally consistent in predicting temperature rise across Africa, they show large differences in the magnitude and directions of changes in precipitation. Averaged across 21 different climate models, an increase in rainfall is projected due to increased greenhouse gas concentrations. By the end of the century, the model calculates an average increase in annual rainfall between 10 and 30% in East Africa. However, there is a large difference between the models. Some models project an increase while others show a reduction in rainfall. It is also important to note that most models have a difficulty in simulating the historical climate, which reduces the confidence in future projections.

A detailed analysis of the global circulation model runs for the IPCC AR4 (Figure 2.3) showed that mean precipitation rates and intensity of high rainfall events are likely to increase in East Africa (Shongwe et al., 2009). Higher precipitation intensity means that the average amount of rainfall per wet day will increase. This usually increases flood risks and can also increase erosion. The same analyses showed less severe droughts for East Africa. An analysis by Sheffield and Wood (2008) showed a slight increase in drought frequency for East Africa. For other parts of Africa a much higher increase of drought frequency is projected. Most models also predict an increase in inter-annual rainfall variability. This increases the chance for extreme dry and wet years. Considering drought projections, there is no clear picture yet. Higher temperatures will increase potential evaporation but this can be partially compensated for by higher rainfall.

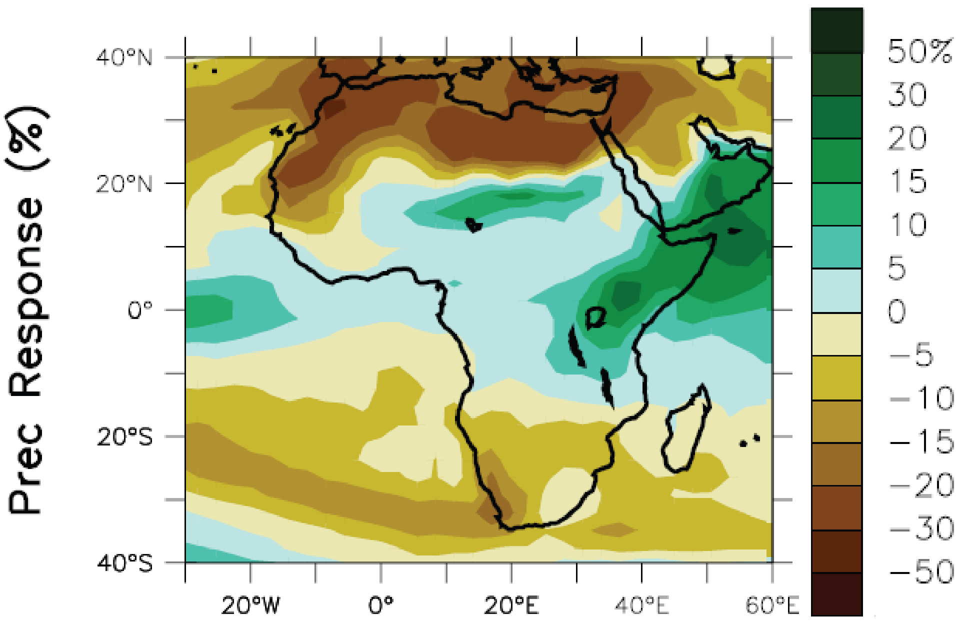


Figure 2.3
Relative change in average annual rainfall for the 2080-2099 period compared 1980-1999. Results are the average of 21 different climate models using the A1B emission scenario. (graph from IPCC AR4 WG1 – Chapter 11)

Downscaled scenarios, using the REMO model of the Max Planck Institute for Meteorology (Figure 2.4), show that rainfall is projected to increase in Uganda, Burundi, Rwanda and the western parts of Kenya and Tanzania, while along the coast of Kenya and Tanzania and the northern part of Ethiopia, a slight decrease of rainfall is projected. However these results are based on only one model and need to be treated with care.

For a lot of applications and adaptation strategies not the climate at the end of the century is important, but the change in climate projected for the coming decade(s). However, at this moment the capability of the climate models to project climate at the decadal timescale is still very poor and no reliable scenarios are available for the coming decades.

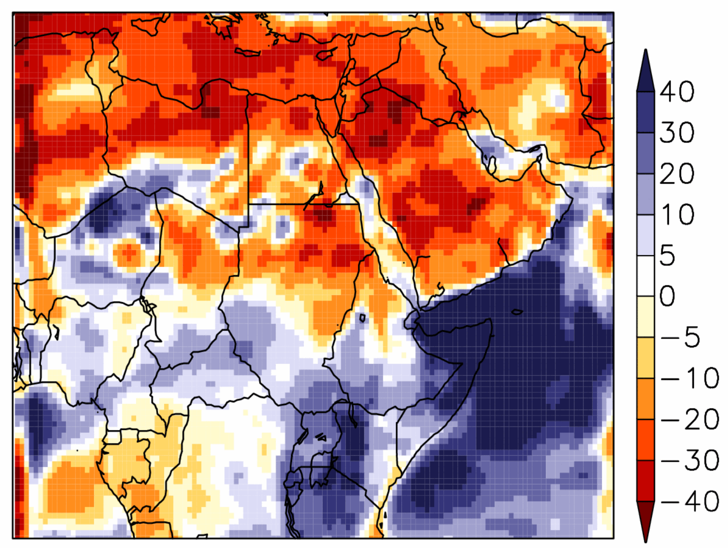


Figure 2.4

Results from the regional climate model REMO showing the relative change in rainfall for the 2071-2100 period compared to 1961-1990 using the A1B emission scenarios.(graph provided by D. Jacob of the Max-Planck-Institute for Meteorology)

2.3 Social and economic drivers influencing climate vulnerability

Land-use policies that anticipate on climate change are strongly dependent on various social and economic projections of future change. In addition, these social-economic drivers put pressure on climate change. Perhaps population change has the strongest effect on anticipated land-use policies, since food production and consumption interfere with proposed land-use changes for mitigation uses. Figure 2.5 depicts the projected population in four African regions. The strongest population growth is expected in Western Africa. The projected population growth in East Africa tends to level off from 2030 onwards, with an approximate population of 530 million in 2050.

Projections on economic development, however, are difficult to make. This development depends on many factors, like technological development and change, productivity changes, (international) trade and supply and demand of commodities. Therefore, to cover the uncertain range of possible future developments, for the IPCC assessments four contrasting scenarios (SRES) were build that predict various levels of GDP development depending on trade structures and policies. Verburg et al. (2009a) describes GDP development of a reference scenario, which projects a global population growth between the SRES scenarios A1 and B2, in various world regions. This reference scenario, however, assumes no new policies as from now including no new WTO trade policies.

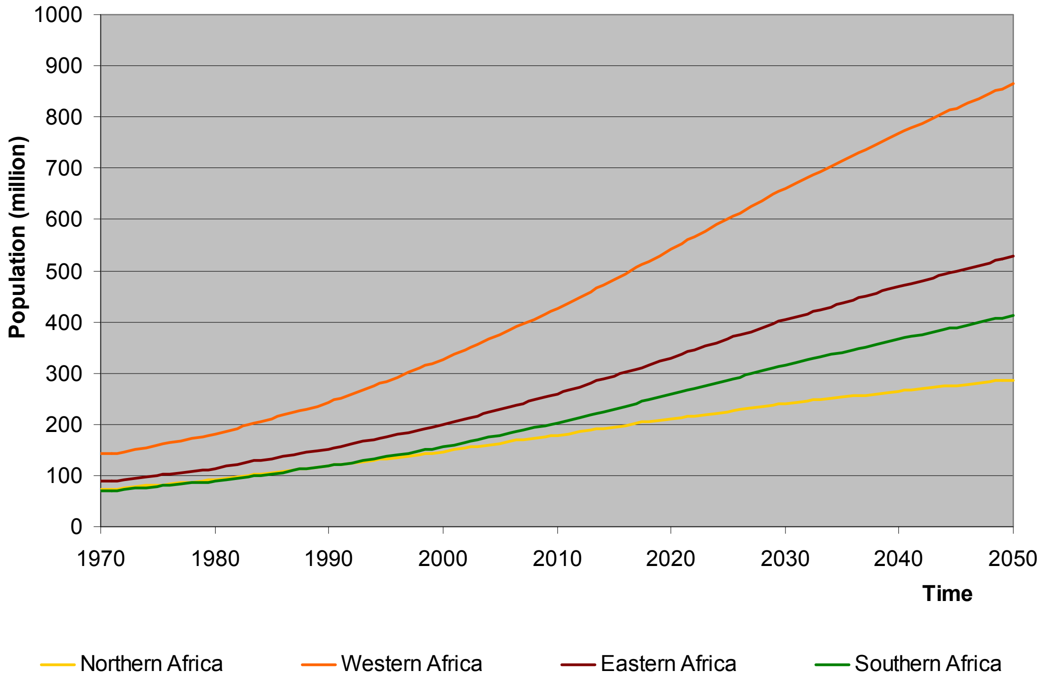


Figure 2.5
Population projections in African regions derived from IMAGE (model output). ***Northern Africa*** *= Algeria, Egypt, Libya, Morocco, Tunisia, Western Sahara.* ***Western Africa*** *= Benin, Chad, Gabon, Liberia, Saint Helena, Burkina Faso, Congo, Gambia, Mali, Sao Tome and Principe, Cameroon, the Democratic Republic of the Congo, Ghana, Mauritania, Senegal, Cape Verde, Cote D'ivoire, Guinea, Niger, Sierra Leone, Central African Republic, Equatorial Guinea, Guinea-Bissau, Nigeria, Togo.* ***Eastern Africa*** *= Burundi, Eritrea, Madagascar, Réunion, Somalia, Comoros, Ethiopia, Mauritius, Rwanda, Sudan, Djibouti, Kenya, Mayotte, Seychelles, Uganda.* ***Southern Africa*** *= Angola, Lesotho, Mozambique, South Africa, Tanzania, Zimbabwe, Botswana, Malawi, Namibia, Swaziland, Zambia*

Figure 2. depicts the development of GDP per capita in different world regions in this reference scenario. For some regions, like North America, Russia and China a steep GDP growth is projected after 2030. Africa as a whole shows a linear growth in GDP per capita. Additionally, Africa also shows the lowest GDP per capita. Although regions differ in GDP growth rate, all regions have positive growth.

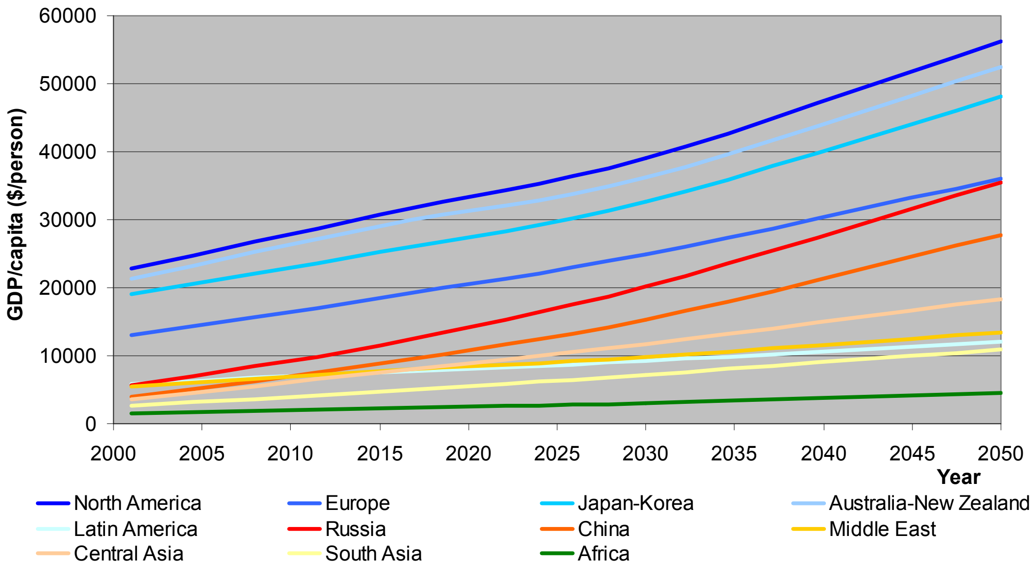


Figure 2.6

Projections on GDP/capita in different world regions in a baseline scenario with no new (trade) policies. Data adopted from Verburg et al.(2009a)

Consumption patterns are dependent on income. It is assumed that with higher income the consumption of animal protein increases (e.g. Nellemann et al., 2009). This pattern has a strong impact on land-use, since livestock production requires feed production. Figure 2.7 depicts the projected changes in grassland and cropland under a reference scenario of climate change in the four African regions of IMAGE. The strongest increase in agricultural grassland area is projected for Southern Africa, while the crop area most strongly increases in Western Africa. East Africa shows a modest growth projection in agricultural grassland and cropland area.

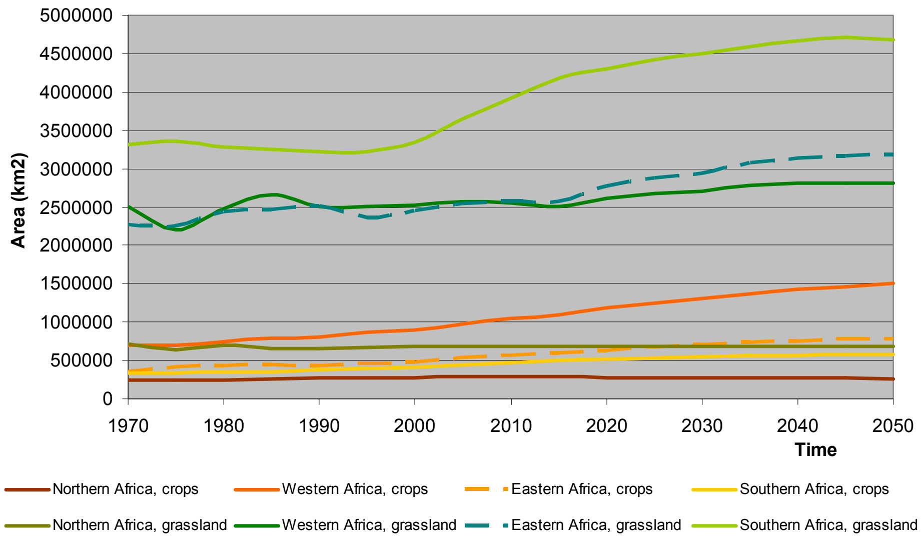


Figure 2.7

Agricultural land-use projections of grassland and cropland in African regions derived from IMAGE data. For country profiles in the four African regions, see figure 2.6

2.4 Climate change vulnerability in East Africa

Agriculture is the most important economic sector in sub-Saharan Africa, accounting for about 20-30% of GDP and 55% of the total value of exports. The World Bank estimated that about 70% of all Africans and 90% of the poor primarily work in agriculture. Similar figures were reported for Ethiopia (Gebre-Selassie, 2003; Khairo et al., 2005). The potentially high impact of climate change in East-Africa combined with the relatively low adaptive capacity of the rural population may lead to a vicious circle of further reduction of the ability to cope with the anticipated changes.

Model projections of future climate in Africa indicate that approximately 80,000 km^2 of land in Sub-Saharan Africa will be taken into use for agriculture, while 600,000 km^2 of currently moderately suitable agricultural land will become unsuitable for agriculture. At the same time the demand for food, forage and water is expected to double as a result of the rapidly increasing population in most parts of Africa.

Agriculture, ecosystem services and food security

Rain fed subsistence agriculture is dominant in the region, this type of agriculture is vulnerable to changes in rainfall patterns. Especially in the (semi-) arid regions increasingly variable conditions during the growing season of crops will disrupt subsistence production. Projections under the HadCM3 climate model with IPCC SRES A2 scenario show that for large areas in eastern Africa, especially in Ethiopia, the potential cereal output will probably decrease, while at the same time in even larger areas the output will probably increase (Appendix 3, Nellemann et al., 2009). The potential impacts vary strongly across regions.

In Africa, currently increasing population is the main driver behind increasing demand for food. At the same time in most of the least developed countries domestic food production is not able to match rapid population growth (Elasha et al., 2006; OECD/FAO, 2009).

Since in East Africa domestic production is the most important source of food (e.g. Elasha et al., 2006; OECD/FAO, 2009), future constraints in crop production will strongly affect food security and may lead to under nutrition. In a context of anticipated climate, bio-physical, economic and social changes Liu et al. (2008) projected that also in the future Ethiopia, Uganda, Rwanda and Burundi remain hotspots for food insecurity.

Based on criteria for importance of and projected sensitivity to climate change of crops Lobell et al. (2008) assessed the most important crops that need prioritized adaptation investments for different world regions. Of the assessed crops in East-Africa especially cassava, sorghum, maize and wheat would need prioritized adaptation investments (see 8; from Richardson et al., 2009, adapted from Lobell et al., 2008). Wheat is expected to show increased production, but projections using different models showed large variation, making this prediction very uncertain with some projections showing decreased production. Because wheat is an important food source, it was classified under high adaptation priority (Lobell et al., 2008).

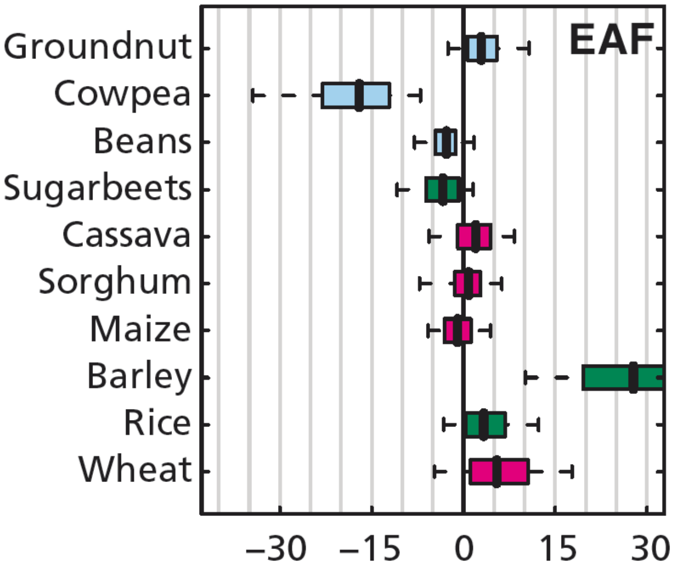


Figure 2.8
Projected climate change impacts on agricultural production in 2030 as percentage change from average 1998-2002 yields. Pink indicates high hunger importance ranking, blue indicates intermediate ranking and green less important. Importance ranking is based on a combination of the importance of the crop in East-Africa, i.e. how many people depend on it, and on it's sensitivity to climate change (from Richardson et al., 2009, adapted from Lobell et al., 2008). Climate change driven changes in crop production of important crops, on which many people depend, are thus ranked highest

Other model projections show that climate change will strongly reduce the yield of wheat, while at the same time the yield of millet was projected to increase (Figure 2.9., Liu et al., 2008). Currently the average temperature during the cropping season is already above the optimal temperature for wheat, which generally lies between 15 and 20 °C. With increasing temperatures crop yields will thus be further reduced (Liu et al. 2008).

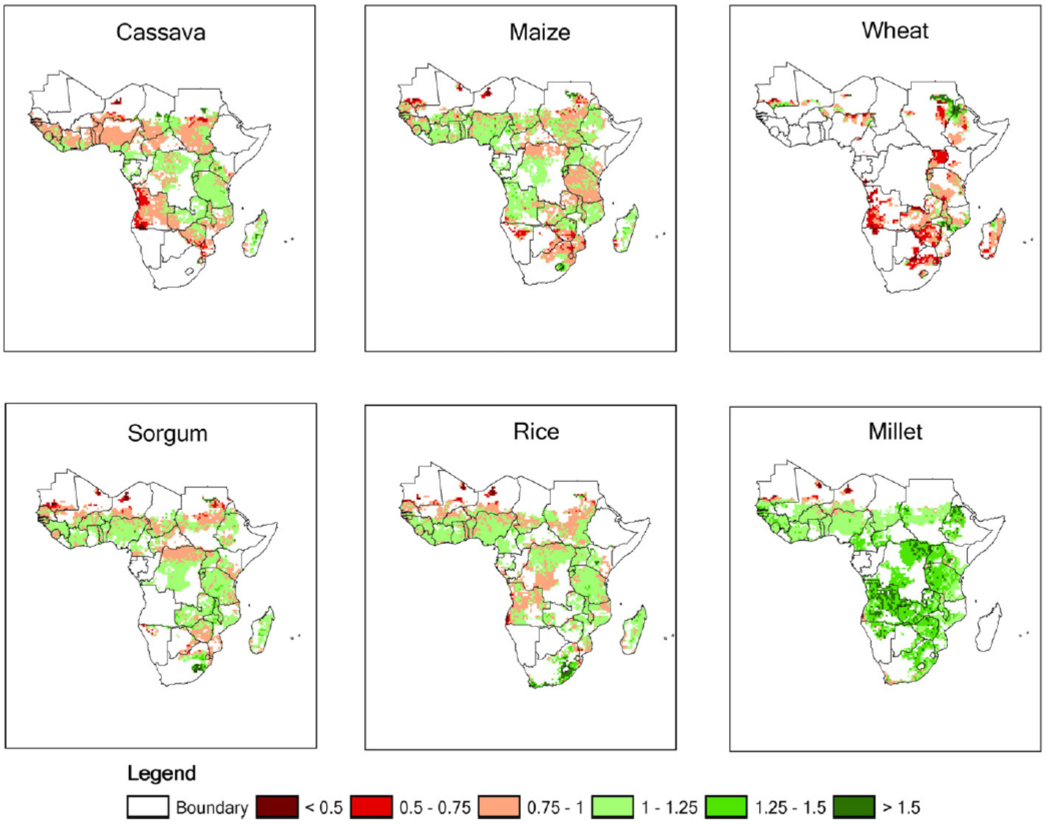


Figure 2.9

Impact ratio of climate on crop yield in 2030 in sub-saharan Africa under the SRES B2 emission and climate change scenario. Other SRES scenarios showed similar trends. (from Liu et al., 2008)

Besides agricultural products many people in East Africa depend on food products from (semi) natural ecosystems and agro-forestry production systems. Moreover these ecosystems essential in provisioning other services like drinking water and erosion control. As a result of climate change, the area of suitable habitat for species is expected to shift and/or decrease. As a result, ecosystem services that rely on sub-Saharan plant diversity, including foods and fibres, like nuts, fruits, gum and timber and locally used plant based medicines are likely to decrease. Usually areas which sustain higher levels of biodiversity generally are much more resilient to such environmental changes (Diaz et al., 2005; Tilman, 1996; Winfree and Kremen, 2009), while degraded systems are much more vulnerable to climate change.

Water availability and regulation

In 2000 in three (Kenya, Rwanda and Burundi) out of the five East-African countries that were included in the South African Millennium Ecosystem Assessment (also including Uganda and Tanzania) the amount of water available per person per year was well below 1000 m^3, which is the minimum target set by the UN to satisfy human need (Van Jaarsveld et al., 2005). Most of this water is consumed by agriculture (74% of all water used) while currently 17% is used in household consumption and 9% by industry.

The past decades have shown rapid deforestation in Ethiopia (Dessie and Christiansson, 2008; Dessie and Kleman, 2007). Usually evergreen forests are often intermixed with open spaces of edaphic grasslands and waterlogged sites (Dessie and Kleman, 2007). The most important direct cause for upland deforestation in Ethiopia is from small holder agriculture, followed in importance by commercial logging and commercial farms (Dessie and Kleman, 2007). Recorded effects of deforestation in the southern Rift Valley include drying up of streams and lakes (Dessie and Kleman, 2007), indicating a strong effect of deforestation on water availability. The degradation of wetland and forest ecosystems reduces their capacity to store and regulate water availability and mitigate flooding. Consequently this will also affect agricultural productivity, and this effect is enhanced if as a result of climate change rainfall becomes more concentrated in time. Growing human populations in combination with increasing and changing household; industrial and agricultural consumption of fresh water will in combination with climate change likely lead to water shortages in East-Africa.

3 Policies for climate change adaptation and mitigation

3.1 Introduction

This chapter firstly focuses on adaptation and mitigation options in general. The National Adaptation Programme of Action (NAPA) is taken as an input to select and define hotspot regions to carry out and deploy such adaptation and mitigation options. Agricultural issues that play an important role in hotspot areas are discussed.

3.2 Adaptation and mitigation options

Adaptation and mitigation are two separate policy responses to climate change. Both are however intrinsically linked. Mitigation is needed to reduce the impacts and allow for adaptation to take place, for ecosystems these boundaries are generally narrower than for human systems. Because mitigation measures will not be able to immediately avoid global warming (Parry et al., 2007), adaptive measurements will be needed to avert the negative consequences of climate change at the short term. On the longer term mitigation measures will be able to avoid further warming or even reduce the effect.

In sustainable development both adaptation and mitigation need to be taken into account. Development should be **climate-safe** i.e. development that leads to a low vulnerability to climate change and **climate-friendly** i.e. development that leads to low emissions. In agricultural and other land-use systems where adjustments in response to climate change will directly have an impact on the emission profile, the link between adaptation and mitigation is particularly strong. Identifying smart combinations of robust and low carbon development pathways is needed. In most cases this will direct development to higher efficiencies of land and inputs.

Greenhouse gas (GHG) emissions from the land-use sector are on one hand caused by existing and changing agricultural practices and on the other hand caused by changes in land-use.

In developing countries increasing development of the agricultural sector often results in increasing numbers of livestock and increasing input of agro-chemicals (especially N) through application of fertilizers, pesticides and herbicides. The increase in nutrient (N) input into agricultural systems may leads to increased Nitrogen emissions (N_2O, NO and N), but could also increase carbon sequestration, contributing to increased soil fertility. Increasing numbers of livestock will contribute to increasing CH_4 emissions through enteric fermentation. Structural changes in agricultural systems should apart from looking at the vulnerability of these systems also address the potential effects on soil carbon, methane and nitrous oxide emissions.

Reid et al. (2004) analysed mitigation options for pastoral ecosystems of the tropics. There are three classes of carbon dioxide options, i.e. (i) protection, such as preventing the conversion of pastoral land to croplands, (ii) sequestration, such as improved pasture productivity, and (iii) substitution, such as the use of renewable biological products. The dominant option for mitigation of methane emission is improved livestock management. Productivity gains are usually associated with reduced methane emissions. There is a wide variety of options to increase productivity such as improved feed quality, reduction of sick and non-productive animals, and genetic improvements. Despite the technological potentials, these options are only realistic if they are accompanied with other efforts that improve the livelihood of pastoral communities.

Increasing emissions from land-use change are mainly driven by deforestation and conversion of forests to agricultural land. In the first place conversion of forests or woodland areas to agricultural use will result in immediate emissions and losses of carbon fixed in the wood. At the same time the carbon fixation potential of the land will be reduced. Finally, also increased emission from agricultural practices should be accounted for in an analysis of GHG emissions from land-use change. Mitigation options from land-use include reforestation and afforestation, more sustainable forest management practices and reducing deforestation and forest degradation. Because about 20% of total global carbon emissions result from deforestation and forest degradation, in the Bali road map resulting from the UNFCCC COP14 in Bali in December 2008, it was agreed to work out a system to financially stimulate developing countries to reduce deforestation and forest degradation (REDD).

Although with the proposed UNFCCC measure of Reduced Emissions from Deforestation and forest Degradation (REDD) a lot of attention goes to tropical rain forests, in for instance Brazil and Indonesia, we have to bear in mind that forest resources are common in most countries. About 11.9% or 3,000,000 hectares of Ethiopia is under forest cover. Between 1990 and 2000, Ethiopia lost an average of 140,900 hectares of forest annually. This amounts to an average annual deforestation rate of 0.93%. Between 2000 and 2005, the rate of decline of forest area increased by 10.4% to 1.03% per annum. In total, between 1990 and 2005, Ethiopia lost 14.0% of its forest cover, or around 2,114,000 hectares.

Using the data as reported in the FAO Forest resource assessment country report of Ethiopia ({FAO, 2005 #3393}) the amount of carbon in total living biomass in high woodland can be estimated at 16.1 ton C ha^{-1}, and in forest at 54.2 ton C ha^{-1}. Of the total annual deforestation of 140,900, about 57% occurs in high woodland and 43% in forest, resulting in an annual loss of 1.3 million ton carbon from high woodland and 3.3 million ton carbon from forest. Together this results in 16.8 million ton CO2 emissions. Reducing the deforestation rate with 50%, about 8.4 million tons of carbon dioxide emission would be avoided annually. Prices are still unclear but with a price of 5 US$ per ton carbon dioxide we are looking at 42 million US$ each year. This crude calculation would not be sufficient to meet forthcoming UNFCCC reporting standards for REDD, and did not take into account discount rates, the transaction costs and risks related to the carbon market, but gives a good impression about the magnitude of the benefits.

Forests and agriculture cannot be seen in separation in developing countries; therefore integrated regional analyses of mitigation are a way forward to support local policy-makers, both for reduction of GHG emissions as well as to support and link to adaptation processes.

Probably facilitating adaptation and mitigation measures in many cases compete for resources (Tol, 2005), especially in countries with limited funds. In the follow-up to the Kyoto protocol, mechanisms for reducing emissions from deforestation and forest degradation (REDD) are likely to be included, potentially providing mitigation related income for developing countries. Cost-benefit analysis of different adaptation and mitigation options subsequently should reveal the most efficient policy options for sustainable development under climate change.

Finding combinations where emission reduction and adaptation to climate change are tackled at the same time, is a big effort for developing countries. **Mainstreaming** this climate change action in land-use related policies is a longer-term need for policy makers.

In the context of climate change the **adaptive capacity** of people and societies indicates how well they are able to cope with the potential impacts of climate changes on provisioning of vital ecosystem goods and services, including food and fibre production, prevention of natural disasters and biodiversity. In general poorer societies that depend more directly on ecosystems for their livelihoods are most vulnerable.

Yohe and Tol (2002) indicate eight main determinants of adaptive capacity according IPCC (2001 - Chapter 18).

- The range of available technological options for adaptation,
- The availability of resources and their distribution across the population,
- The structure of critical institutions, the derivative allocation of decision-making authority, and the decision criteria that would be employed,
- The stock of human capital including education and personal security,
- The stock of social capital including the definition of property rights,
- The system's access to risk spreading processes,
- The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers, themselves, and
- The public's perceived attribution of the source of stress and the significance of exposure to its local manifestations.

3.3 Ecosystem goods and services

In East Africa many people depend directly on the many services that ecosystems provide such as food, fibre, water resources, climate regulation and flood mitigation. The concept of ecosystem services (MEA, 2003; MEA, 2005) links human well-being to goods and services that ecosystems provide. 'Ecosystem' in this context refers to both natural and human managed ecosystems, including agricultural systems, as sources of services (MEA, 2003). It includes both tangible and intangible benefits that humans get from ecosystems. Besides goods and services that represent a direct economic value and trade opportunities, there are also services that don't represent a direct economic value, but still are important for ecosystem functioning, agricultural productivity and human well being in general.

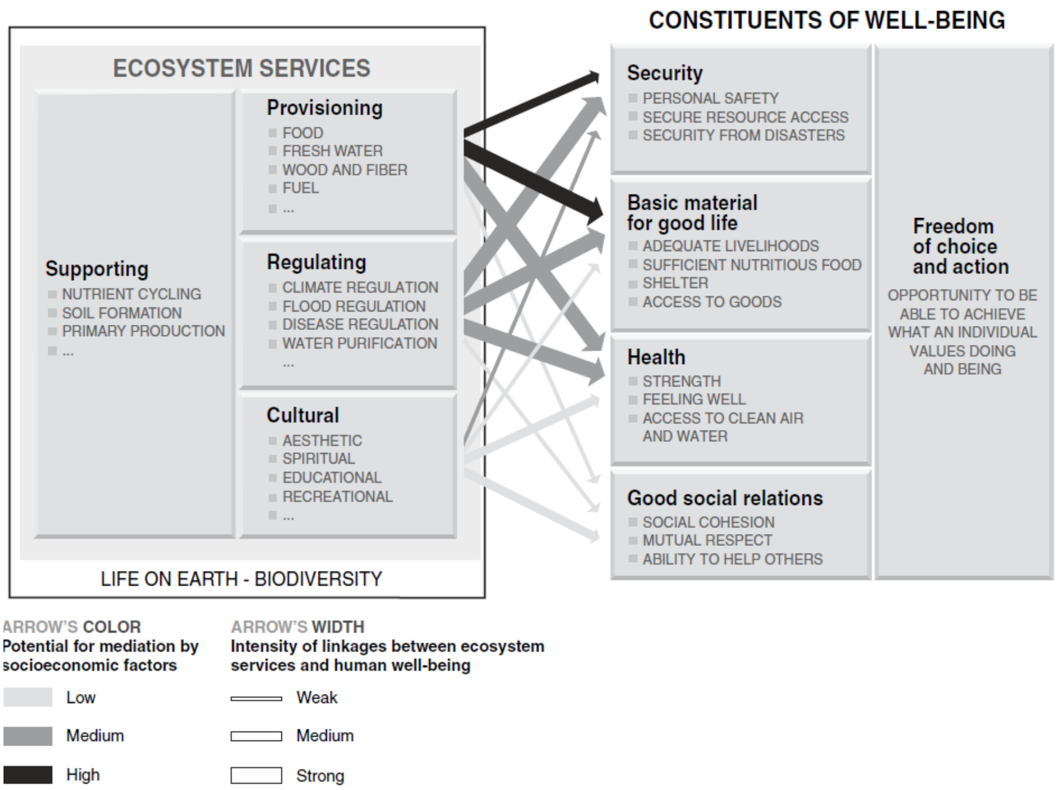


Figure 3.1
Linkages between ecosystem services and human wellbeing (from: MEA, 2005)

Biodiversity is an important factor determining availability of certain ecosystem services. Changes in biodiversity will have effects on how the ecosystem functions and the services it is able to provide (Schulze and Mooney, 1993). The link between biodiversity and level of services that the ecosystem provides are nevertheless complex (Diaz et al., 2005; Kremen, 2005; Luck et al., 2009). Most of the services appear to depend mainly on relatively few functional components of biodiversity (Balvanera et al., 2006; Diaz et al., 2005; Jackson et al., 2007). There is, however a more direct link between level of biodiversity and ability of ecosystems to respond to environmental and anthropogenic changes, with more diverse system generally being more resilient to changes (Diaz et al., 2005; Tilman, 1996; Winfree and Kremen, 2009).

In general humans are very good at cultivating important agricultural species, but less good at managing ecosystems to provide regulating services. Intensive management on one hand maximises ecosystem provisioning of certain goods, such as agricultural products, but also results in replacing diverse systems with one or a few species of importance (e.g. Braat and Ten Brink, 2008; Ten Brink et al., 2007). When productivity of one or a few (agricultural) species is maximized, usually some of the ecosystems services are replaced by human activities, such as the substitution of soil fertility based on nutrient cycling with application of artificial fertilizers (e.g. Van Jaarsveld et al., 2005). Overexploitation and oversimplification of ecosystems will lead to degradation of the system and eventually to loss of services provided by the ecosystem (Braat and Ten Brink, 2008).

Natural or well-managed ecosystems are able to buffer part of the climate variability, especially for water availability. Dessie and Kleman (2007) showed that deforestation during the last decades in the south central rift valley in Ethiopia resulted in drying up of streams and lakes. The main causes of deforestation were expansion of mainly small subsistence farming and to a lesser extent commercial logging and commercial farming. Although subsistence farming is an important local livelihood activity, its relatively widespread practice has resulted in environmental degradation and loss of vital ecosystem functions, such as water storage and regulation. As a result agricultural productivity was reported to rapidly decrease in this region. With more extreme events and more concentrated rainfall, the effect will likely worsen under climate change. A climate adaptation strategy should therefore include restoration of the degraded ecosystems and a shift to more efficient and sustainable management practices.

3.4 National Adaptation Programmes of Action

The National Adaptation Programmes of Action (NAPAs) focus on urgent and immediate needs - those for which further delay could increase vulnerability or lead to increased costs at a later stage. NAPAs should use existing information; no new research is needed. They must be action-oriented and country-driven, be flexible and based on national conditions. Finally, in order to effectively address urgent and immediate adaptation needs, NAPA documents should be presented in a simple format, easily understandable both by policy-level decision-makers and by the public (http://unfccc.int/national_reports/napa/items/2719.php).

The steps for the preparation of the NAPAs include synthesis of available information, participatory assessment of vulnerability to current climate variability and extreme events and of areas where risks would increase due to climate change. They should identify key adaptation measures as well as criteria for prioritizing activities, and select a prioritized short-list of activities. The development of a NAPA also includes short profiles of projects and/or activities intended to address urgent and immediate adaptation needs for least developed countries (LDC Parties). The UNFCCC secretariat had received NAPAs from 38 least developing countries by October 2008. Amongst East African countries, Burundi, Djibouti, Eritrea, Ethiopia, Rwanda, Sudan, Tanzania and Uganda have produced a NAPA. Kenya, as a non-annex 1 country, does not have a NAPA, but made a National Communication. In all NAPAs agricultural land-use and forestry play an important role in the implementation of adaptation strategies.

3.5 The NAPA of Ethiopia

In the NAPA of Ethiopia, 37 adaptation options are identified through vulnerability assessment and different consultative workshops. These are then prioritized using a multi-criteria assessment, using criteria as suggested by the Least Developed Countries Expert Group (Table 3.1). Weights are assigned and approved by the Ethiopian National Climate Change Steering Committee (Tadege, 2007). The strongest weight was put on the level of climate change risk (see Table 3.1)

Table 3.1
Description of Criteria and their weight from the NAPA of Ethiopia

Criteria	**Weights**
Level of Climate Change Risk (Loss Avoided by Poor People)	0.20
Poverty reduction potential (Impact on poor peoples' Income Growth)	0.20
Cost effectiveness	0.15
Complementarities with national and sectoral plans, policies & strategies and other MEAs	0.15
Synergy with national plans including action plans under MEAs	0.30

The National Adaptation Program of Action (NAPA) of Ethiopia (2008) recognises a high climate vulnerability of its main economic activities. In the NAPA vulnerability assessments are carried out, based on existing information and rapid assessments. This information has indicated that the most vulnerable sectors to climate variability and change are agriculture, water and human health. In terms of livelihood approach smallholder rain-fed farmers and pastoralists are found to be the most vulnerable (Tadege, 2007). The arid, semiarid and the dry sub-humid parts of the country are affected most by drought. Based on a multi-criteria analysis where weights were put on the urgency of matter a ranking of projects was carried out. The NAPA of Ethiopia describes a number of adaptation projects to be carried out in climate change vulnerability. Based on this full list (Appendix 2) an analysis of selected projects of the NAPA (Appendix 2) was carried out where a clear land-use component was emerging. This has brought the project list down to 11 projects (Table 3.2).

Although all projects listed in table 3.2 have a clear land-use component, not all issues can be addressed by the framework developed in the next chapter. A next step was carried out where the list depicted in table 3.2 was analysed using the following criteria:

- Focus on natural resource management and agriculture
- Relevant contribution from research possible
- A mitigation component or possibility to add this component

Based on these criteria the eleven projects were reviewed for use in the current project. Table 3.3 lists the projects and their usefulness for the climate change project.

Table 3.2
Projects described in the NAPA of Ethiopia with a land-use component (Appendix 2 of Ethiopia NAPA)

Nr	**Description of NAPA project**	**Estimated Cost (million USD)**
1	Promoting drought/crop insurance programme in Ethiopia	8
2	Strengthening/enhancing drought and flood early warning systems in Ethiopia	10
3	Development of small scale irrigation and water harvesting schemes in arid, semi-arid, and dry sub-humid areas of Ethiopia	30
4	Improving/enhancing rangeland resource management practices in the pastoral areas of Ethiopia	2
5	Community-based sustainable utilization and management of wetlands in selected parts of Ethiopia	2
6	Capacity building program for climate change adaptation in Ethiopia	3
7	Realizing food security through multi-purpose large-scale water development project in Genale–Dawa Basin	700
8	Community Based Carbon Sequestration Project in the Rift Valley System of Ethiopia	1
9	Establishment of national research and development (R&D) center for climate change	2
10	Strengthening malaria containment program(MCP) in selected areas of Ethiopia	6
11	Promotion of on-farm and homestead forestry and agro-forestry practices in arid, semi-arid and dry-sub humid parts of Ethiopia	5
	Total	770

Table 3.3
Short review of the NAPA projects

Nr	Natural resource management	Research possibilities	Mitigation component	Remarks
1	Limited link aims at developing an insurance program	Not clear	No	-
2	Possible but not clearly stated.	Yes	Fire risk could be part of the early warning.	Strong focus on meteorology but aims at early warning for end users.
3	Yes, crop and livestock	Yes: water utilization at the farm and landscape level.	Not clear but could be included via soil and livestock management	Focus on water harvesting and irrigation
4	Rangeland management	Yes rehabilitation of rangelands.	Yes via land degradation and livestock	Adaptive research is mentioned but not specified.
5	Wetland utilization	Identification of wise use options given climate change	No	-
6	Capacity building	Training	Yes	Fits the course
7	Assessment of on existing plans aiming at food security	Yes	Via electricity	Location clear: Genale-Dawa Basin. Focus on food, water, livestock
8	Forestry	Identification of potential areas	Yes	Afforestation
9	Establish research centre	No	No	-
10	No	Yes	No	Focus on health (malaria)
11	Forestry/ agroforestry	Yes	Yes	Fruit trees, stakeholder consultation.

Based on this list, linkages to proposed NAPA projects in the area of rangeland management (land degradation and livestock, and forestry/agroforestry (coffee/regreening) are most obvious to assess adaptation and mitigation options using a framework in which the different options can be explored. This assessment is in agreement with the vulnerability analysis done during the NAPA process; where ‘in terms of livelihood approach’ smallholder rain-fed farmers and pastoralists are found to be the most vulnerable’ (Tadege, 2007).

3.5.1 Coffee/Re-greening of (semi-) arid regions in Ethiopia

The Central Rift Valley is an important area providing many commercially important natural resources, while at the same time densely populated. Degradation of the Acacia forests in the region during the past decades has resulted in profound erosion problems and loss of biodiversity. One of the priorities in the NAPA is to rehabilitate these Acacia forests. The project will assess and quantify the possibilities of such rehabilitation to improve provisioning of essential ecosystem goods and services like erosion control, carbon sequestration, and fuel wood. This will be linked to the 'Horn re-greening programme' as coordinated by the Horn of Africa Regional Environment Centre (HoA-REC).

Because coffee is a major export commodity for Ethiopia and considered to be relatively sensitive to future climate change, it is an important focus for adaptation strategies. Different alternative options of agro-forestry systems and/or replacement to suitable areas will be assessed. Because this will need to be done on a large landscape scale level, also other land-use planning needs are to be considered. Therefore this will be considered as an integral part of the re-greening thematic focus.

Many native tree species play an important role in nitrogen fixation in soils in the arid, semi-arid and dry sub-humid parts of Ethiopia, leading to natural soil improvement and fertilisation. As a consequence harvesting of these trees without replanting, or replanting with non-native tree species leads to soil degradation and loss of tree productivity. The project will further assess the possible replanting with native species in an agro-forestry system and asses the effects on provisioning of various ecosystem services from a climate adaptation and mitigation perspective.

3.5.2 Pastoralists

As stated in the NAPA, pastoralists are among the most vulnerable people. Their livelihoods depend on the environment, which is both threatened by climate change, as well as climate variability and related the extorted balance between carrying capacity/population pressures.

3.6 Closing statements

With a focus on different hotspots in the area, climate change adaptation and mitigation options can be analysed. Rehabilitation of (agro) forest areas and reforestation will be able to provide multiple ecosystem functions reducing land degradation, reducing climate vulnerability and potentially improving local livelihoods.

Once a framework for analysis has been established, the project will assess the consequences of potential improvement of ecosystem functions as proposed in the NAPA and from a perspective of climate adaptation and mitigation. Provisioning of ecosystem services will be quantified, in which the following functions may be considered:
- Mixed agro-forests with coffee farming in higher altitudes
- Reforestation for carbon credits
- Retention of water in the soil for agricultural production
- Provisioning of fodder and firewood from forest debris
- Land use changes
- Animal feed as used by pastoralists

The wider perspective is that climate change adaptation contributes to an on-going change process, in which multiple stakeholders are engaged, which takes place at different levels, and where uncertainties and risks need to be addressed in a complex situation. The future cannot be predicted and some results will emerge during the process. However, it is certain that the future requires the ability of people to adjust, which may be difficult for people living in an already vulnerable position.

For a country as a whole, this means a changed science-policy interface, where scientists face increasing uncertainty, and the need to communicate this uncertainty to policy makers, while policy makers need to operate in a complex situation, where they need transparent and democratic decision making.

4 Description of the framework

4.1 Introduction

The framework addresses the impact and effectiveness of adaptation and mitigation land-use policy options in the context of sustainable development. Hence, proposed policy options should not only take into account responses to climate change, but should also add to sustainable development goals in a hotspot region.

A hotspot is a region of high or special activity within a larger area of low or normal activity (Wikipedia, 2009). With regard to climate change, climate change impacts and the need for adaptation and mitigation, hotspots can be identified.

In Ethiopia the vulnerability to climate change varies over the country (see chapter 2). Besides climate change differences, there are differences in farming systems, population density and related population pressure. The eight regions of Ethiopia, Somali, Oromiya, Afar, Amhara, Tigray, Benshangul, Southern and Gambela, are therefore vulnerable to climate change in different ways.

In June 2009 a course on climate change adaptation was given in Addis Ababa. This course was set up for scientists from East African countries. During the course three different climate change hotspots were identified, using the three perspectives of sustainable development (people - planet - profit); the ecosystem in which the highly important export crop coffee is grown by smallholders; the pastoralists in the south- eastern part of the country, living in a highly degraded area; and the food insecurity of vulnerable groups throughout the country.

4.2 Analytical framework with sequential steps

An analytical framework in which various models will assess effects of land-use change should be generic in its application for different kinds of land-use policies relating to adaptation and mitigation, in an array of hotspot regions throughout East Africa.

The 6th EU framework project LUPIS developed an analytical framework to assess impacts of land-use policies. This LUPIS framework is adapted for use with the current models described in this chapter and implementation of climate change mitigation and adaptation policy options for the East Africa region. Figure 4.1 depicts this conceptual framework.

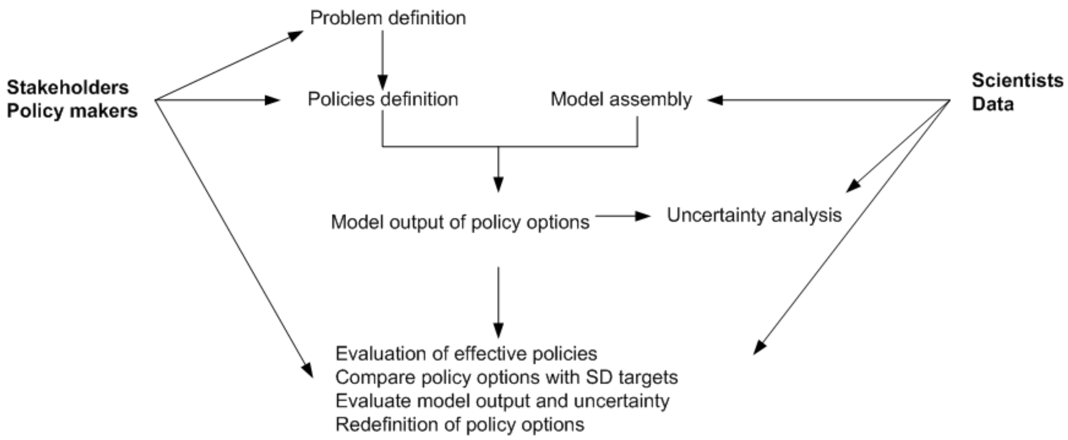


Figure 4.1
Analytical framework of the science-policy interface. Stakeholders and policy-makers are involved in problem and policy definition while scientists provide data and models. The model assesses policy options and uncertainty of model output. Calculated effects of model output are evaluated by stakeholders and policy-makers. Policies might be redefined according to (desired) model output. Evaluation scheme adopted from Reidsma et al. (2008a)

The framework is an example of an (interactive) interface between policy making and science. On one side policy-makers and stakeholders are involved by describing and defining the problem and the proposed (adaptation and mitigation) policies in a hotspot area. Scientists on the other side provide data and run the models that assess the different policy options. The evaluation of results involves both sides; scientists, policy-makers and stakeholders. Both the uncertainty of model output, provided by scientists, and the effectiveness of policy options against sustainable development goals are evaluated by all parties. A feedback loop can be included where policies are redefined according to the preferred results and deviation from sustainability targets.

The following section describes the more technical aspects of the framework.

4.3 The modelling framework

The proposed modelling framework comprises a projection compartment, a policy compartment, a simulation compartment and an evaluation compartment. The projection and policy compartment provides input for the simulation compartment. For each policy option a full modelling cycle will be carried out. Based on this input, data are modelled and the output of data is distributed among dimensions of sustainable development (People-Planet-Profit) and associated Land Use Functions (see section 4.7). All data output (in terms of data responses to policy options, given assumptions on future projections on climate change, social and economic change) are then put into the evaluation compartment. In this compartment performance of policy options is calculated and policy options will be ranked according to their performance. A feedback loop can be included in which the effects of policy options can be anticipated in such way that policy options can be adapted. In that case a new full simulation cycle should be carried out. Each compartment is briefly described in the following sections.

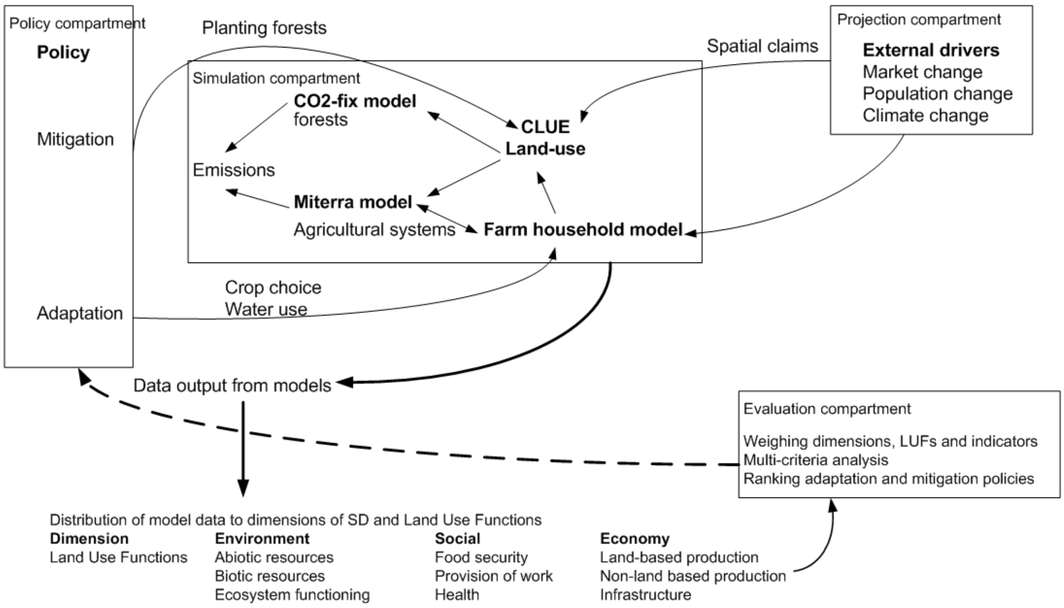


Figure 4.2
The modelling framework

4.4 The projection compartment

This compartment produces projected data on climate change, demography, and market change like trade negotiations. The compartment is considered an autonomous process of factors affecting the efficiency and effectiveness of applying local (land-use) policies. Although some projected changes are the result of policy choices, like WTO negations on trade, they are considered external drivers for hot spot case studies since they cannot be affected or influenced by local policy-makers. Projected data on autonomous processes are described in Chapter 2.

4.5 The policy compartment

Within this compartment adaptation and/or mitigation policies are described. These policies are described precisely with actions that should be undertaken. Moreover, a baseline policy should be described where no particular adaptation and/or mitigation options are included. This baseline is considered the policy inaction variant. The policy options are specific for the hotspot case studies, are land-use based and described in general terms in Chapter 3. The design of the policies is carried out in consultation with local stakeholders, policy-makers and adaptation from country specific NAPAs. All described policies are input for the simulation compartment.

4.6 The simulation compartment

This compartment is the core of the modelling framework and comprises a set of simulation models. Each model has been used in different Wageningen UR projects and combined in this framework. The following section briefly describes each model component.

4.6.1 CO2-fix model

The CO2-fix model can be used to assess carbon sequestration potential of forest management, agro-forestry and afforestation and of the potential carbon emission of land-use change (i.e. deforestation, forest conversion to other land-uses such as agriculture). It was originally designed for even aged mono-species stands, but has also been used for a wide variety of forest types from all over the world, including tropical plantations and selective logging systems. The model simulates stocks and fluxes of carbon in trees, soil, and -in case of a managed forest- the wood products, as well as the financial costs and revenues and the carbon credits that can be earned under different accounting systems. The model is able to assess potential revenues from round wood production, as well as carbon trading. Stocks, fluxes, costs, revenues and carbon credits are simulated at the hectare scale with time steps of one year. The results have been used in the second IPCC report, for example. A beta version of a landscape scale model is available to assess the consequences of land-use change on carbon dynamics. This model combines landscape level land-use projections from the CLUE land use model (e.g. Verburg et al., 2007) with the CO2-fix projections on the 1 ha scale.

The CO2-fix model is extensively described in Masera et al. (2003) and Schelhaas et al. (2004). Applications of the model can be found in for example Gaboury et al. (2009), Groen et al. (2006), Nabuurs et al. (2008), Nabuurs and Schelhaas (2002) and one for soil organic carbon sequestration in south-western Ethiopia (Lemma et al., 2007). Here only a short summary is given. The model exists of six modules: 1) biomass module, 2) soil module, 3) products module, 4) bio-energy module, 5) financial module, and 6) carbon accounting module.

The modular structure of the model is illustrated in Figure 4.3. The biomass module converts volumetric net annual increment data of the tree stand with the help of additional parameters to annual carbon stocks in the biomass compartment. Biomass turnover and harvest parameters drive the fluxes into the soil and the products compartment. In the soil module, decomposition of litter and harvest residues is simulated using basic climate and litter quality information. The fate of the harvested carbon is determined in the wood products module, using parameters like processing efficiency, product longevity and recycling. In the bio-energy module, discarded products or by-products from the product module can be used to generate bio-energy, using varying technologies. The carbon accounting module keeps track of all fluxes to and from the atmosphere and determines the effects of the chosen scenarios, using different carbon accounting approaches. The financial module uses costs and revenues of management interventions to determine the financial profitably of the different scenarios.

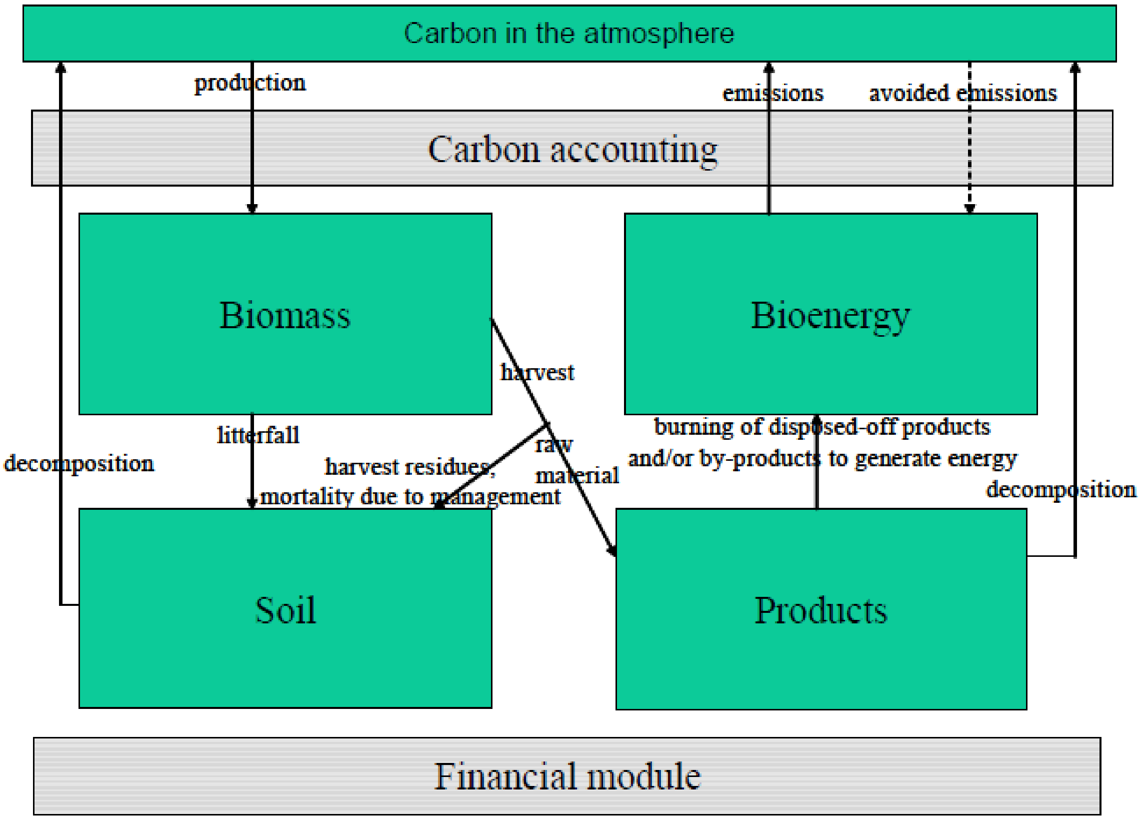


Figure 4.3
The modules of CO2-FIX V 3.1 (Schelhaas et al. 2004)

4.6.2 Miterra model

The Miterra model is a tool for integrated assessment of N, CH_4 and CO_2 emissions from agriculture. The effects of measures and policies aiming at reducing emissions can be quantitatively assessed, while benefits and tradeoffs of measures and policies can be identified. Primary input data are soil maps, with information on texture, organic carbon and area of peat soils and statistical data on crop areas, number and type of livestock, fertilizer consumption, yield, type of manure and amount of processed manure. Scenarios can be built to assess for instance the potential effects of changes in crop areas, animal numbers, fertilizer use and the adoption of specific mitigation and emission reduction techniques. An extensive description of Miterra is given in Van Groenigen et al. (2008) and Velthof et al. (2009).

4.6.3 Farm household model

Agricultural activity depends on inputs and results in outputs. Inputs and outputs can be expressed in physical units (e.g. tons/ha) and in monetary units. To analyse resource use efficiency the use of inputs can be expressed per unit primary output, or per unit area. Emissions can be expressed also per unit primary output, per unit area or per unit input. The information relating inputs and outputs is presented in so-called technical coefficients (e.g. Reidsma et al., 2008b).

FSSIM

In the EU 6th framework project SEAMLESS, the Agricultural Management Module (FSSIM-AM) is developed as input for the mathematical programming model FSSIM-MP. FSSIM-MP requires quantitative information on input-output relationships of agricultural activities. Computer programs, often referred to as Technical Coefficient Generators (TCGs), have been developed to quantify a large number of activities (Hengsdijk and Van Ittersum, 2003). Most of these TCGs are targeted at specific regions or production systems. FSSIM-AM is a generic system that can generate all feasible production enterprises (crop rotations or livestock systems) and production techniques (a set of agronomic inputs characterized by type, level, timing and application). The set of activities as generated by FSSIM-AM can be evaluated by the dynamic and mechanistic cropping systems model Agricultural Production and Externalities Simulator (APES) in terms of yields and environmental effects, before use in FSSIM-MP. FSSIM-AM is applicable for all farming systems in the European context and potentially also in other situations.

FSSIM-AM includes (1) a procedure to derive (current) activities using a survey and a complementary procedure using European farm accountancy data, (2) a Production Enterprise Generator, (3) a Production Technique Generator and (4) a Technical Coefficient Generator.

The first step is mainly used to quantify current activities, but some of the data can also be used to generate alternative activities. The procedures for constructing production enterprises and production techniques are quite different for both types of activities. As the procedure to quantify current activities (Bellocchi et al., 2006; Zander et al., 2008) differs from quantifying alternative activities (Janssen et al., 2006).

4.6.4 Land-use allocation

Adaptation and mitigation strategies claim land in a region. The allocation of a particular land-use to other uses determines the capacity for such strategies and the efficiency. In the modelling framework land-use allocation should be accounted for and several methods can be applied. Simple accounting measures can be calculated with Excel accountancy sheets. Moreover, specific software programmes can be applied, which are solely developed for such purposes. CLUE is a modelling framework that can take into account land-use allocation and this framework is highly suitable to calculate land-use allocation for different policy options on adaptation and mitigation strategies.

The Conversion of Land Use and its Effects modelling framework (CLUE) (Veldkamp and Fresco, 1997; Verburg et al., 1999) was developed to simulate land use change using empirically quantified relationships between land use and its driving factors in combination with dynamic modelling of competition between land use types (Verburg, 2008).

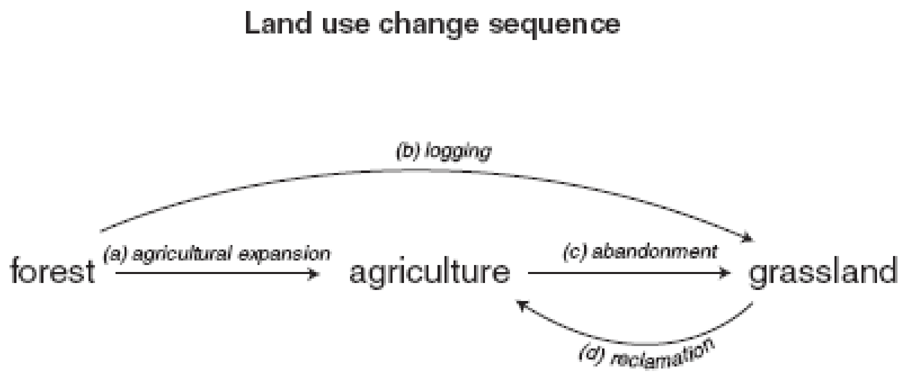


Figure 4.4
Illustration of the translation of a hypothetical land use change sequence into a land use conversion matrix. Source: Verburg (2008)

4.7 Evaluation compartment

The final phase of the framework evaluates the effectiveness of mitigation and adaptation options (policies) in relation to climate change in the evaluation compartment. Basically, this compartment consists of two aspects: data retrieval from the simulation compartment and the valuation of criteria by stakeholders and policy-makers. For the evaluation both aspects are combined in an integrated tool (multi-criteria analysis).

Indicator response data
The simulation compartment produces data that are used for evaluation. For this purpose, the data produced by the models may have to be aggregated into different indicators (see Appendix 5). Such modelled data varies with the policy options that are assessed. A useful approach to study the effectiveness of policies (alternative options) is to include current policies without climate change and current policy with projected climate change. These current policies are considered a non anticipating climate action plan. Hence such policies can be defined as policy inaction variants, therefore providing information on the so-called 'cost of policy inaction' (e.g., Verburg et al., 2009b). The responses of indicator values under various policy options are then calculated in the Land Use Function (LUF) approach.

Dimensions of sustainable development
The evaluation explicitly takes into account the development of social, economic and environmental issues. Hence, the evaluation procedure gives insight into sustainable development in a particular case study (hotspot area).

The framework is based on the interaction between the three dimensions through land-use. External drivers from the projection module such as market change, demographic change and climate change affect land-use and therefore the performance of the dimensions. Special reference should be given to the institutional dimension. This dimension refers to the ability of institutions to employ policies and regulations effectively and efficiently. The institutional dimension is therefore crucial in the practical world, but difficult to quantify. While numerical models (and data) exist to project changes in the three 'classical' dimensions, this is not the case for the institutional domain. The SEAMLESS project developed a tool for the institutional capacity in Europe to deploy policy options (Schleyer et al., 2006). Such a tool however is not available for less developed countries and therefore the institutional capacity to carry out effective policies will only be described in qualitative terms within the framework.

Evaluation with Land Use Functions
The land use function (LUF) approach connects the dimensions of sustainable development, as described in the previous section, with land-use. This approach is originally developed in the SENSOR project (EU 6th framework project e.g., Pérez-Soba et al., 2008) and adopted in climate change projects (Verburg et al., 2009b).

The LUF approach aims at pointing out regional differentiations of land use-relevant goods and services on human society within rural areas that are primarily affected by land use changes. Thus land-use is redefined in terms of functions. Each dimension (social, economic, environmental) is represented by three functions that have a land-based origin. In total nine LUFs are developed for all dimensions of sustainable development (see Figure 4.5) and defined as follows (i.e. Reidsma et al., 2008a):

Social functions
1. **Provision of work**: refers to the employment provision for all, according to activities in relation with natural resources; quality of jobs, lack of job security, localisation of jobs (constraints / commuting);
2. **Human health & Recreation** (spiritual & physical): refers to access to health and recreational services and factors that influence services quality;
3. **Food security**: refers to food self sufficiency.

Economic functions
1. **Residential and non-land industry and services**: refers to the space where residential, social and productive human activity takes place in a concentrated mode. The utilisation of the space is mainly irreversible due to the high concentrations of the buildings;
2. **Land based production**: refers to human productive activities that determine changes which are mainly reversible (agric, for, natural energy sources, land based industry -mining);
3. **Infrastructure**: refers to the space used for infrastructures that determine changes which are irreversible.

Environmental functions
1. **Provision of abiotic resources**: refers to the capacity of the land to provide sufficient quantity and quality of air, water and soil;
2. **Support & Provision of biotic resources**: refers to factors affecting the capacity of the land to provide biodiversity, from the genetic diversity of organisms to a diversity of habitat in the landscape that are in suitable ecological condition;
3. **Maintenance of ecosystem processes**: refers to the capacity and factors affecting to vital processes such as water purification, nutrient cycling, etc.).

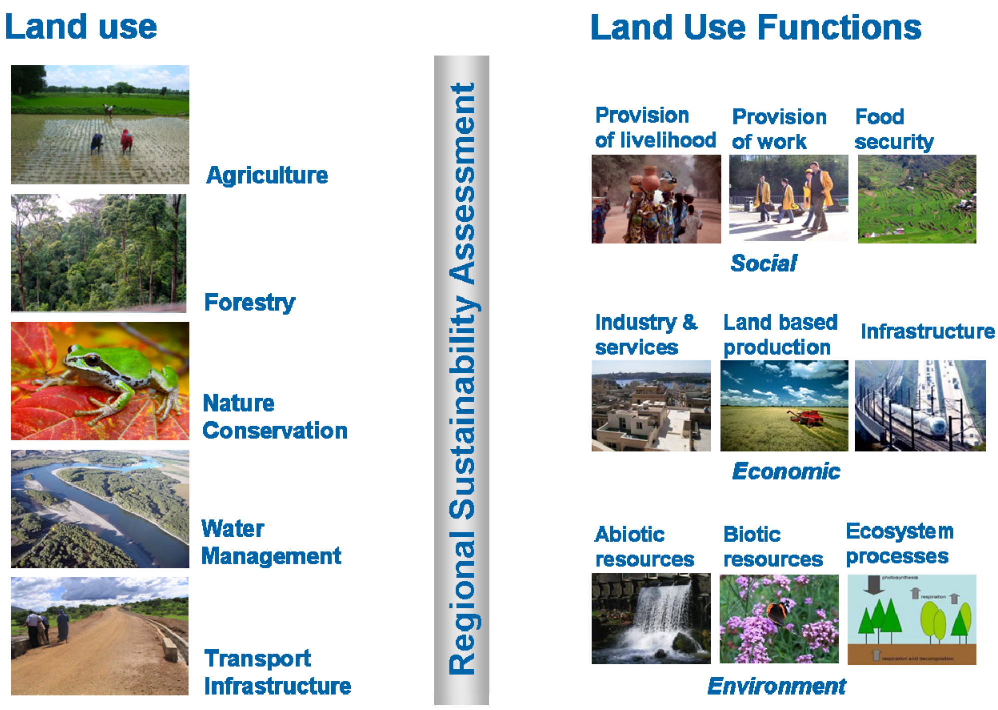


Figure 4.5
The Land Use Function approach. Source: König et al. (2008).

Addition of indicators to Land Use Functions
The Land Use Functions are arbitrary descriptions of land-use. To make them useful response variables or indicators are measured. Indicators therefore represent aspects of Land Use Functions. A balanced set of indicators can be linked to the nine LUFs, which is depicted in Appendix 3. A selection of indicators is based on four criteria: (1) facility of analysis, i.e. their relevance with respect to the problems and the drivers; (2) facility for decision making, i.e. the balance between different stakeholders such as policy makers, researchers and farmers; (3) ability to reflect the transformations of the environment, and (4) the effect of practices, validity at several scales of analysis (Reidsma et al., 2008a).

Each Land Use Function is therefore represented by one to a number of indicators. Some indicators have a clear meaning for policy makers. Therefore, discussions taking place to develop a multi-criteria analysis are often focussed on the improvement of such indicators, rather than Land Use Functions or dimensions of sustainability.

When a number of indicators represent a single Land Use Function two different methods of aggregation can take place. In the first method policy-makers explicitly weigh the importance of indicators within a LUF. For example, a social LUF like provision of work might comprise indicators like educational level, employment rate and immigration rate. A policy-maker might, for example, conclude that for a specific policy option the development of the educational level is the most important. In such case a stronger weight of this indicator can be given to the performance of the LUF provision of work.

In a second method the weighing of indicators is more analytic. As described in Pérez-Soba et al. (2008). This method defined the relative score of an indicator to the LUF. Thus a small change in the value of an indicator strongly or moderately changes the value of a LUF. In Pérez-Soba et al.

(2008) the relative contribution of an indicator varies between -2 and + 2. Thus the values of a - n vary between -2 and +2.

The LUPIS project deviates from this structure, since there is a lot of subjective interpretation in assigning the relative contribution of indicators. Therefore, LUPIS simply assumes that each indicator in a LUF contributes equally to that LUF. Thus when a LUF has 4 indicators, each indicator contributes ¼ to the final value of the LUF.

Note that the LUF value is arbitrary and relative. But the values allows to compare among different LUFs. To compare the effects of climate change on the relative performance of the LUFs and eventually on the performance of the three dimensions of sustainable development, all data will be put in a multi-criteria analysis.

The weighing procedure of criteria is, amongst others, sensitive to the number of criteria, like indicators, used. Because in each dimension of sustainable development three LUFs are used, a first step is to give equal contribution of each LUF in a dimension. The proposed indicators (see Appendix 3) can have an equal distribution. The less indicators are used, the stronger the weight of an indicator on a particular land use function.

Hierarchical evaluation procedure

Figure 4.6 depicts the hierarchical procedure of the various criteria in the sustainable development evaluation.

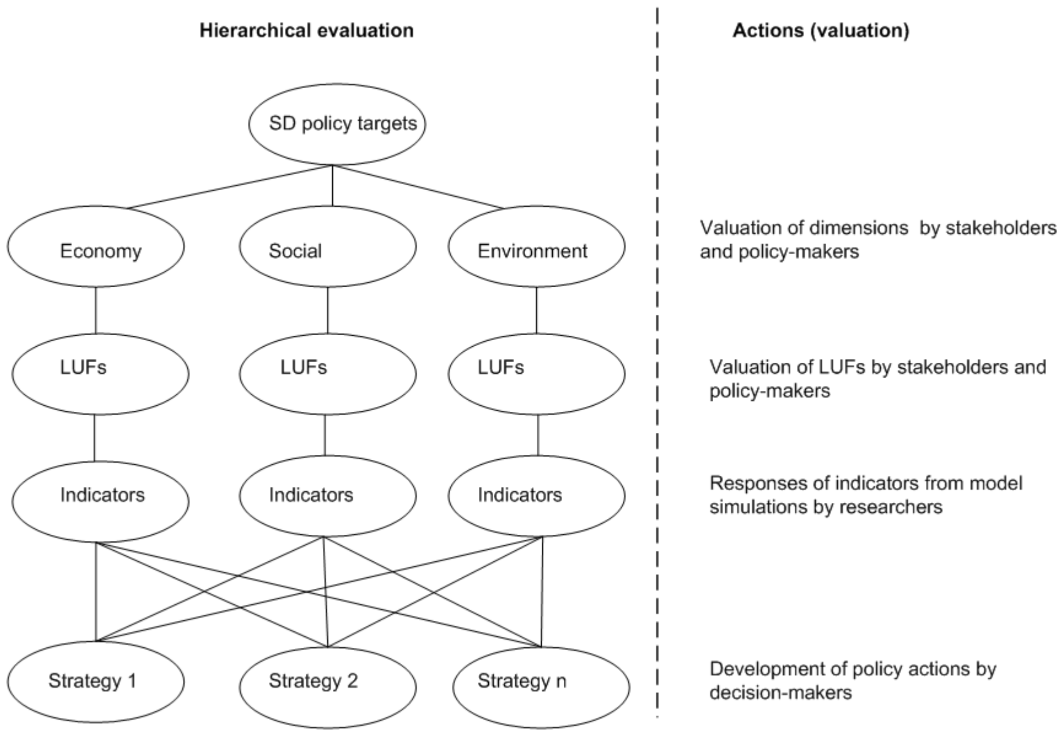


Figure 4.6

Hierarchical procedure of the multi-criteria analysis. The criteria are broken down (from top to bottom) into dimensions of sustainable development, associated Land Use Functions, indicators and an array of policy options (called alternatives in a multi-criteria analysis)

The evaluation procedure is strictly hierarchical, which is a typical multi-criteria analysis approach. The policy target that is assessed is split over the three dimensions and each dimension is divided over three Land Use Functions (LUF). Each LUF is then represented by a number of indicators. For practical reasons only the generalized LUFs and indicators are depicted in Figure 4.6. The full multi-criteria analysis outline is depicted in Appendix 4.

Different actions are undertaken in the different levels in the hierarchical evaluation. The valuation (weighing) of dimensions and LUFs should take place in close cooperation with decision makers and stakeholders. The weights given to dimensions and LUFs represent the weights given to the criteria in policy making. The indicator values are derived from models and other statistical assessments. This valuation is the domain of scientists. Indicator values depend on the policy option studied. Thus the various policy options (mitigation, adaptation, land-use strategies) should be assessed with model instruments.

Multi-criteria evaluation

In typical multi-criteria analysis (MCA) problems, criteria and indicators have inherent trade-off relations (e.g. Verburg et al., 2009b). Due to such hidden relations, ranking of policy alternatives also depend on the weighing decision-makers make on criteria like the dimensions and LUFs.

A multi-criteria analysis can be considered as a starting point of a decision making process. The values for policy options that are calculated are arbitrary, without units. Thus, the policy values do not give any information on monetary costs or alike. Such costs can be included in a MCA, but only as separate criteria (like investment costs, or costs to carry out policy options). Therefore, the MCA provides a ranking of policy options, given the weights that are put on the different criteria. As a starting point dimensions can be weighed equally, with respect to the primary goal of sustainable development for which we assume the development should be balanced. The same procedure can be applied to weight LUFs. This does not mean however, that stakeholders or decision-makers would prefer unbalanced weighing of criteria.

A discussion could start here with the question whether the ranking of policy alternatives is something stakeholders would expect. In the decision arena unbalanced weights of criteria, like dimensions, land use functions or indicators may be given. Altering the weights will affect the ranking of policy alternatives Such task can be useful to assess the robustness of the ranking pattern of policy options. When the ranking of policy alternatives is only changed by a strong unbalanced criteria weighing, the pattern in ranking of policy alternatives can be considered robust. Robustness can also be explored in multi-criteria analysis by changing the criteria weights partially.

5 Discussion and summary

5.1 Mitigation and adaptation options in relation to the Millennium Development Goals (MDG)

According to the UN, poverty rates in developing countries are estimated to have fallen from 52 % in 1981, 42 % in 1990 to 26 % in 2005. Over a 25-year period, the poverty rate in East Asia fell from nearly 80 % to under 20 %. In sub-Saharan Africa, however, the poverty rate remained constant at around 50 % (UN MDG factsheet). Although many developing regions, between 1990 and 2006, were successful in halving the proportion of underweight children, sub-Saharan Africa is still making least progress in reducing child malnutrition. In Ethiopia 23% of the population had less than one dollar per day for consumption and 47% of the children under 5 are severely underweight (UN MDG website).

Climate change is likely to further inhibit any development in Africa. Food production and agricultural practices may be threatened by more extreme climate events such as frequent droughts and floods. Access to safe drinking water can also be affected by such developments. The proportion of people with access to improved drinking water in Ethiopia has increased from 13% in 1990 to 42% in 2006, but this MDG target may also be jeopardised by climate change in the future.

The framework presented in this report is focused on land-use adaptation and mitigation strategies on climate change. Natural resources management and land-use change are crucial factors for sustainable development in a region and their contribution to the millennium goals. For example, the rate of deforestation has been fastest in some of the world's most biologically diverse regions and old growth forest ecosystems, including sub-Saharan Africa. In Ethiopia the forest area has been reduced from a 13.8% cover in 1990 to 11.9% in 2003 (UN MDG website). Forests play a crucial role in combating desertification and water and nutrient losses. Therefore forest management is taken central in the development of both adaptation and mitigation options. Amongst others, actions suggested by the UN include ensuring effective conservation and management to reverse the loss of natural resources and significantly reduce biodiversity loss. This may be achieved by introducing measures or mechanisms to reduce global greenhouse gas emissions by assisting developing countries - especially in sub-Saharan Africa - to transform subsistence agriculture in order to ensure long-term, sustainable production and developing a more diversified economic base. This can be done by supporting research and development in yield-enhancing agricultural and climate change technologies and enhancing climate adaptation programmes to reduce the negative impact of climate change.

5.2 Climate change and sustainable development

Numerous definitions of sustainable development exist and the 6th EU framework project LUPIS, from which parts of the framework is adopted, adjusted the definition of Brundtland's report 'Our common future' into the definition of sustainable development as 'the elimination of poverty of present and future generations through management of land and natural resources which avoids the risk of radical ecosystem change' (e.g., Verburg et al., 2008).

Sustainable development in developing countries mainly includes social aspects like equity, while in rich countries environmental issues play a prominent role. The agricultural sector and rural areas in East Africa will be strongly affected by climate change. In the long run environmental issues as droughts, floods and temperature rise will severely affect developments in equity and poverty reduction. Diversification of agricultural activities may help to reduce vulnerability of rural societies to climate change. On one hand, by the production of different agricultural commodities with various demands of natural resources, like water, and on the other hand by the diversification of income by such diversification.

5.3 Uncertainty and the science – policy interface

Climate change adaptation in the context of sustainable development must be understood through the perspective of systems thinking and complexity. The development of a framework that we attempt to offer in this publication tries to capture much of the systems involved. At the same time we acknowledge the high levels of uncertainty in this system. On the one hand these uncertainties include the poor predictability of climate change and its impact as shown in uncertainties of projections. On the other hand there are uncertainties in the dynamics on the human systems involved.

The development of NAPAs or any other adaptation strategy or plan, is driven by different institutions including stakeholders ranging from government departments, research institutes, donors, to civil society. These are understood to belong to multiple, evolving systems with unpredictable relationships, including informal and intangible dimensions in which power and politics play important roles.

Policy makers involved in the development of climate change adaptation strategies have to deal with these uncertainties. Science can assist policy makers to understand the complexities of climate change and the unknowns. However, the interface between science and policy is a challenging one. Policy makers often want to get quick and straightforward answers to problems, while researchers would want time to thoroughly investigate options to meet high scientific standards. Investing in the mutual understanding of both sides of the science-policy interface will help to decrease the challenges.

5.4 The modelling framework

The framework and its use to develop and prioritise policy options should not be seen as a purely scientific and theoretical exercise. As with LUPIS, the framework should be used in a process that links science to policy. Within this science-policy interface, there is need for a multiple stakeholder approach to bring together different perspectives in government, civil society and private sector that should be used to validate the choice of variables in the models and to develop and carry out the multi-criteria evaluation.

The use of the framework should be applied to the reality of policy development in East Africa. This is associated with several challenges. First, the general time scale policy makers look at for the development of strategies is often the short to medium term (3-10 years), while much of the climate change impact and adaptation options are considering much longer time spans. Second, the framework has to be applied within the unpredictable realm of politics and policy development. This brings in non-linear and irrational, thus unpredictable planning processes. Scientists have to look for the right 'policy window' for the use of the framework to influence policy development on climate change adaptation. This requires a good stakeholder analysis.

Application of the framework
The proposed framework includes a set of models that assess various aspects of the application of mitigation and adaptation policy options. Through land-use allocation in CLUE the models interact. In LUPIS various models are used to assess impacts of land-use policies in developing countries. During the pre-modelling phase of the project (see Chapter 4) various modelling tools were discussed in the project team. Most partner institutes in developing countries use adaptations of the farm household model FSSIM with the environmental tool APES. Moreover, global trade models, like LEITAP are used to run trade scenarios and to assess supply and demand of agricultural commodities. Therefore, the focal point was more on economic development during this first phase.

The LUPIS project showed that the modelling expertise of partner institutes is a crucial factor to implement a framework, rather than the models that are used. Many different models exists that can assess impacts of land-use and land-use policies like adaptation and mitigation strategies. The proposed models in chapter 4 are previously used in a variety of projects and for different problems. In the LUPIS project amendments were made by partner institutes on the proposed model chain. This showed that most partners had difficulties to work with and apply all the models that were described in the pre-modelling phase due to a lack of experience and of the scientific knowledge that form the basis of these models.

A modelling framework as described in chapter 4 integrates various scientific disciplines which makes it comprehensive to apply it at a research organization in developing countries where hardly all disciplines are present. Modelling support can be given from developed countries, but data specific input must still be gathered in the area that is studied. A tight cooperation between local researchers and researchers from developed countries are therefore needed.

Issues addressed by the framework
The framework addresses various issues related to land-use and land-use change. In addition, the modelling components have a strong emphasis on agricultural land-use and reforestation. This implies that the framework will assess only land-use related climate change policies on mitigation and adaptation strategies.

The LUPIS framework includes three phases in the project design; a pre-modelling, modelling and post-modelling phase. In all phases stakeholders are involved, but their role differs as the input to the framework changes. During the pre-modelling phase the design of policy options takes place in collaboration with stakeholders and policy-makers. In LUPIS this is organised through (inter)national policy forums that take the case studies as the central theme of discussion. The post-modelling phase is designed to interact with policy-makers. The resulting ranking of policy options, calculated with the modelling tools and evaluated with multi-criteria analysis, is the basis of debate. A feedback loop to the pre-modelling phase can take place when new insights are found in the effectiveness of policy options. Adjustment of policy options, as the result of a discussion during the evaluation, may call for a need to recalculate variants of policy option by the modelling tools.

5.5 Adaptation and mitigation options

The framework developed needs to be tested on practical cases. In the situation of Ethiopia, such cases could look at reforestation, coffee, regeneration of degraded soils and animal husbandry. The challenge now is, to find - during the next project phase - the relevant data and to involve policy makers in the assessment. This will require close involvement of researchers and policy makers in Ethiopia. Large uncertainties exist, both with regard to the process, as with regard to the data and modelling involved.

The identification of hotspots for climate change, i.e. the Central Rift Valley with regreening/smallholder coffee growers, and pastoralists is clearly identifiable when related to the three perspectives of sustainable development (people, planet, profit).

However, the wider perspective is that climate change adaptation contributes to an on-going change process, in which multiple stakeholders are engaged, which takes place at different levels, and where uncertainties and risks need to be addressed in a complex situation. The future cannot be predicted and some results will emerge during the process. It is certain that the future requires the ability of people to adjust, which may not be possible to people living in an already vulnerable position.

For a country as a whole, this means a changed science-policy interface, where scientists face increasing uncertainty, and the need to communicate this uncertainty to policy makers, while policy makers need to operate in a complex situation, where they need transparent and democratic decision making, and sound knowledge to build this decision making upon.

Reforestation in the Central Rift valley of Ethiopia becomes eminent where soil erosion should be prevented and the water holding capacity of the soil should be increased. Coffee is highly temperature and rainfall sensitive and adaptation is needed for future commercial production. These issues will be addressed in the follow up of the project in 2010.

Literature

Bai, Z. G., D.L. Dent, L. Olsson and M.E. Schaepman, 2008. *Global assessment of land degradation and improvement. 1. Identification by remote sensing*. Report 2008/01. ISRIC - World Soil Information, Wageningen, the Netherlands.

Balvanera, P., A.B. Pfisterer, N. Buchmann, J.S. He, T. Nakashizuka, D. Raffaelli and B. Schmid, 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters* 9, 1146-1156.

Bellocchi, G., G. Stockstad, P. Zander, S. Uthes, N. Karstens and F.J. Reinhardt, 2006. *D. 3.3.9.1 - Conceptual approach to identify and assess current activities.* SEAMLESS integrated project, EU 6th Framework Programme (www.seamless-ip.org).

Berry, P.M., M.D.A. Rounsevell, P.A. Harrison and E. Audsley, 2006. Assessing the vulnerability of agricultural land use and species to climate change and the role of policy in facilitating adaptation. *Environmental Science and Policy* 9, 189-204.

Braat, L. and B. ten Brink, 2008. *The cost of policy inaction, The case of not meeting the 2010 biodiversity target.* Alterra, Wageningen UR, Wageningen, the Netherlands.

Dessie, G. and Christiansson, C., 2008. Forest Decline and Its Causes in the South-Central Rift Valley of Ethiopia: Human Impact over a One Hundred Year Perspective*. AMBIO: A Journal of the Human Environment* 37, 263-271.

Dessie, G. and J. Kleman, 2007. Pattern and Magnitude of Deforestation in the South Central Rift Valley Region of Ethiopia*. Mountain Research and Development* 27, 162-168.

Diaz, S., D. Tilman, J. Fargione, F.S. Chapin III, R. Dirzo, T. Kitzberger, B. Gemmill, M. Zobel, M. Vilà, C. Mitchell, A. Wilby, G.C. Daily, M. Galetti, W.F. Laurance, J. Pretty, R. Naylor, A. Power and D. Harvell, 2005. *Biodiversity regulation of ecosystem services.* in (Millenium Ecosystem Assessment. Ecosystems and Human Well-being: Current State & Trends Assessment, Washington D.C., USA, Island Press.

Dorward, A., J. Kydd, J. Morrison and I. Urey, 2004. A policy agenda for pro-poor agricultural growth*. World Development* 32, 73-89.

Elasha, B.O., M. Medany, I. Niang-Diop, T. Nyong, R.Tabo and Vogel, 2006. *Background paper on impacts, vulnerability and adaptation to climate change in Africa for the African workshop on adaptation - Implementation of decision 1/CP.10 of the UNFCCC Convention*. Commissioned by the secretariat of the United Nations Framework Convention on Climate Change, Accra, Ghana.

FAO, 2005. *The State of Food Insecurity in the World. Eradicating world hunger – key to achieving the Millennium Development Goals.* FAO report.

Fischer, G., M. Shah, F.N. Tubiello and H. van Velhuizen, 2005. Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990-2080*. Philosophical Transactions of the Royal Society B: Biological Sciences* 360, 2067-2083.

Gaboury, S., J.F. Boucher, C. Villeneuve D. Lord and R. Gagnon, 2009. Estimating the net carbon balance of boreal open woodland afforestation: A case-study in Qubec's closed-crown boreal forest*. Forest Ecology and Management* 257, 483-494.

Gebre-Selassie, S., 2003. *Policy module Ethiopia - Summary Report on Recent Economic and Agricultural Policy*. Agricultural and Development Economics Division (ESA) Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Groen, T., G.J. Nabuurs and M.J. Schelhaas, 2006. Carbon accounting and cost estimation in forestry projects using CO2-FIX V.3*. Climatic Change* 74, 269-288.

Hengsdijk, H. and M.K. van Ittersum, 2003. Formalizing agro-ecological engineering for future-oriented land use studies. *European Journal of Agronom*y 19, 549-562.

IAASTD, 2008. *Agriculture at a Crossroads.* Beverly, D. McIntyre, Hans R. Herren, Judi Wakhungu, Robert T. Watson (Eds.)

Jackson, L.E., U. Pascual and T. Hodgkin, 2007. Utilizing and conserving agrobiodiversity in agricultural landscapes. *Agriculture, Ecosystems and Environment* 121, 196-210.

Janssen, S.J.C., H. Hengsdijk and M.K. van Ittersum, 2006. *PD3.3.3-PD3.3.4-PD3.3.5 - Agricultural Management-module of FSSIM: produres to generate and quantify alternative agricultural activities.* SEAMLESS integrated project, EU 6th Framework Programme (www.seamless-ip.org).

Kemp, R. and P. Martens, 2007. Sustainable development: How to manage something that is subjective and never can be achieved? Sustainability: Science, Practice and Policy 3, 1-10.

Khairo, S.A., G.E. Battese and J.D. Mullen, 2005. Agriculture, food insecurity and agricultural policy in Ethiopia*. Outlook on Agriculture* 34, 77-82.

Khor, M., 2008. *Food Crisis, Climate Change and the Importance of Sustainable Agriculture.* Presentation at FAO Food Security Summit, Rome 4 June 2008.

Kremen, C., 2005. Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters* 8, 468-479.

Kuznets, S., 1955. Economic growth and income inequality*. American Economic Review* 45, 1-28.

Lemma, B., D.B. Kleja, M. Olsson and I. Nilsson, 2007. Factors controlling soil organic carbon sequestration under exotic tree plantations: A case study using the CO2Fix model in southwestern Ethiopia*. Forest Ecology and Management* 252, 124-131.

Liski, J., A. Nissinen, M. Erhard and O. Taskinen, 2003. Climatic effects on litter decomposition from arctic tundra to tropical rainforest. *Global Change Biology* 9, 575-584.

Liski, J., T. Palosuo, M. Peltoniemi and R. Sievänen, 2005. Carbon and decomposition model Yasso for forest soils*. Ecological Modellin*g 189, 168-182.

Liu, J., S. Fritz, C.F.A. van Wesenbeeck, M. Fuchs, L. You, M. Obersteiner and H. Yang, 2008. A spatially explicit assessment of current and future hotspots of hunger in Sub-Saharan Africa in the context of global change*. Global and Planetary Change* 64, 222-235.

Lobell, D.B., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon and R.L. Naylor, 2008. *Prioritizing Climate Change Adaptation Needs for Food Security in 2030.* Science 319, 607-610.

Locatelli, B., V. Rojas and Z. Salinas, 2008. Impacts of payments for environmental services on local development in northern Costa Rica: A fuzzy multi-criteria analysis*. Forest Policy and Economics* 10, 275-285.

Luck, G.W., R. Harrington, P.A. Harrison, C. Kremen, P.M. Berry, R. Bugter, T.P. Dawson, F. de Bello, S. Diaz, C.K. Feld, J.R. Haslett, D. Hering, A. Kontogianni, S. Lavorel, M. Rounsevell, M.J. Samways, L. Sandin, J. Settele, M.T. Sykes, S. van den Hove, M.Vandewalle and M. Zobel, 2009. Quantifying the Contribution of Organisms to the Provision of Ecosystem Services. *Bioscience* 59, 223-235.

Masera, O.R., J.F. Garza-Caligaris, M. Kanninen, T. Karjalainen, J. Liski, G.J. Nabuurs, A. Pussinen, B.H.J. de Jong and G.M.J. Mohren, 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2-FIX V.2 approach*. Ecological Modelling* 164, 177-199.

MEA, 2003. *Millenium Ecosystem Assessment. Ecosystems and Human Well-being: A Framework for Assessment.* Washington D.C., USA, Island Press, 212.

—, 2005. *Millenium Ecosystem Assessment. Ecosystems and Human Well-being: Synthesis*. Washington D.C., USA, Island Press.

Nabuurs, G.J. and M.J. Schelhaas, 2002. Carbon profiles of typical forest types across Europe assessed with *CO2-FIX. Ecological Indicators* 1, 213-223.

Nabuurs, G.J., B. van Putten, T.S. Knippers and G.M.J. Mohren, 2008. Comparison of uncertainties in carbon sequestration estimates for a tropical and a temperate forest*. Forest Ecology and Management* 256, 237-245.

Nellemann, C., M. MacDevette, T. Manders, B. Eickhout, B. Svihus, A.G. Prins and B.P. Kaltenborn, 2009. *The environmental food crisis - The environment's role in averting future food crises*. United Nations Environment Programme, GRID-Arendal (www.grida.no), Norway.

OECD/FAO, 2009. *OECD-FAO agricultural outlook 2009-2018*, Organization for Economic Co-Operation and Development (OECD) and the Food and Agriculture Organization of the United Nations (FAO).

Parry, M.L., O.F. Canziani, J.P. Palutikof and Co-authors, 2007. *Technical Summary*. In Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, UK, Cambridge University Press, p. 23-78.

Pérez-Soba, M., S. Petit, L. Jones, N. Bertrand, V. Briquel, L. Omodei-Zorini, C. Contini, C., K. Helming, J. Farrington, M. Tinacci Mossello, D. Wascher, F. Kienast and D. de Groot, 2008. *Land*

Use Functions - a multifunctionality approach to assess the impact of land use change on land use sustainability., in (Sustainability impact assessment of land use changes, Berlin, Heidelberg, New York, Springer, p. pp. 375-404.

Reid, R.S., P.K. Thornton, G.J. McCrabb, R.L. Kruska, F. Atieno and P.G.Jones, 2004. Is it possible to mitigate greenhouse gas emissions in pastoral ecosystems of the tropics? *Environment, Development and Sustainibility* 6, 91-109.

Reidsma, P., H. Koening, S. Sieber, K. Tscherning, K. Helming, I. Bezlepkina and M. van Ittersum, 2008a. *Deliverable 4.2.1: preliminary indicator framework for assessment of land use policies in developing countries*. LUPIS project, EU 6th Framework Programme. contract no. 36955, www.lupis.eu

Reidsma, P., M. van Ittersum, H. van Keulen and S. Feng, 2008b. *D4.4.1 Procedures for assessing agro-ecological relationships and quantifying alternative production systems.* LUPIS project, EU 6th Framework Programme. contract no. 36955, www.lupis.eu

Richardson, K., W. Steffen, H.J. Schellnhuber, J. Alcamo, T. Barker, D.M. Kammen, R. Leemans, D. Liverman, M. Munasinghe, B. Osman-Elasha, N. Stern and O. Wæver, 2009. Climate change - Global risks, challenges & decisions. Synthesis report of Climate Congress University of Copenhagen, Denmark.

Rigg, 2005. Land, Farming, Livelihoods, and Poverty: Rethinking the Links in the Rural South. *World Development* 34, 180-202.

Rosegrant, M.W., C. Ringler,X. Diao, D. Resnick, J. Thurlow, M. Torero and D. Orden, 2006. *Agriculture and Achieving The Millennium Development Goals.* The World Bank (Agriculture & Rural Development Department).

Schelhaas, M.J., P.W. van Esch, T.A. Groen, B.H.J. de Jong, M. Kanninen, J. Liski, O. Masera, G.M.J. Mohren, G.J. Nabuurs, T. Palosuo, L. Pedroni, A. Vallejo and T. Viln, 2004. *CO2FIX V3.1 - A modelling framework for quantifying carbon sequestration in forest ecosystems*. 1068 Alterra, Wageningen, the Netherlands.

Schleyer, C., I. Theesfeld, K. Hagedorn, O. Aznar, J.M. Callois, R.W. Verburg, M. Yelkouni and J. Alkan Olsson, 2006. *Approach towards an operational tool to apply institutional analysis for the assessment of policy feasibility within SEAMLESS-IF.* SEAMLESS integrated project, EU 6th Framework Programme (www.seamless-ip.org).

Schulze, E.D, H.A. Mooney, 1993. *Biodiversity and Ecosystem Function*. New York, USA, Springer-Verlag.

Sheffield, J. and E.F. Wood, 2008. Projected changes in drought occurrence under future global warming from multi-model, multi-scenario, IPCC AR4 simulations. Climate Dynamics 31, 79-105.
Shongwe, M.E., G.J. van Oldenborgh, B. van den Hurk, and M. van Aalst, 2009. Projected changes in mean and extreme precipitation in Africa under global warming, Part II: East Africa. *Journal of Climate*, in press.

Stern, D.I., M.S. Common E.B. and Barbier, 1996. Economic growth and environmental degradation: The environmental Kuznets curve and sustainable development. *World Development* 24, 1151-l 160.

Tadege, A., 2007. *Climate change National Adaptation Programme of Action (NAPA) of Ethiopia*. The Federal Democratic republic of Ethiopia, Ministry of Water Resources, National Meteorological Agency, Addis Ababa, Ethiopia.

Ten Brink, B., J.R.M. Alkemade, M. Bakkenes, J. Clement, B. Eickhout, L. Fish, M. de Heer, T. Kram, T. Manders, H. van Meijl, L. Miles, C. Nellemann, I. Lysenko, M. van Oorschot, F. Smout, A. Tabeau, D. van Vuuren and H. Westhoek, 2007. *Cross-roads of Life on Earth: Exploring means to meet the 2010 Biodiversity Target*. Secretariat of the Convention on Biological Diversity and Netherlands Environmental Assessment Agency, Montreal, Canada.

Terwisscha van Scheltinga, C. and J. van Geene, forthcoming. *Business as usual is not an option (worktitle).* In (Paassen, V and et al.), Knowledge for Action, p. -.

Thritle, C., L. Lin J. and Piesse, 2003. The impact of research-led agricultural productivity growth on poverty reduction in Africa, Asia and Latin America. *World Development* 31, 1959-1975.

Tilman, D., 1996. Biodiversity: Population versus ecosystem stability*. Ecology* 77, 350-363.

Van Jaarsveld, A., R. Biggs, R. Scholes, E. Bohensky, B. Reyers, T. Lynam, C. Musvoto and C. Fabricius, 2005. Measuring conditions and trends in ecosystem services at multiple scales: the Southern African Millennium Ecosystem Assessment (SA f MA) experience*. Philosophical Transactions of the Royal Society B: Biological Sciences* 360, 425-441.

Veldkamp, A. and L.O. Fresco, 1997. Exploring land use scenarios, an alternative approach based on actual land use*. Agricultural Systems* 55, 1-17.
Verburg, P.H., 2008. *The CLUE-S model. Tutorial CLUE-s (version 2.4) and DYNA-CLUE (version 2).* Wageningen University, Wageningen.

Verburg, P.H., G.H.J. de Koning, K. Kok, A. Veldkamp J. Jouma, 1999. A spatial explicit allocation procedure for modelling the pattern of land use change based upon actual land use*. Ecological Modelling* 116, 45 - 61.

Verburg, P.H., K.P. Overmars, E. Koomen, J.Stillwell, A. Bakema and H.J. Scholten, 2007. *Dynamic simulation of land-use change trajectories with the CLUE-s Model.* In (Modelling Land-Use Change - Progress and applications, Dordrecht, The Netherlands, Springer, p. 321-335.

Verburg, R., I. Bezlepkina, D. McNeill, M. Bonin et al., 2008. *D2.3: Defining sustainable development in the context of LUPIS*. LUPIS project, EU 6th Framework Programme. contract no. 36955, www.lupis.eu

Verburg, R., E. Stehfest, G. Woltjer and Eickhout, 2009a. The effect of agricultural trade liberalisation on land-use related greenhouse gas emissions*. Global Environmental Change* 19, 434 - 446.

Verburg, R.W., L. Chen, Y. Cissé, S.R. Filho, B.Keita, D. Lindoso, M. Demba, C. Gucciardi, A.T Diarra and N. Debortoli, 2009b. *Climate change in Mali and Brazil: towards an evaluation method of climate change and land use policies.* LEI Wageningen UR, The Hague.

Winfree, R. C. and Kremen, 2009. Are ecosystem services stabilized by differences among species? A test using crop pollination. *Proceedings of the Royal Society B-Biological Sciences* 276, 229-237.

Zander, P., S. Uthes, N. Borkowski, G. Stokstad and G. Bellocchi, 2008. *PD 3.3.9 Conceptual Approach to Identify and Assess Current Activities. SEAMLESS integrated project.* EU 6th Framework Programme (www.seamless-ip.org).

Appendix 1: Vulnerability description

The term vulnerability is used in many different contexts. Generally it contains a dimension that is related to the exposure to certain hazards or risks and a dimension that is related to the capacity to anticipate to (and avert), cope with or recover from the impacts (e.g. Berry et al., 2006).

In relation to climate change assessments, vulnerability generally includes three components, exposure, sensitivity and adaptive capacity. The combination of these concepts together determines the actual level of vulnerability to climate change (Figure 1). Vulnerability can be applied to both human and to natural systems. In general, in a coupled human - environmental system these two are not independent and are likely to interact with each other (Figure 2; Locatelli et al., 2008). Systems are most vulnerable to climate change if exposure and sensitivity is high and adaptive capacity is low.

The potential impact of climate change will be determined by the level of exposure to climate change (how strong is the climatic change?) and the sensitivity of the component that is considered (what is the impact of that level of change). The potential impact can be expressed as the relative loss of provisioning of a number of ecosystem goods and services as a result of climate change. These can be determined based on information on current level of potential delivery of ecosystem services and information on level of delivery of these services under changes in the climate.

Adaptive capacity is the result of both autonomous trends determined by inherent coping capacity of societies, and additional policies to adapt to anticipated changes. Especially in systems where people directly depend on the ecosystem goods and services that the bio-physical system provides appear to be sensitive to climate change. In regions where adaptive capacity is low, such impact will subsequently result in high vulnerability to climate change. Mitigation actions will especially aim to lower the level of the exposure to the pressure on the long term, while adaptation strategies are aimed to lower the sensitivity and improve adaptive capacity at the short to medium term.

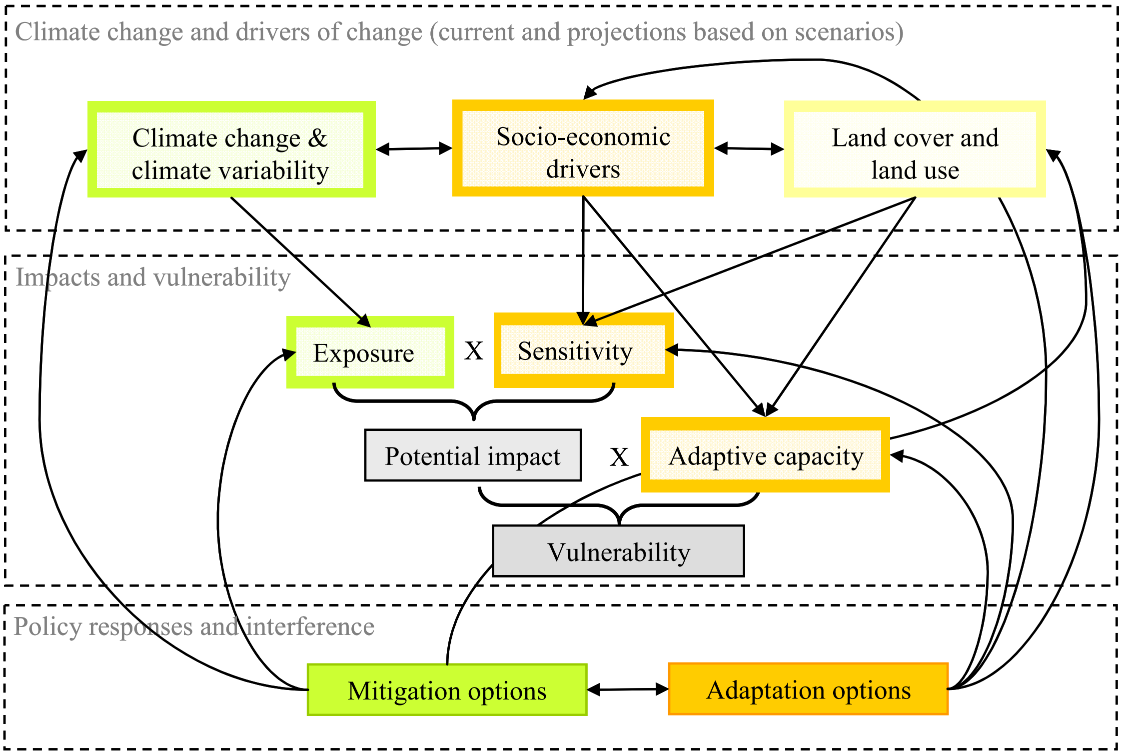


Figure 1
Schematic overview of vulnerability assessment and relation to mitigation and adaptation strategies. Adapted from IPCC (2001)

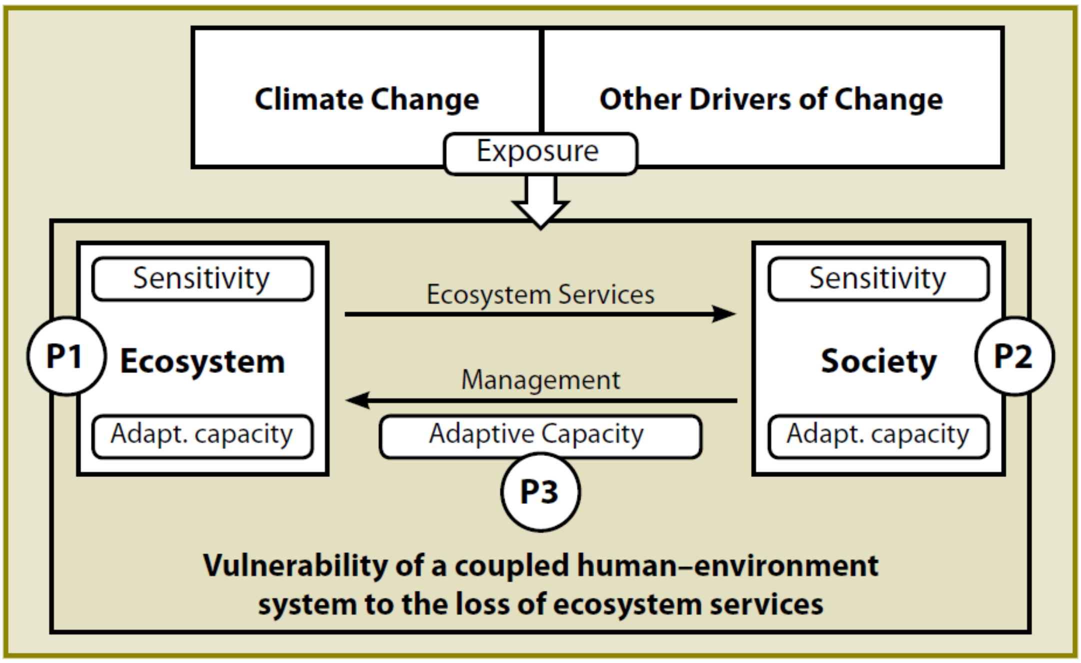


Figure 2
Schematic overview of coupling of human and environmental vulnerability to climate change (Locatelli et al. 2008)

Appendix 2: Project list described by the NAPA of Ethiopia

Nr.	Description
1.	Promoting drought/crop insurance program in Ethiopia
2.	Realizing food security through multi-purpose large-scale water development project in Genale-Dawa Basin
3.	Community Based Development and Commercialization of Non-timber Forest Products (Gum Arabic, Myrrah and Frank Incense)
4.	Community Based Rehabilitation of Degraded Eco-Systems in Selected Parts of Ethiopia
5.	Propagation and Commercial Scale Cultivation of Wild Essential Oil Crops
6.	Establishment of Centre for Propagation and Commercialization of Traditional Herbal Medicinal Plants
7.	Establishment of Acacia Woodland Nature Reserve in the Ethiopian Rift Valley System
8.	Community Based Carbon Sequestration Project in the Rift Valley System of Ethiopia
9.	Range Shift Cultivation of Selected Cash Crops int Drought Prone Areas
10.	Establishment of National R&D Center for Climate Change
11.	Development of an Incentive Scheme for Farmers (Hill-farming communities) to Reforest Hill Areas in the Northern Parts of Ethiopia
12.	Participatory Approach to Rehabilitate Degraded Hills/Ecosystem in Northern Ethiopia
13.	Institutional Re enforcement for Bio-diversity Conservation
14.	Establishment of National Environmental Education Program
15.	Reforestation for Fuel in the Highlands of Ethiopia
16.	Regional Capacity Building for Monitoring and Inventorying of Biodiversity
17.	Establishment of Potato-centered Small-sized Cottages
18.	Reclamation of Bush Encroached Rangelands
19.	Promotion of Legume-based Agroforestry Systems and Home-garden Agriculture
20.	Development of New and Rehabilitation (upgrading) of the existing watering sites in Pastoral Areas
21.	Aquaculture Development for Efficient Harvest of Commercial Spirulina Species in the Lakes of the Ethiopian Rift Valley System
22.	Reorganization of drought Affected Communities
23.	Stall feeding promotion and free range grazing restriction in selected regional states of Ethiopia
24.	Promotion of on farm and homestead forestry and agroforestry practices in arid, semi-arid and dry-sub humid parts of Ethiopia
25.	Undertake soil and water conservation practices for improved land husbandry in Afar, Somali and Gambella regional states and Diredawa city administration
26.	Develop community seed bank and food storage facilities in Amhara, SNNPRS, Tigray, Oromia.
27.	Capacity building for small scale irrigation planning and development in Afar, Gambella, Somali and SNNPRS.
28.	Community based sustainable utilization and management of wet lands in selected wet lands in Ethiopia
29.	Strengthening/enhancing drought and flood early warning systems in Ethiopia
30.	Capacity building for climate change adaptation in Ethiopia at all levels mainly federal as well as regional levels
31.	Public awareness program on climate change in Ethiopia at national as well as regional levels
32.	Enhancing the use of water for agricultural purpose on small farms in arid and semi arid parts of Ethiopia
33.	Community capacity building to initiate and implement environmental health program and or projects in the national regional states
34.	Commercial level uses of some indigenous, wild edible fruits in selected arid and semi arid areas of Ethiopia
35.	Malaria containment program (MCP) in selected areas of Ethiopia-Gambella, Ethiopian rift valley, Somali.
36.	Institutional development; enhancement of research and development capacity of the national dry land research centers in Somali, Gambella, Benishangul-gumuz, low lands of Oromia, Amhara, Tigray, Afar and SNNPR.
37.	Improving/enhancing the range land resources management practices in the pastoral areas of Ethiopia

Appendix 3: Relevant maps and graphs

Climate change vulnerability in Africa

Currently most of East Africa is already prone to multiple stresses as a result of extreme and unpredictable weather events and degradation of ecosystems. Climate change will likely further increase vulnerability of the coupled human-environmental system in large parts of Africa. Figure A3-1 shows which regions will become vulnerable and gives examples of the most likely effects.

Figure A3-1

Climate change vulnerability in Africa.UNEP/GRID-Arendal Maps and Graphics Library. 2002, updated 2004, 2005. Available at: http://maps.grida.no/go/graphic/climate_change_vulnerability_in_africa. Accessed March 04, 2009.

Impacts of climate change on agricultural output in Africa
Model projections of cereal production on currently cultivated land under different climate change scenarios and different global circulation models indicate that in East Africa changes in potential cereal production by 2080 are spatially very heterogeneously (Fischer et al., 2005)(Figure A3-2). Especially Ethiopia and Somalia would likely lose cereal production potential, while at the same time Tanzania, Kenya, and Uganda are likely to gain production potential (Fischer et al., 2005). The projected reduction in cereal output are mainly a consequence increased heat and of water stress.

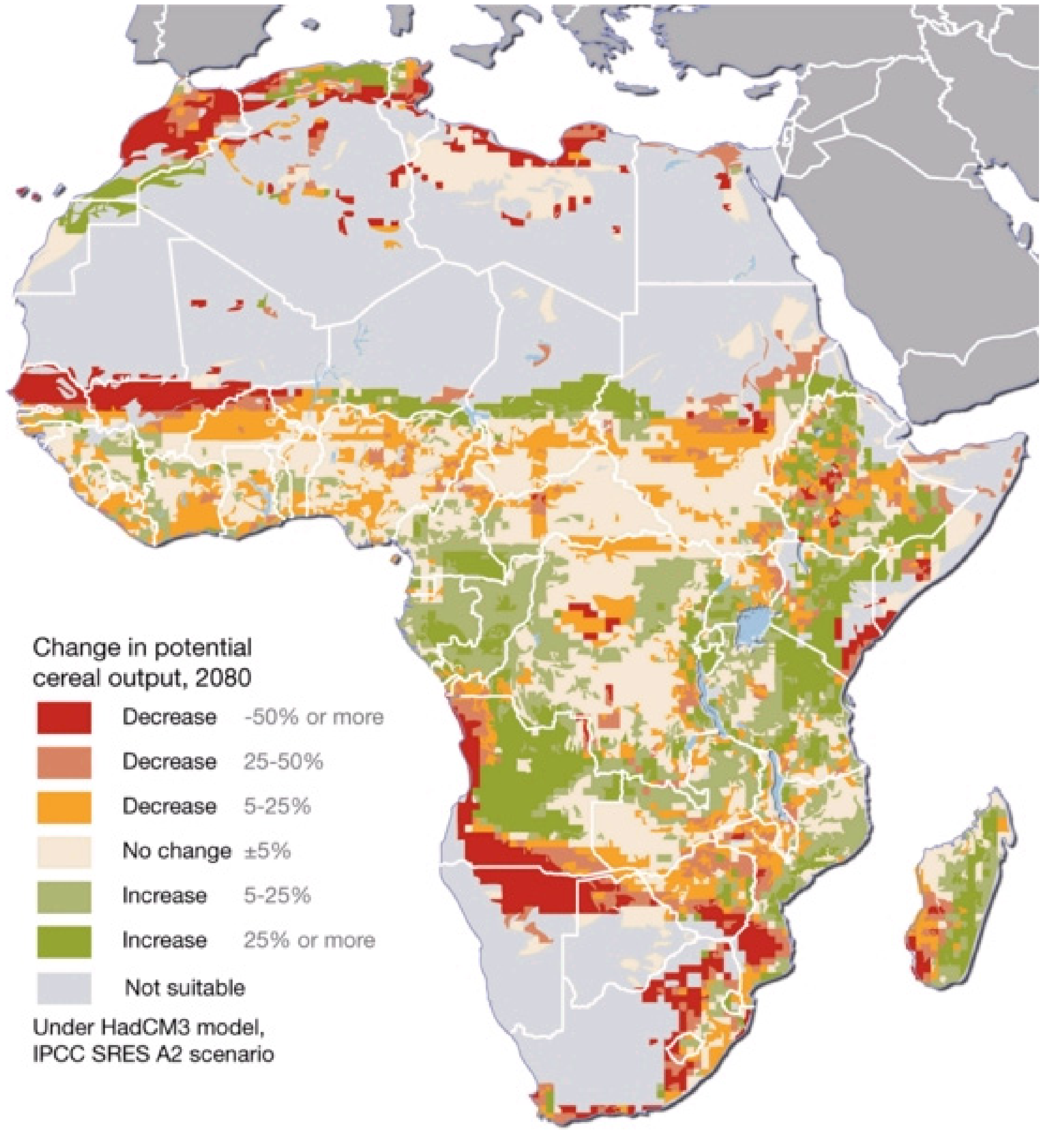


Figure A3-2
From UNEP/GRID-Arendal. Impacts of climate change on cereal output in Africa. UNEP/GRID-Arendal Maps and Graphics Library. 2009, Edited by Joel Benoit. Available at: http://maps.grida.no/go/graphic/impacts-of-climate-change-on-cereal-output-in-africa. Accessed March 04, 2009 (see also Nellemann et al. 2009, source Fischer et al., 2005).

Other projections of potential future yields of a number of crops with climate change show that in East Africa especially yields of wheat and maize will be reduced, while yields of sorghum, rice and millet could increase in most regions (Liu et al., 2008), see also Figure 2.9, although the projections by Lobell et al. (2008) show that such predictions have a large portion of uncertainty. Combining the changes in yield as a result of climate change and the increasing number of people depending on subsistence production in the same regions show that especially in Ethiopia subsistence farmers will experience reduced per capita calorie availability (Liu et al., 2008).

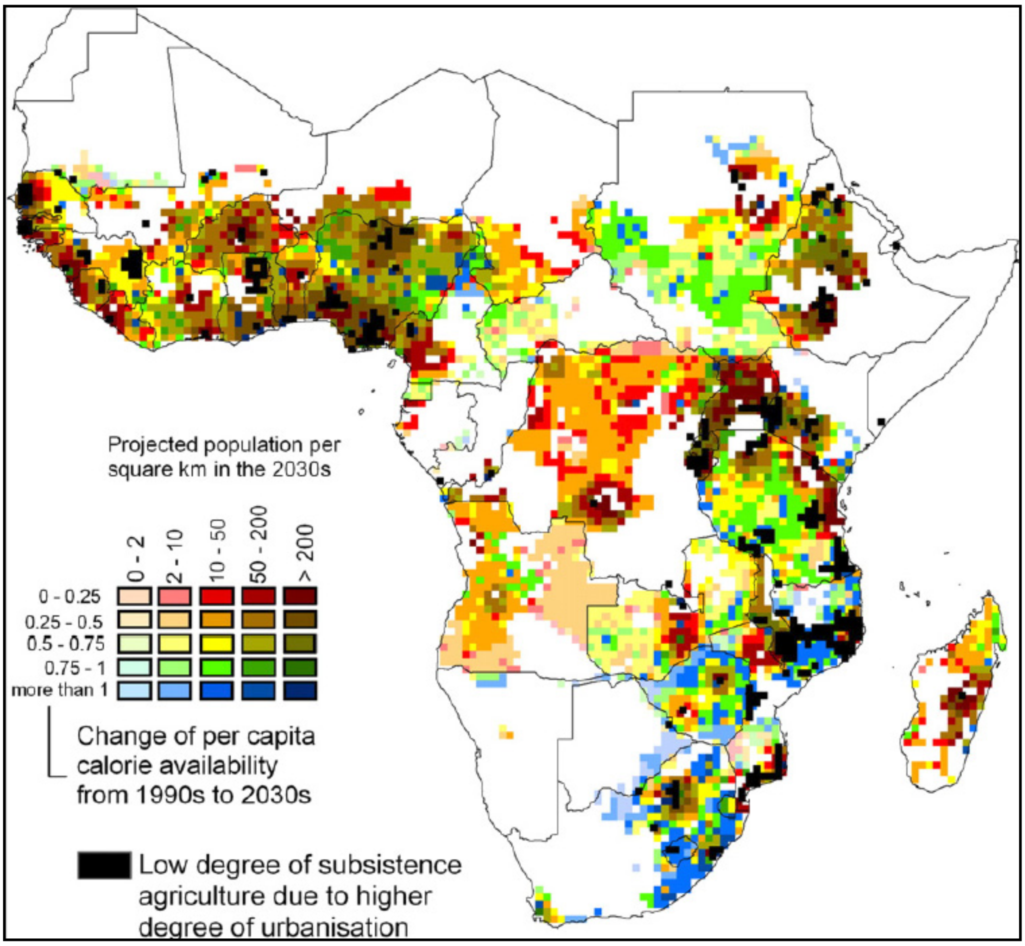


Figure A3-3

Risk of food insecurity for people depending on subsistence farming based on projected population densities per km2 in the 2030s and the changes in per capita calorie availability between the 1990s and 2030s. Towards the more red colours the impact is stronger, with 0-0.25 (red) reflecting the fraction of the per capita calories available in 2030 compared to 1990. In the green areas in 2030 per capita between 75 and 100% of the calories available in 1990 are still available. In the blue areas per capita calorie availability increases. The darker the colour, the more people are affected by the reduction in calorie availability. (From Liu et al., 2008)

The uncertainty mainly results from uncertainty in the climate projections, with different global circulation models (GCM) providing predicting different changes. To improve the results from GCM's or Regional Circulation Models, better and more information is needed on current climate parameters in Africa.

Impacts of drought on livestock numbers in selected African countries
Increasing seasonal drought events not only impact crop yields, but also will impact livestock. The problem is particularly strong in regions with relatively high human population pressure or regions with increasing permanent settlement in combination with the use of seasonal pastures, through depletion of ground water and high pressure from overgrazing by livestock. Especially southern Ethiopia appears to be vulnerable for drought impacts on livestock. (Figure A3-4).

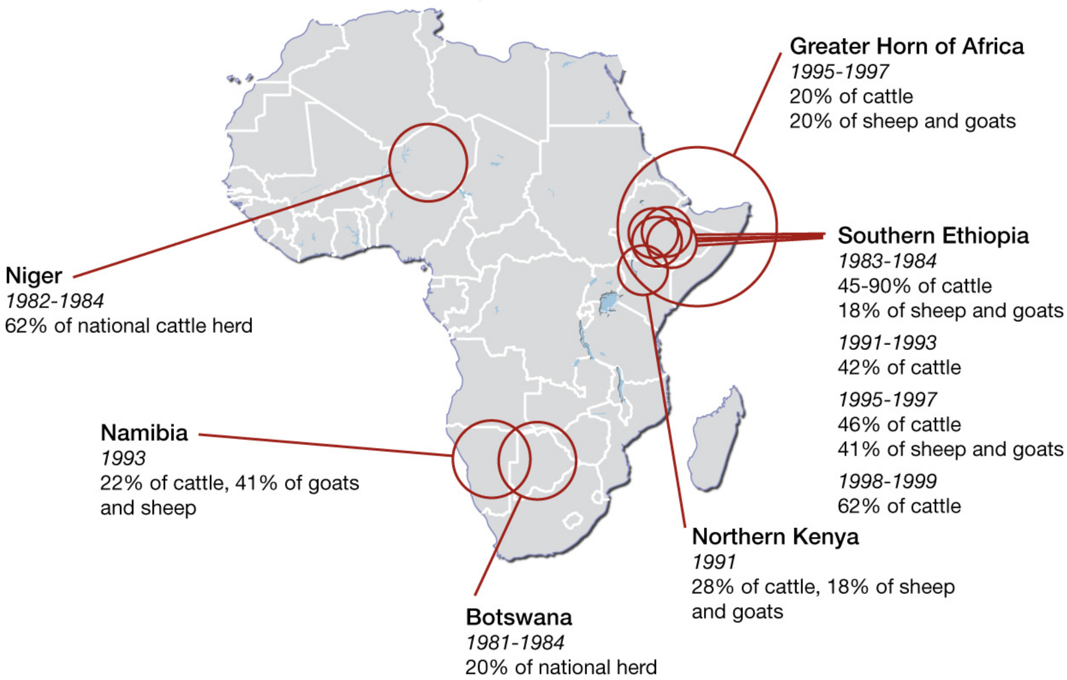


Figure A3-4
From UNEP/GRID-Arendal. Loss of livestock (%) as a result of drought in selected African countries. UNEP/GRID-Arendal Maps and Graphics Library. 2009, Edited by Joel Benoit. Available at: http://maps.grida.no/go/graphic/impacts-on-drought-on-livestock-numbers-in-selected-african-countries Accessed March 04, 2009. (see also Nellemann et al., 2009)

Losses in land productivity due to land degradation
Besides effects of changes in seasonal rain fall, also land degradation has a strong effect on productivity. Land degradation results in the long term loss of ecosystem functions caused by exploitation and other pressures the land cannot recover unaided (Bai et al., 2008). Except Somalia, large parts of East Africa experienced a strong loss of land productivity as a result of land degradation between 1981-2003.

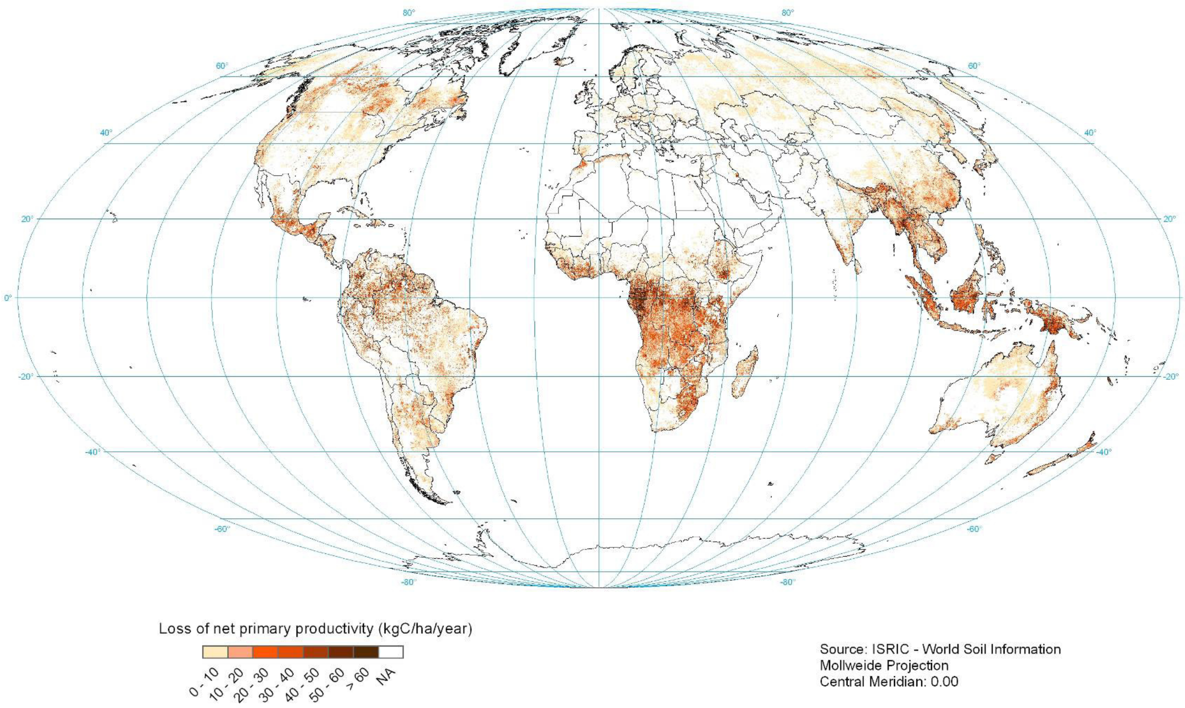


Figure A3-5

Loss of net primary production resulting from land degradation during the period 1981-2003. Losses are corrected for the effect of rain fall. (Bai et al., 2008)

Appendix 4: Data requirements of the models

CO2-fix model

Biomass module
The biomass module can flexibly be applied to different forest types and if necessary other vegetation types. It simulates the carbon stocks and flows in the forest's living (below- and aboveground) biomass. For this different cohorts (or functional types) are identified that group individuals with similar growth, turnover, mortality, wood and harvest characteristics. This may be different species or successional groups of species, or different strata in multi-strata in agro-forestry systems, or even different species groups like for instance trees and crops in agro-forestry systems. Most of the required data can usually be obtained from permanent sample plots, management information and flora.

Data requirements:
- Volume increment (as function of age or as function of standing biomass).
- Allocation of biomass increment to other compartments (branches, foliage roots). Must be inserted in relative terms compared to stem increment, but can be calibrated to biomass measurements.
- Biomass turnover of each compartment (stem, branches, foliage, roots).
- Wood density.
- Carbon content of each compartment (kg c/kg dry matter).
- Mortality (as a function of age or standing biomass).
- Management mortality (optional; as a function of harvest intensity).
- Management (timing and intensity of thinnings, timing of final felling).
- Removal of harvest residues (optional).
- Influence on increment of other cohorts.

Soil module
Decomposition and dynamics of soil carbon can be modelled using the dynamic soil carbon model Yasso (Liski et al., 2005) in one soil layers. The model includes the effect of climate on decomposition rates of several litter types and has been tested for a wide range of ecosystems, from arctic tundra to tropical rain forest (Liski et al., 2003).

Data requirements:
- Monthly temperature and precipitation data.
- Litter composition (default values for conifers and broadleaves available).
- Initial soil carbon (optional; can be derived as equilibrium state).

Product module (optional)
The products module tracks the carbon after wood is extracted from the forest system. Several processing and allocation steps towards carbon in end-products, mill site dumps or bio-energy, are part of this module. At the end of a products life-time it is recycled, disposed in a land fill or used for bio-energy.

Data requirements:
- Allocation of wood over product categories with different life times.
- Efficiency of wood processing.
- Life span of products.
- Recycling rates.
- End-of-life destination of products.

Bioenergy module (optional)
CO2-fix considers two types of fuels from forest biomass: residues from the processing in the products module, or direct removals from the forest site. Based on different baseline and fuel substituting technologies, the GHG mitigation potential of biofuels is calculated.

Data requirements:
- Technology to be replaced.
- New technology to be studied.
- Emission parameters of both technologies (defaults are provided).

Financial module (optional)
CO2-fix calculates discounted costs and incomes from forest management, and the Net Present Value per carbon credit.

Data requirements:
- Costs and revenues related to harvest and forest management in general.

Carbon accounting module
The model assesses carbon credits for a user defined period and user selected crediting scheme with CDM afforestation and reforestation schemes and carbon pools (http://unfccc.int/resource/docs/cop9/06a02.pdf).

Data requirements:
- Information on crediting period, start year of project and crediting.
- Baseline and alternative scenarios (depending on the mechanisms selected).

Miterra model

Data requirements
Spatial data
- Map indicating the regions
- Land use (arable land and grassland)
- Soil map with related soil properties:
- Texture

- Organic carbon
- Area peat soils

Optional:
- N-deposition map
- Altitude (to derive slope, which is needed for the runoff fraction)
- Precipitation or precipitation surplus
- Surface water map (useful to calculate which fraction of the runoff and leaching can easily reach surface water)

Statistical data
- Regional level:
  - Crop areas
  - Animal numbers (currently distinguished classes: dairy cows, other cows, pigs, laying hens, other poultry, sheep and goats, horses, fur animals and other animals)
  - National level (or regional if available):
  - Fertilizer consumption
  - Yield
  - Type of manure (liquid or solid)
  - Amount of processed manure

Other data available from MITERRA-Europe (if available use country specific data)
- Excretion factors (now national values from RAINS are used)
- Climate data (annual rainfall, rainfall surplus and temperature)
- Grazing intensity (number of grazing days)
- Grassland types (rough, extensive and intensive grazing)
- Nutrient content crops
- Leaching from manure storage
- Milk production
- Crop residue removal
- Use of emission reduction techniques
- Use of urea as fertilizer
- Amount of liming ($CaCO_3$)
- Emission factors

Data for simulation of scenarios
- Changes in crop areas
- Changes in animal numbers
- Changes in yield
- Changes in fertilizer use
- Adoption of mitigation and emission reduction techniques

FSSIM model

Data requirements.

On farm level, data is needed for each specific farm type:

- Cropping system
- Planting dates
- Yields
- Herbicide use
- Pesticide use
- Fertilizer use
- Irrigation (use)
- Selling price of the crop
- Total revenues
- Costs of fertilizer use
- Costs of crop protection
- Other variable costs (seeds, planting material e.g.)
- Labour demand

CLUE

Data requirements

In CLUE the following data and conditions are needed for an analysis:

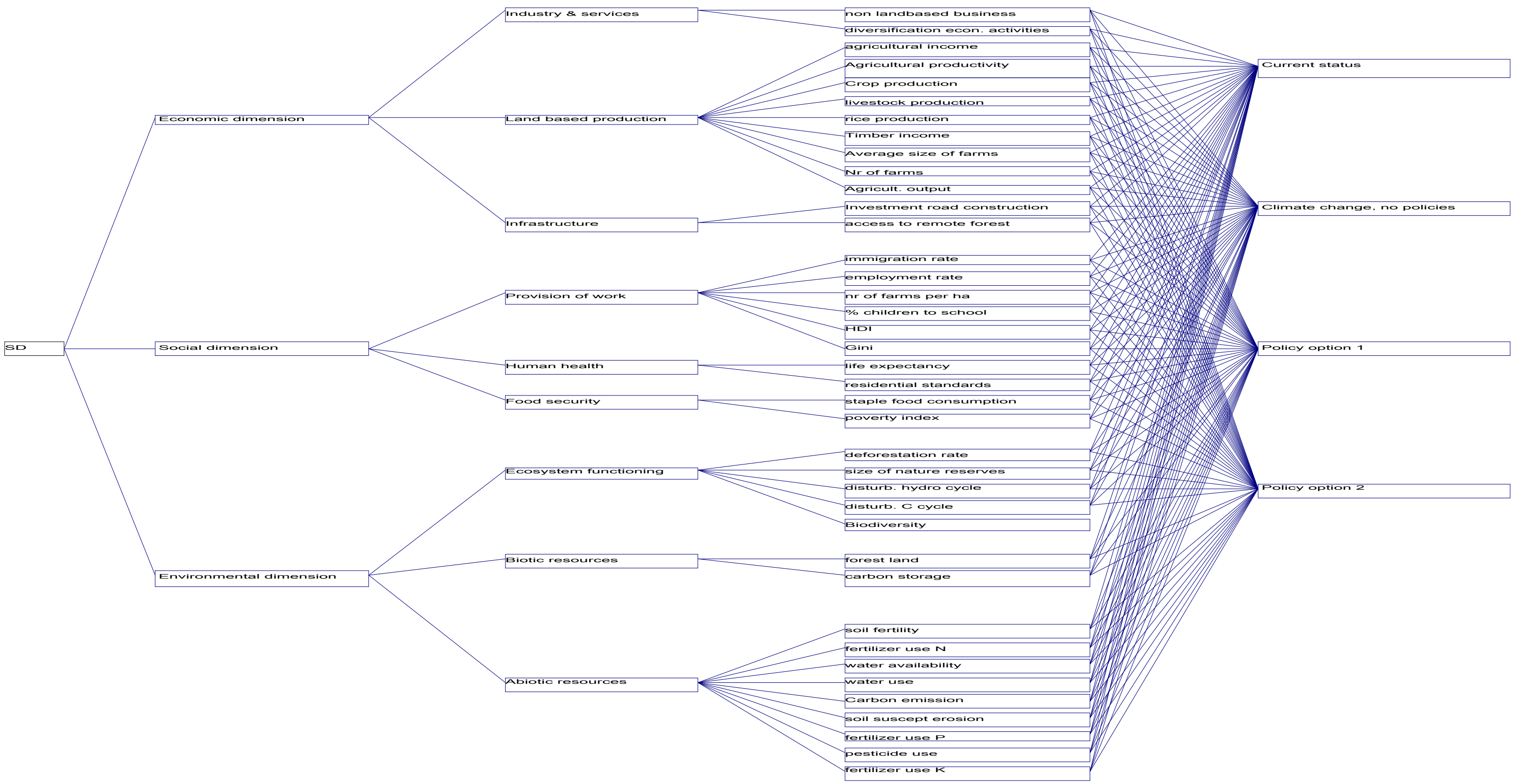
- GIS maps in grid format
- Suitability maps of land-use types needed
- Geo-referenced data of land-use types are needed
- Transition matrices from one land-use type to another can be calculated
- Effects of policies can be assessed with changes in transition coefficients
- Dynamics in land-use are modelled, therefore time series of land-use types are needed
- Sum of all land-use types must be equal between years

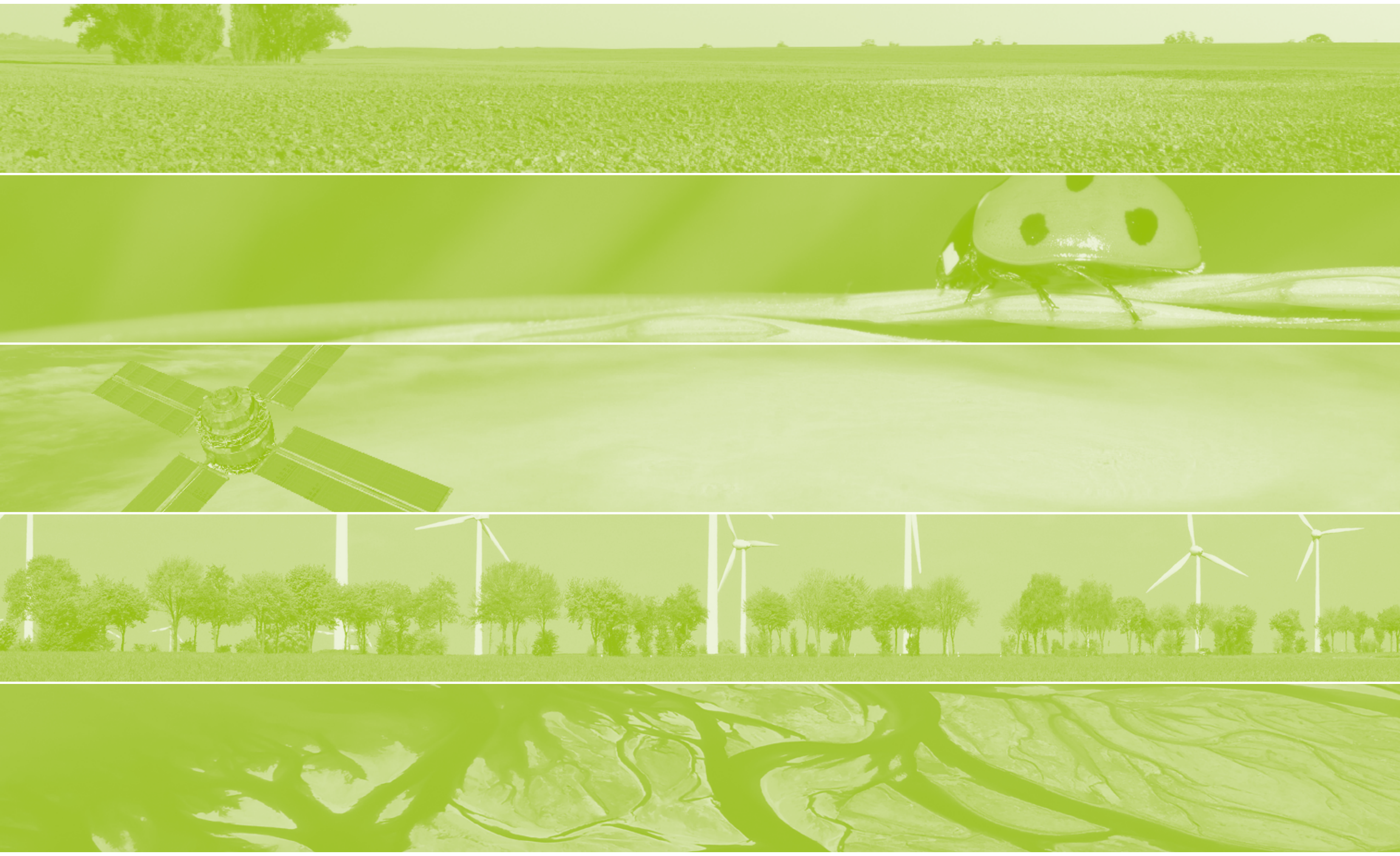
Appendix 5: Proposal of indicators to be used in the project

Dimension	LUF	Indicator
Economic dimension	Industry and services	Diversification of economic activities
		Non land-based business
		Land lease price
		Land market price
		Price of labor
Economic dimension	Infrastructure	Investment in road construction
		Access to roads (average distance to the nearest shopping center)
Economic dimension	Land based production	Farm income
		Agricultural productivity
		Crop production
		Livestock production
		Timber income
		Average size of farms
		Number of farms
		Output (yield/area)
Environmental dimension	Abiotic resources	Soil organic carbon
		Water quality
		CO_2 emissions
		Fertilizer use
		Pesticide use
		Water availability
		Water use
		Soil erosion (tonne/hectare)
		Nitrate leaching
Environmental dimension	Biotic resources	Biodiversity (Index)
		Carbon storage
		Deforestation risk
		Forest land
		Potential carbon storage
		Disturbance in the hydrological cycle
		Size of nature reserves
Environmental dimension	Ecosystem processes	Agro biodiversity
		Change in temperature
		Deforestation rate
		Disturbance in carbon cycle
		Disturbance in the hydrological cycle
		Size of nature reserves
		Soil processes, organic matter rate
		Number of species
Social dimension	Food security	Poverty Index
		Immigration rate
		Population growth rate

		Average staple food consumption per farm household per year Self sufficiency various crops
Social dimension	Human health	Life expectancy Residential Standards Prevalence of nutritional diseases HDI, poverty measure Human health (number of diseases)
Social dimension	Provision of work	Employment rate Percentage of children attending school Number of trained farmers Number of immigrants Off-farm employment

Appendix 6: Example of a multi-criteria decision tree





Alterra is part of the international expertise organisation Wageningen UR (University & Research centre). Our mission is 'To explore the potential of nature to improve the quality of life'. Within Wageningen UR, nine research institutes – both specialised and applied – have joined forces with Wageningen University and Van Hall Larenstein University of Applied Sciences to help answer the most important questions in the domain of healthy food and living environment. With approximately 40 locations (in the Netherlands, Brazil and China), 6,500 members of staff and 10,000 students, Wageningen UR is one of the leading organisations in its domain worldwide. The integral approach to problems and the cooperation between the exact sciences and the technological and social disciplines are at the heart of the Wageningen Approach.

Alterra is the research institute for our green living environment. We offer a combination of practical and scientific research in a multitude of disciplines related to the green world around us and the sustainable use of our living environment, such as flora and fauna, soil, water, the environment, geo-information and remote sensing, landscape and spatial planning, man and society.

More information: www.alterra.wur.nl